Overview of SnT SIGCOM 6GSPACE Lab and QCI Lab Activities

Dr. Jorge Querol
Research Scientist
Head of the 6GSPACE Lab

UNIVERSITY OF LUXEMBOURG

University of Luxembourg – SnT

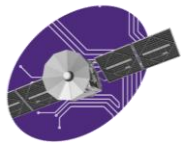
630+
Workforce

Strategic Research Areas


FinTech

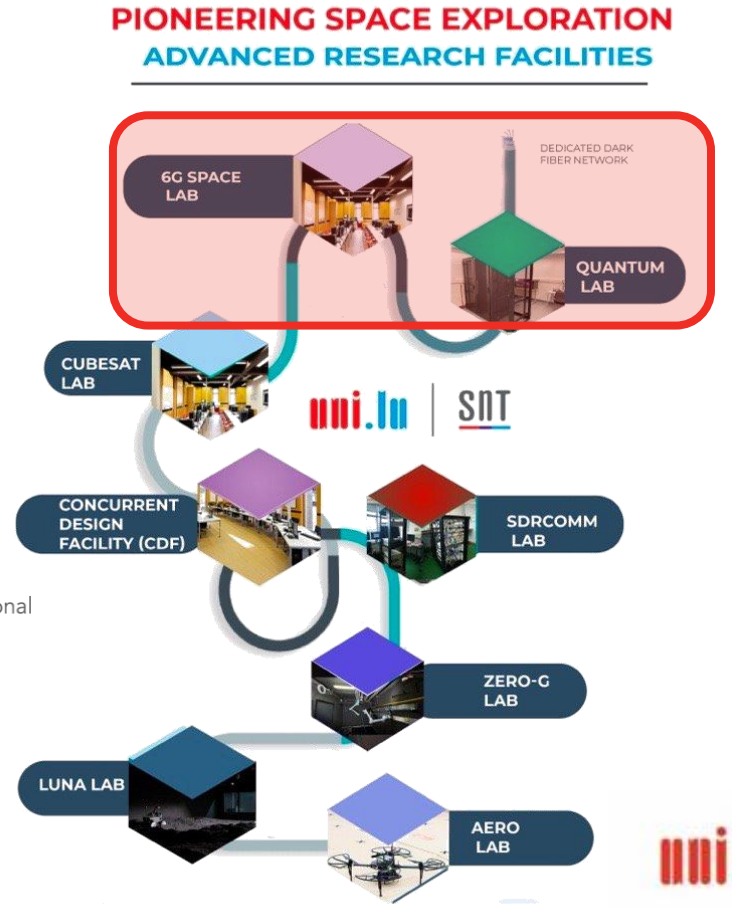

Autonomous Vehicles & IoT


Cybersecurity


Space Systems

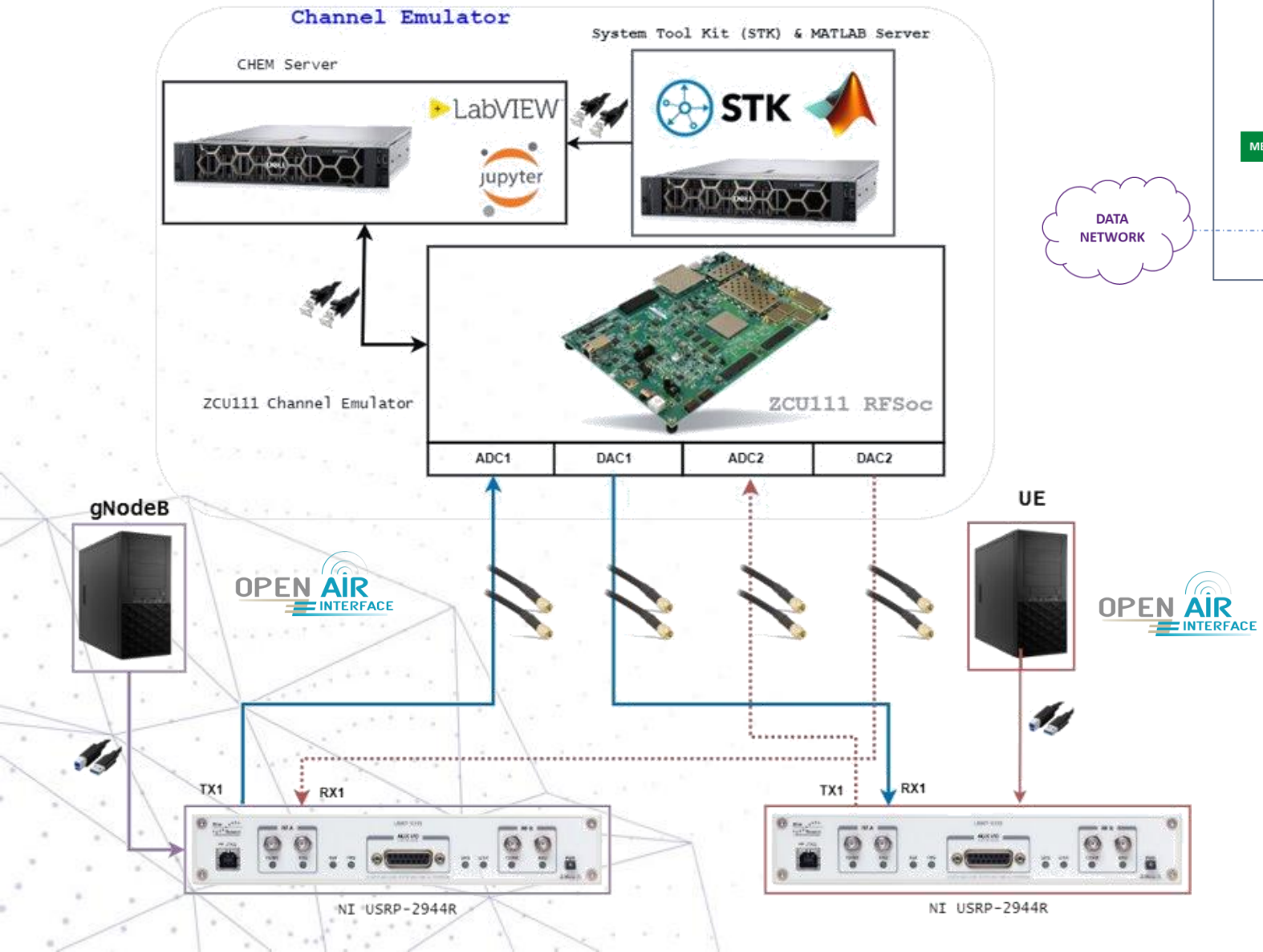
SIGCOM – 6GSPACE Lab

- 6GSPACE Lab (20+ people) composed SnT SIGCOM researchers
- Facility for design and testing of 5G/6G Satellite-NTN-Space
- Multiple 5G/6G NTN research testbeds:
  - 6G NTN Multiorbit Emulation
  - 6G NTN AI-acceleration
  - 6G NTN OTS & OTA
  - Joint Communications and Sensing – PNT

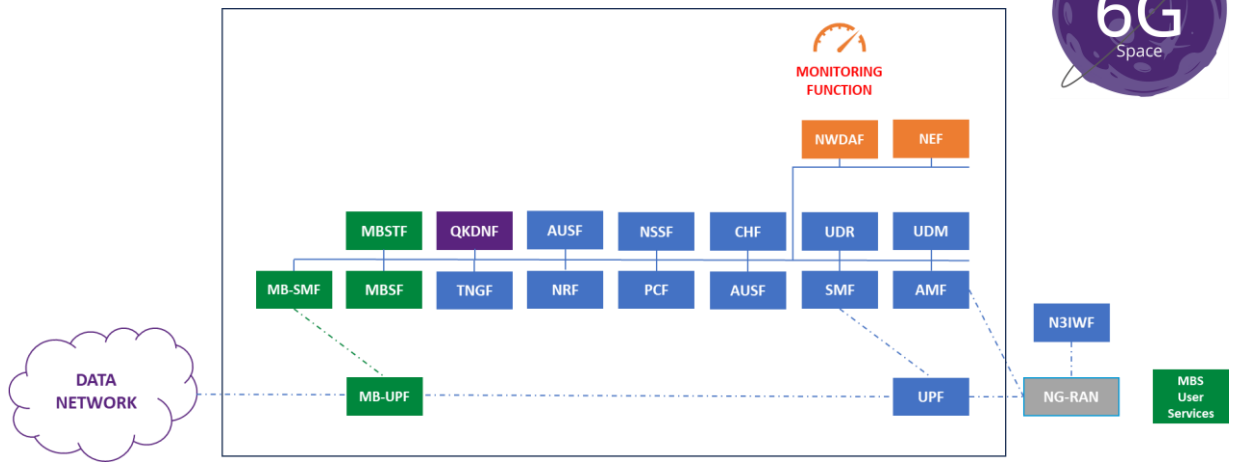


6G NTN Multiorbit Emulation

5G/6G RAN



5G/6G Core Network

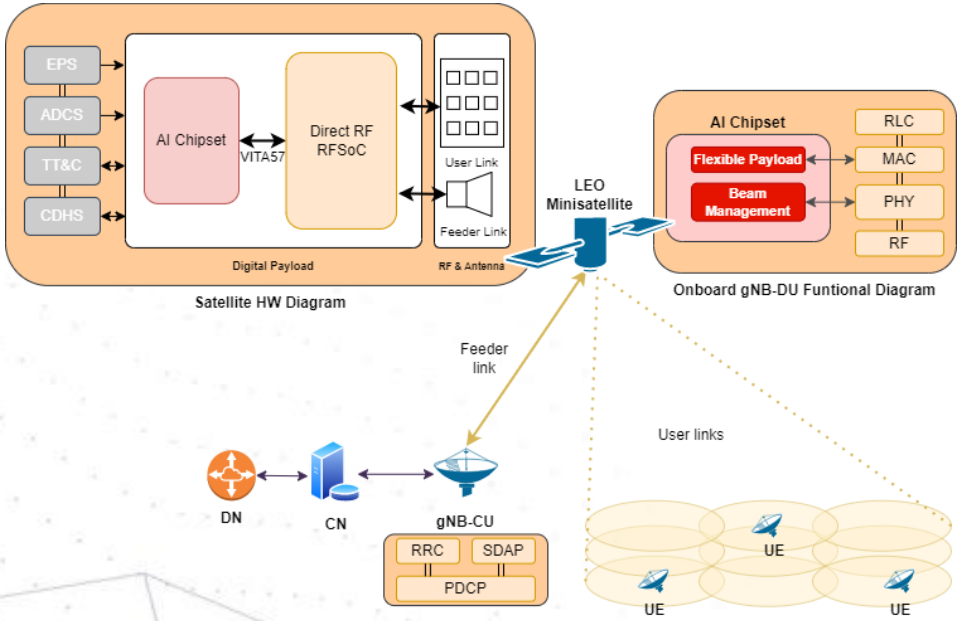


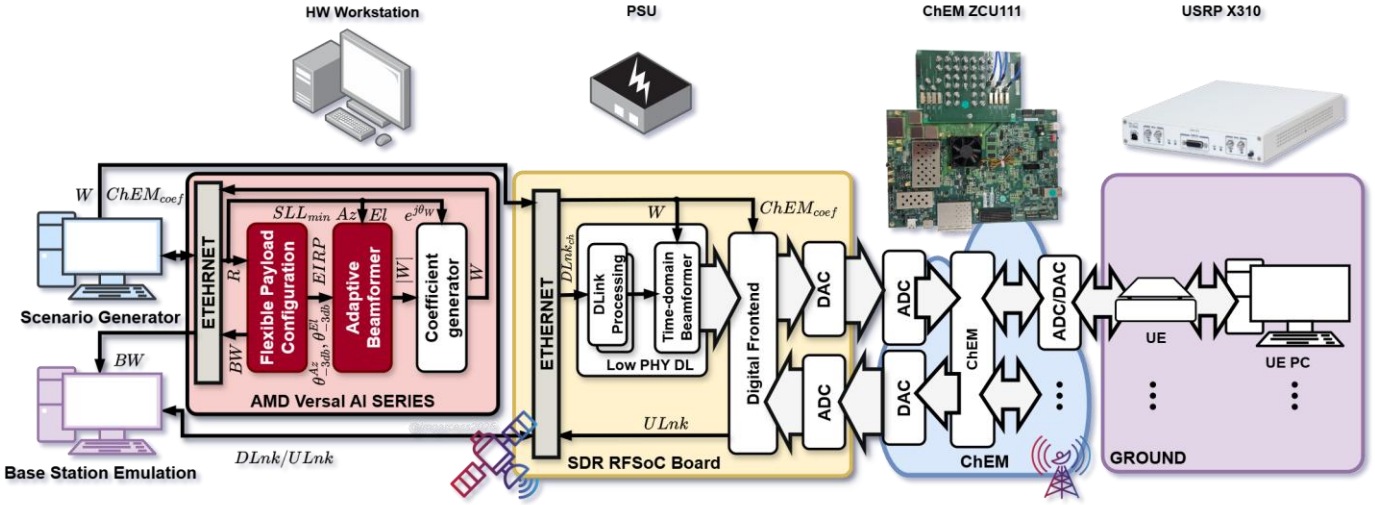
5G/6G NTN Demonstrations

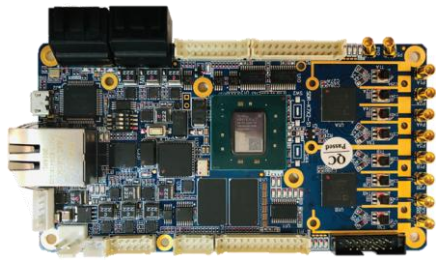
- ❑ Multiorbit 5G connectivity LEO/MEO/GEO
- ❑ TN-NTN Handover (F1/N2)
- ❑ In-orbit UE Demonstration
- ❑ 5G NTN + Multicast Broadcast Services
- ❑ Security and Automation (QKD + NWDAF)
- ❑ Dual-connectivity / Dual-steer (Multiorbit)

6G NTN AI-acceleration

Onboard/onground AI-based resource allocation and beam management + AI PHY-enhancement



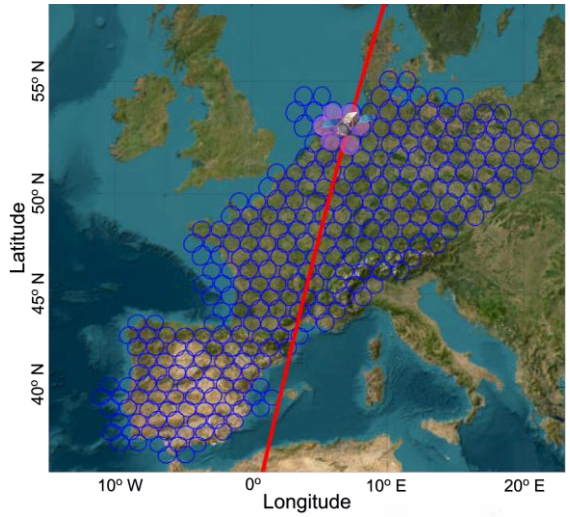


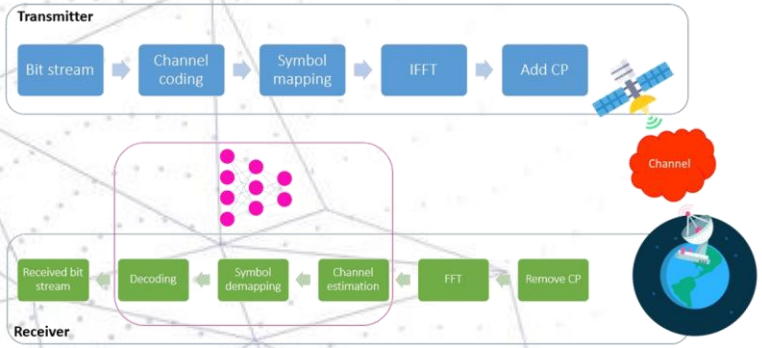


Custom SDR

Versal AI

Testbed





6G NTN OTS & OTA

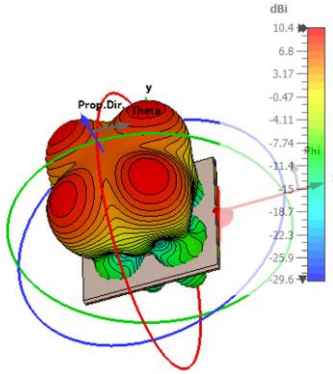
C-/Ku-/Ka-bands GEO/NGSO/Terrestrial

Ku-band
BUC + LNB
1.2 m dish
GEO

Ku-band LNB + Ka-band LNB – 3-axis NGSO

0-40 GHz
EMF

- ❑ OTS Demos
- ❑ Spectrum monitoring
- ❑ Direct-to-X Connectivity



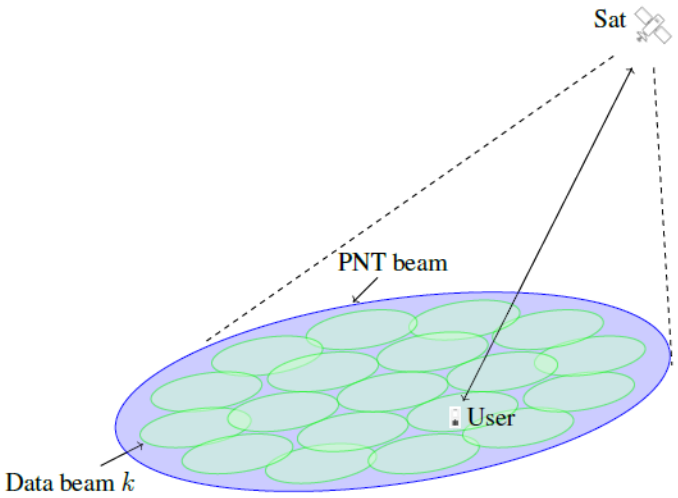
ILR
INSTITUT LUXEMBOURGEOIS DE RÉGULATION

C-band Test License

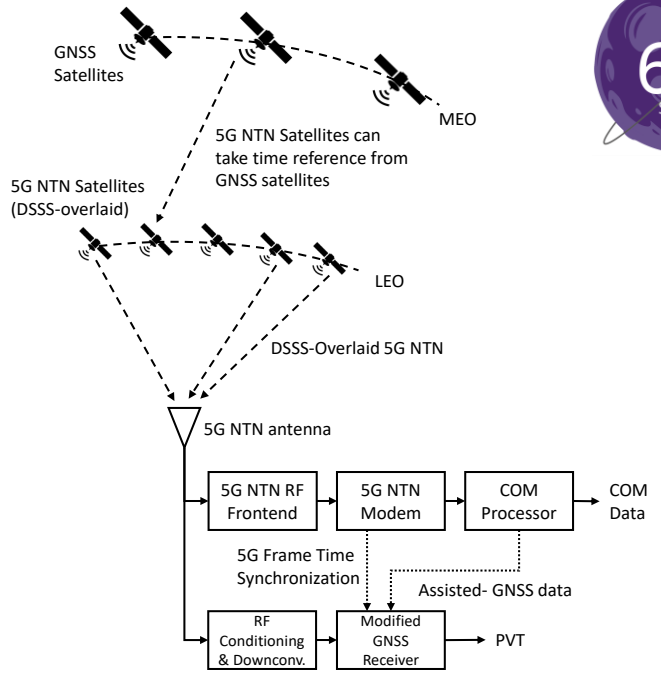
Joint Communications, Sensing and PNT

Joint Communication and Positioning (JCAP)

- ToA-Based Positioning in 5G/6G NTN using Pilots (achievable accuracy)
- Joint Waveform and Receiver Architectures (JCAP PHY)
- Interference modeling and performance limits in NTN systems



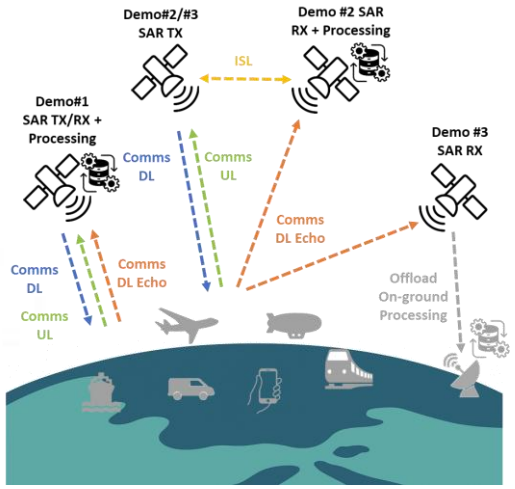
DSSS overlay receiver design

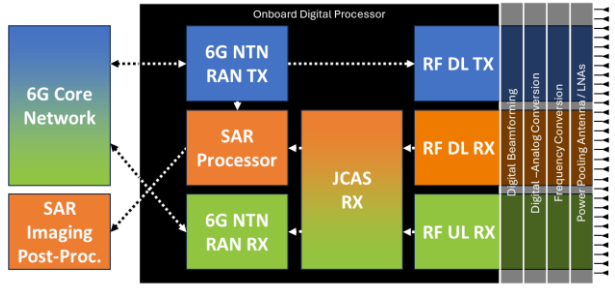


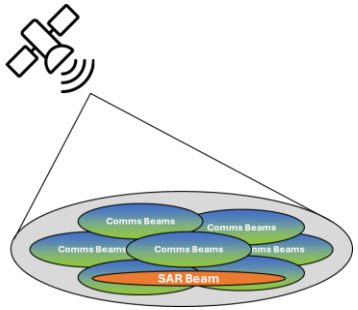
Legacy GNSS and 5G/NTN Signal Coexistence

Joint Communication and Sensing (JCAS)

- Use case feasibility study (weather sensing, imaging radar, reflectometry/altimetry)
- Technology enablers (In-band full-duplex, new waveforms)
- Early demo testbed







Quantum Lab

QKD Testbed Overview

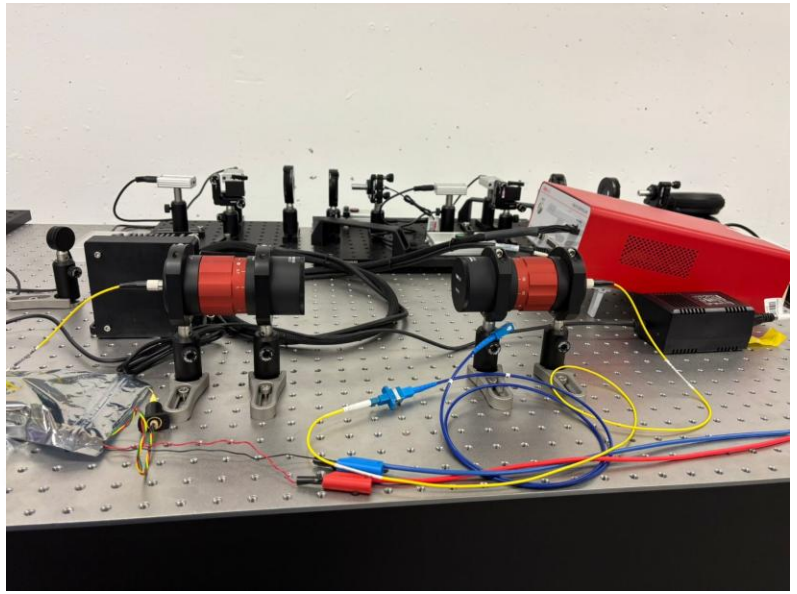
- ❑ 6 QKD Links
- ❑ 7 PoP with SDN KMS orchestration
- ❑ 4 providers with different technologies

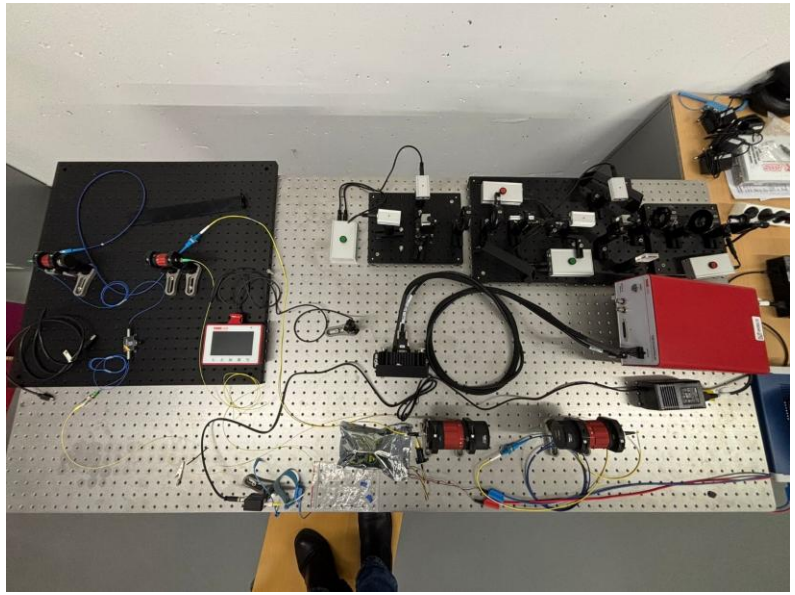
(MDI-QKD, CV-QKD, COW, BB84)

- ❑ Eagle-1 Emulator
- ❑ Crossborder Link between Luxembourg and Belgium

FSO Testbed Overview

- ❑ Free space optics demonstrations without turbulence (e.g ISL)
- ❑ QKD testbed based on Entangled States with SPDC sources
- ❑ Free Space QKD (Integration of BBM92 in FSO link)





Interdisciplinary Centre for Security, Reliability and Trust

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Connect with us

@SnT_uni_lu

SnT, Interdisciplinary Centre for Security, Reliability and Trust

Overview of 6GSPACE Lab activities

Outline

- 6GSPACE Lab Introduction
- 6G NTN Over-The-Satellite
- 6G NTN AI-acceleration
- 6G NTN Spectrum Sensing
- Lunar 5G Proximity & Edge Computing
- Joint Communications and Sensing - PNT

6GSPACE Lab Introduction

UNIVERSITY OF LUXEMBOURG

SnT – University of Luxembourg

PEOPLE

450+
Workforce

65+
Nationalities

36%
Alumni who stay in Luxembourg

43%
Doctoral candidates on Industrial projects

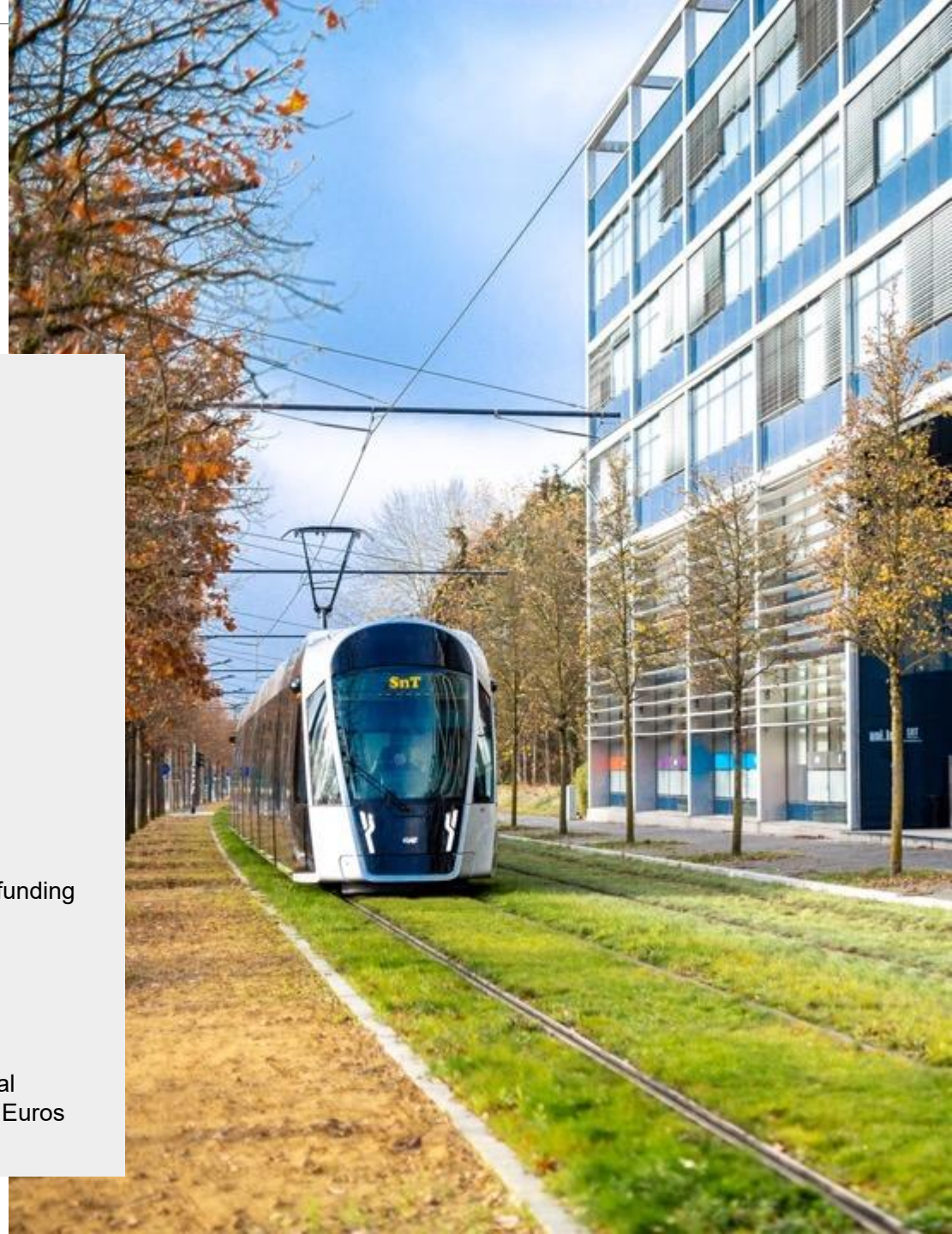
PARTNERSHIPS & INNOVATION

60+
Partners

6
Spin-offs

70%
External project funding

5.2M
Partners annual contribution in Euros



SnT SIGCOM Research Group

Track Record (2024)

- **15** years in operation
- **90+** Researchers
- **60+** R&D projects
- **60M€+** Funding
- **6** Industrial Partnerships

Research Areas

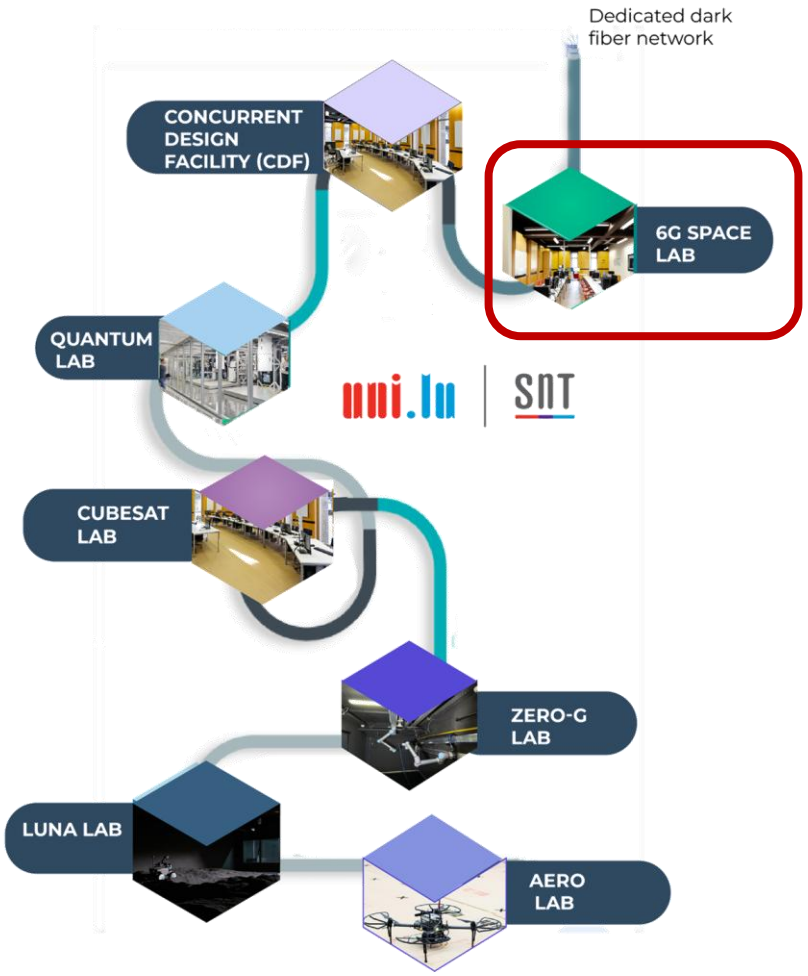
- 6G Communication Systems
- Non-Terrestrial Networks (SatCom-UAVs)
- Massive Antenna Arrays
- Quantum Communication Infrastructure

Industry Partners

Funding Bodies

Associations & Standards

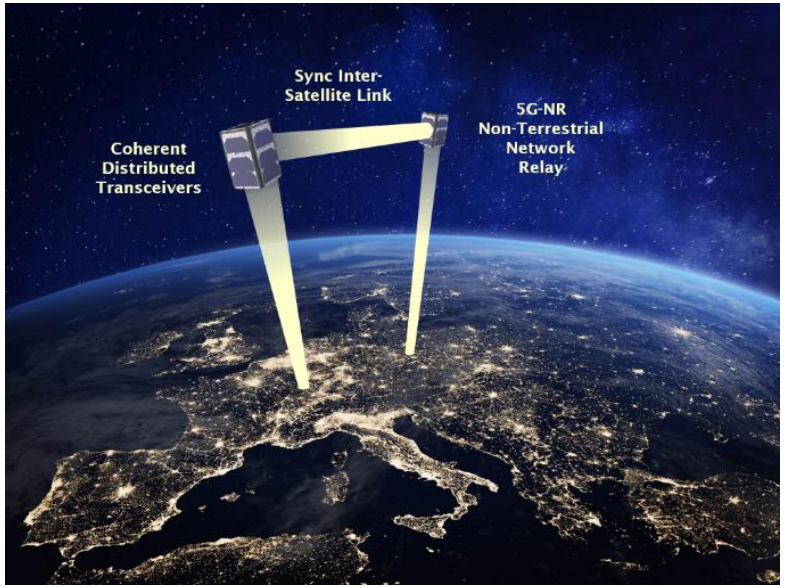
SnT Space labs

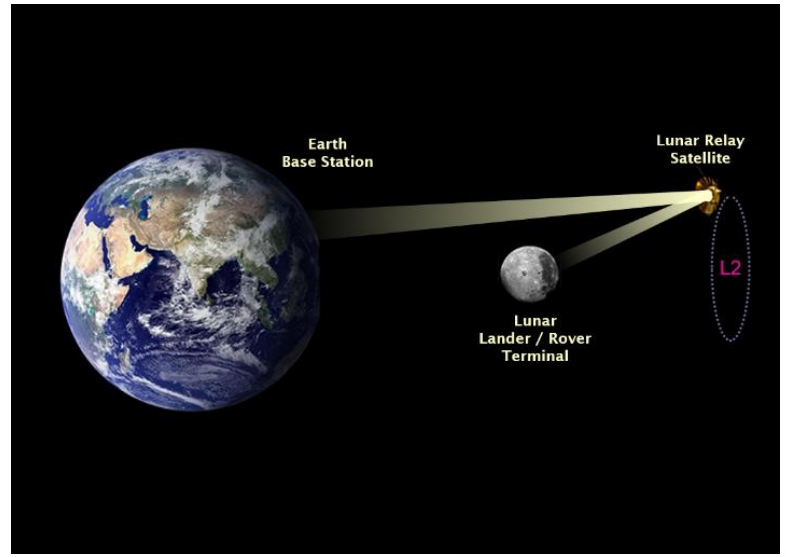


6GSPACE Lab

Overview

- 6GSPACE Lab (15+ people) composed SIGCOM researchers
- Funded under the ISM / MSTB framework (Lux MECO & LSA)
- Facility for design and testing of 5G/6G Satellite-NTN-Space
- Current features:
  - OpenAirInterface-enabled 5G gNB and UEs
  - RU with PHY layer offloading for functional splits 6/7.X
  - STK-powered channel emulator
  - Edge Computing infrastructure
- Multiple 5G/6G NTN research testbeds:
  - 6G NTN Multiorbit Emulation
  - 6G NTN Over-The-Satellite
  - 6G NTN AI-acceleration
  - 6G NTN Spectrum Sensing
  - Lunar 5G Proximity & Edge Computing
  - Joint Communications and Sensing - PNT





6GSPACE Lab

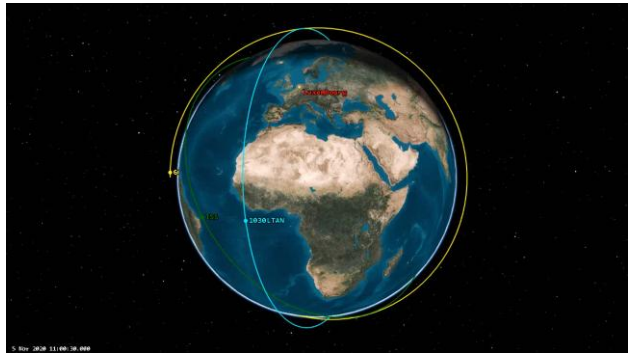
Hardware and Space Labs integration

6GSPACE Lab Integration

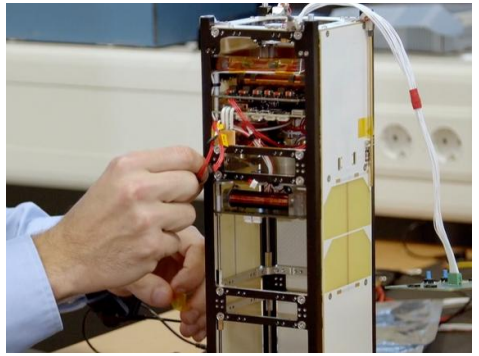
Cubesat SDR

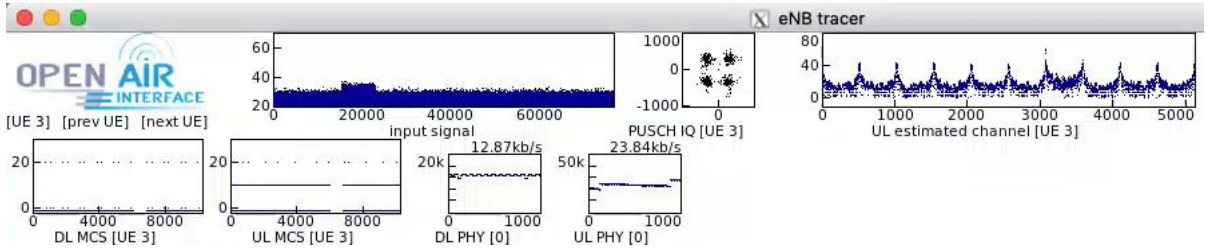
Channel Emulator

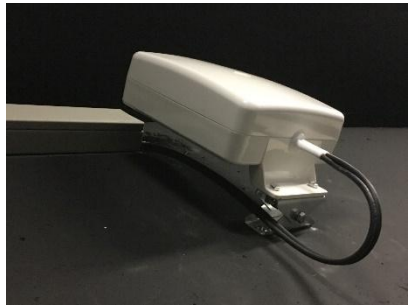
STK Scenario Design

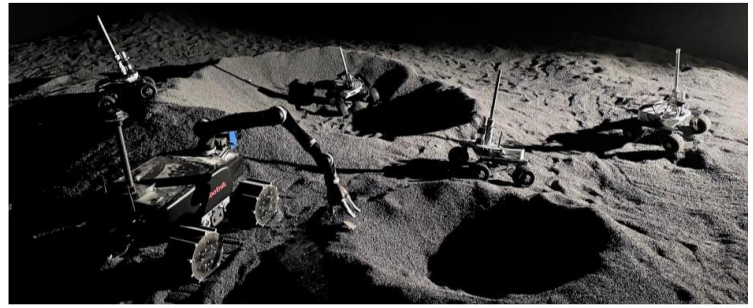


CubeSatLab Integration









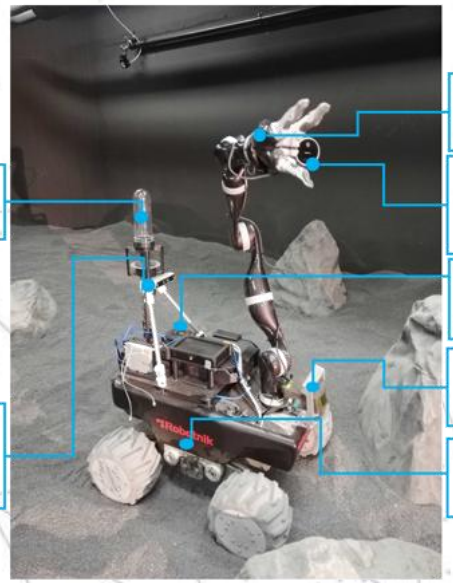
LunaLab Integration

6GSPACE Lab

- **Interdisciplinary Joint Lab**
  - Communications, Robotics, CubeSats, Concurrent Design

CDF

5G/6G OPEN AIR INTERFACE



Robotic arm Kinova Gen2

ArmCam LiDAR Intel RealSense L515

Nvidia JETSON Xavier NX

Lidar (RS-Lidar-M1)

SUMMIT-XL Rover & accessories

PanCam Ricoh Theta 360°

NavCam RealSense camera D455

LUNA LAB

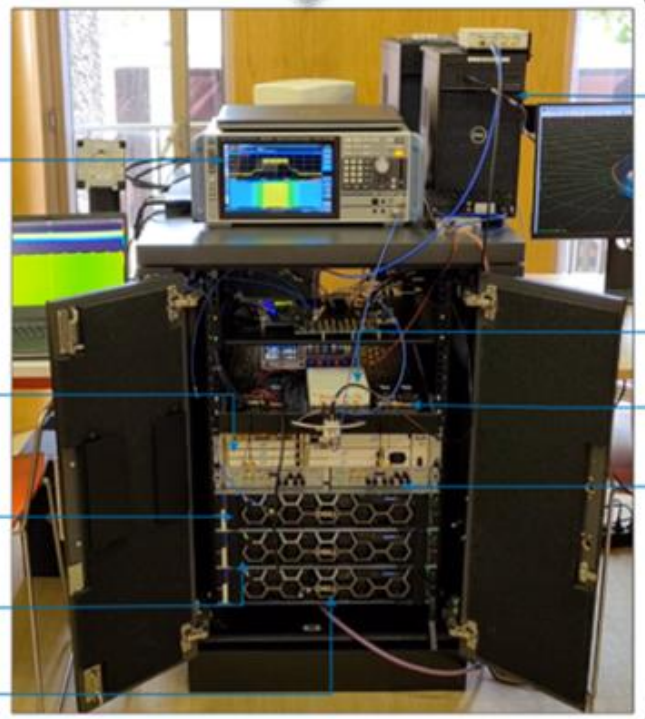
Spectrum Analyzer

Channel Emulator VADATECH

STK Server

Channel Emulator Server

gNodeB Server



UE Workstation

USRPB210

GomSpace SDR

USRPN310

SATCOM

NVIDIA.

intel

AI

XILINX.

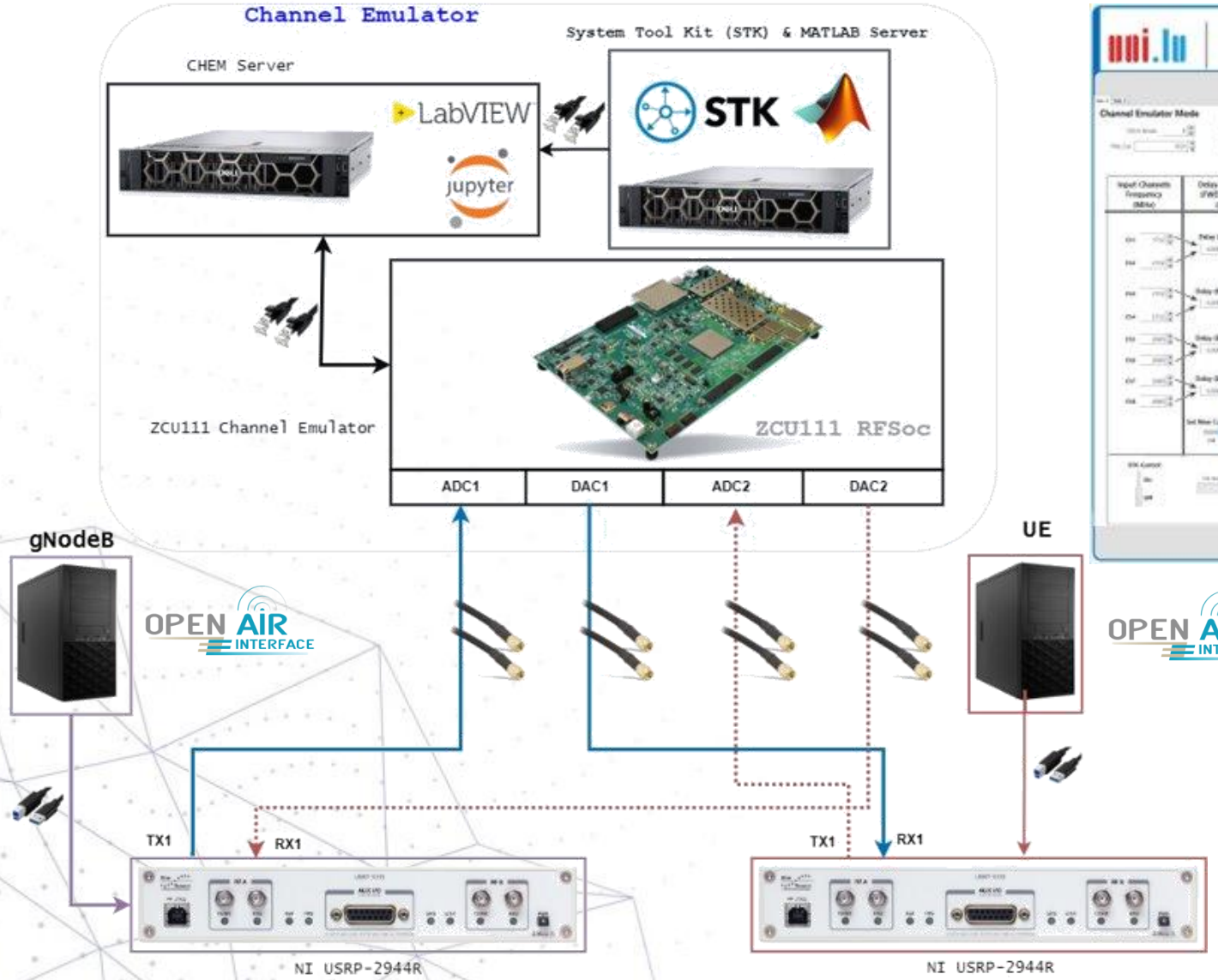
Cubesat

CAN CONNECTION

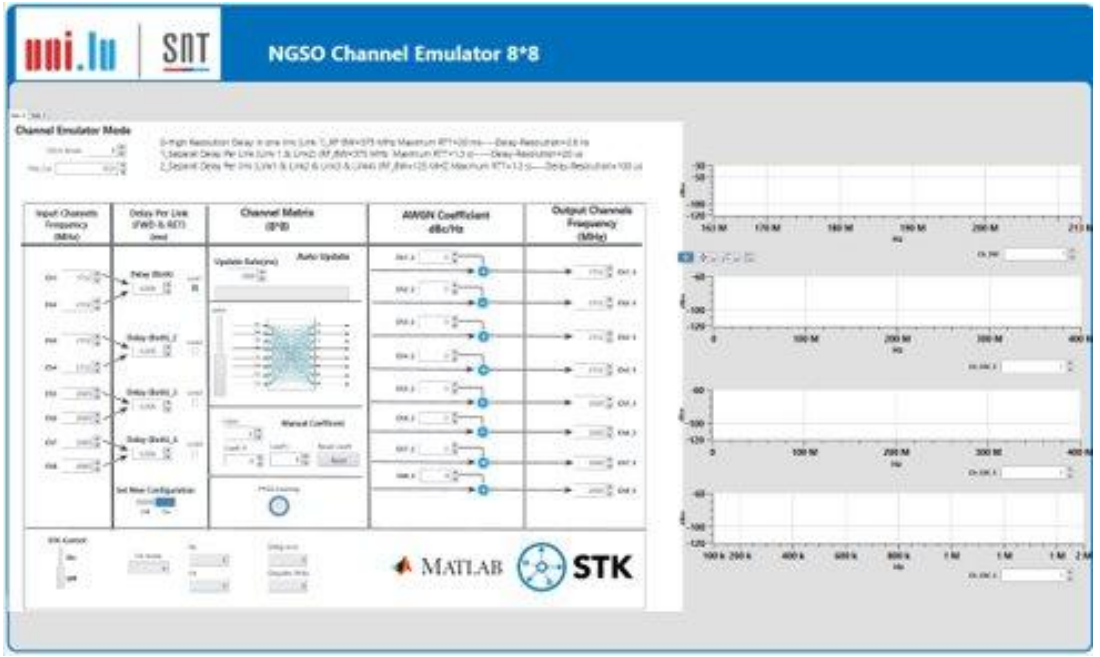
uni.lu | SnT

6GSPACE Lab

6G NTN Multiorbit Emulation (6gspacelab.uni.lu)

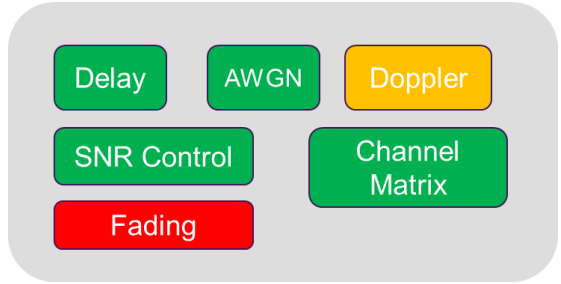


GUI



OPEN AIR INTERFACE

Functional blocks



- Multiorbital
- Customizable
- 8 Independent Channels
- Up to 330 ms delay
- ±34 ppm / 0.5ppm/s Doppler / Doppler Rate

6GSPACE Lab

OAI RAN Roadmap (Q4 2023)

Quarter 1 2024

- Handling of Multiple RUs per DU
- LDPC Encoding and Decoding Offload on T2
- FR2 Basic SA Interoperability with COTS UE
- Support for O-RAN Through OSC's FHI Release F
- Inline Acceleration with Aerial

Quarter 2 2024

- OAI UE Initial Access Procedures with 3rd Party gNB
- DL MIMO: 4 Layers
- NRPP Support in gNB
- 2-step RACH Rel16
- F1 Handover
- Sidelink Rel16

Quarter 3 2024

- Support for Short-Data Transmission Rel17
- QoS Aware Scheduler
- Support of 5G RAN Slicing
- Basic NTN Support Rel17
- N2 Handover Procedures

Quarter 4 2024

- Xn Handover Procedures
- Multi UE Bandwith Part Handling
- Beamforming Procedures for FR2


SnT
6G
Space
6G NTN Over-The-Satellite
uni.lu
UNIVERSITY OF
LUXEMBOURG

TRANTOR: 5G+ evoluTion to mutioRbitAl multibaNd neTwORks

Objectives

1. Adoption of 5G Advanced and pre-6G NTN by satellite operators
2. Provide novel satellite components for 5G Advanced NTN
3. Development of 5G Advanced NTN user equipment and gNB
4. Development of AI governance modules for resource management
5. Creation of mission planner for the design of future satellite networks
6. Secure satellite operator network

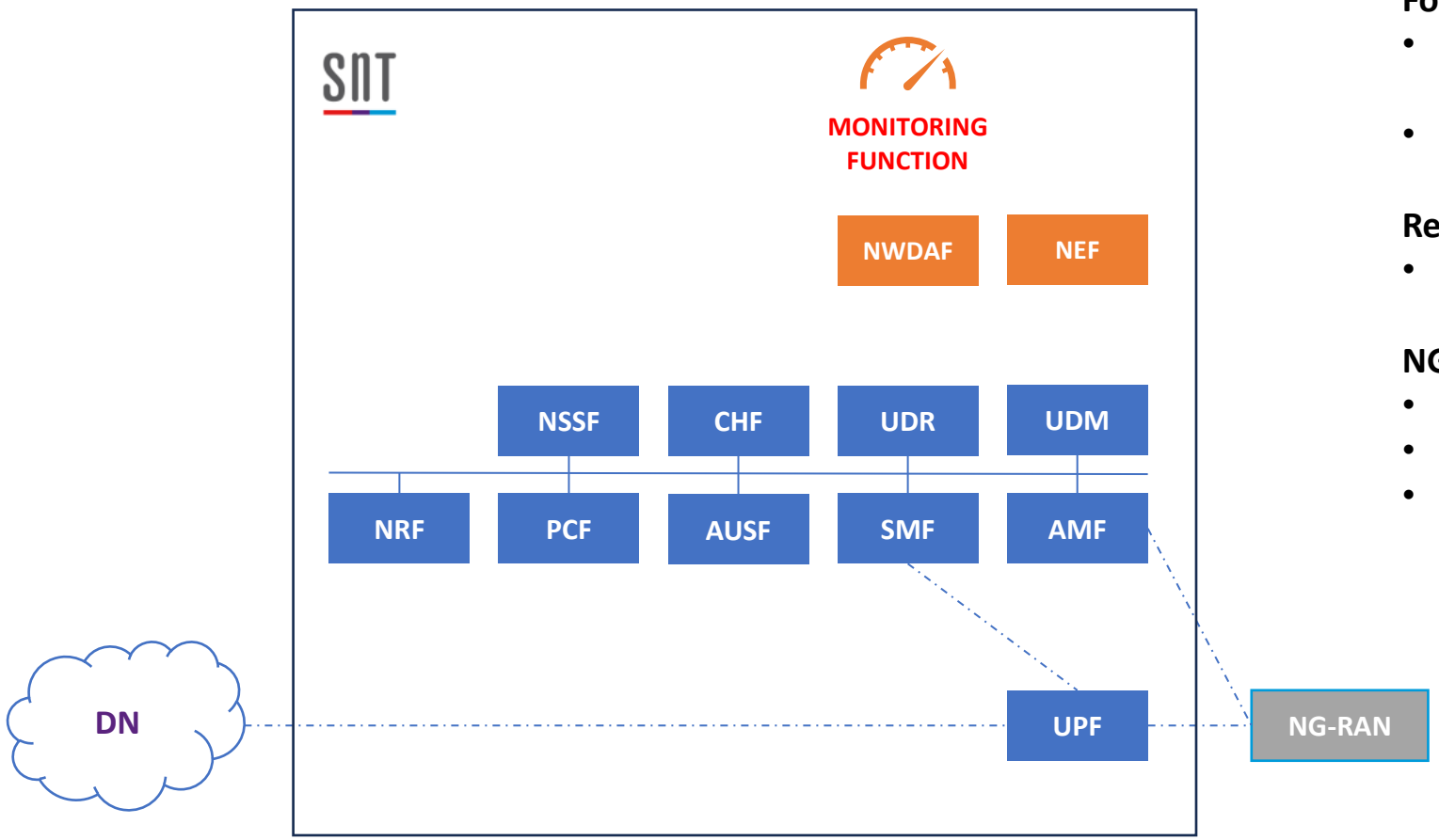
Demonstration TRL 3 → TRL 6

1. End-to-End single band connectivity with a single GEO satellite
2. End-to-End single band connectivity with a single drone-emulated LEO satellite
3. End-to-End single band connectivity with CU/DU split with OBP satellite
4. Multi-band transmission from a single GEO satellite
5. Multiorbital, multi-band transmission using a GEO and a drone-emulated LEO satellite
6. Multi-satellite, multi-band transmission using two GEO satellite

→ SnT develops its own Core Network

QUADSAT ttc Fraunhofer IIS hispasat Consiglio Nazionale delle Ricerche RHEA GROUP inster grupo oesía SRS SOFTWARE RADIO SYSTEMS uni.lu | SnT

SnT – Core Network



Fork of Free5gc Release 17

- Support of Network Data Analytics Function (NWDAF)
- Support of Network Exposure Function (NEF)

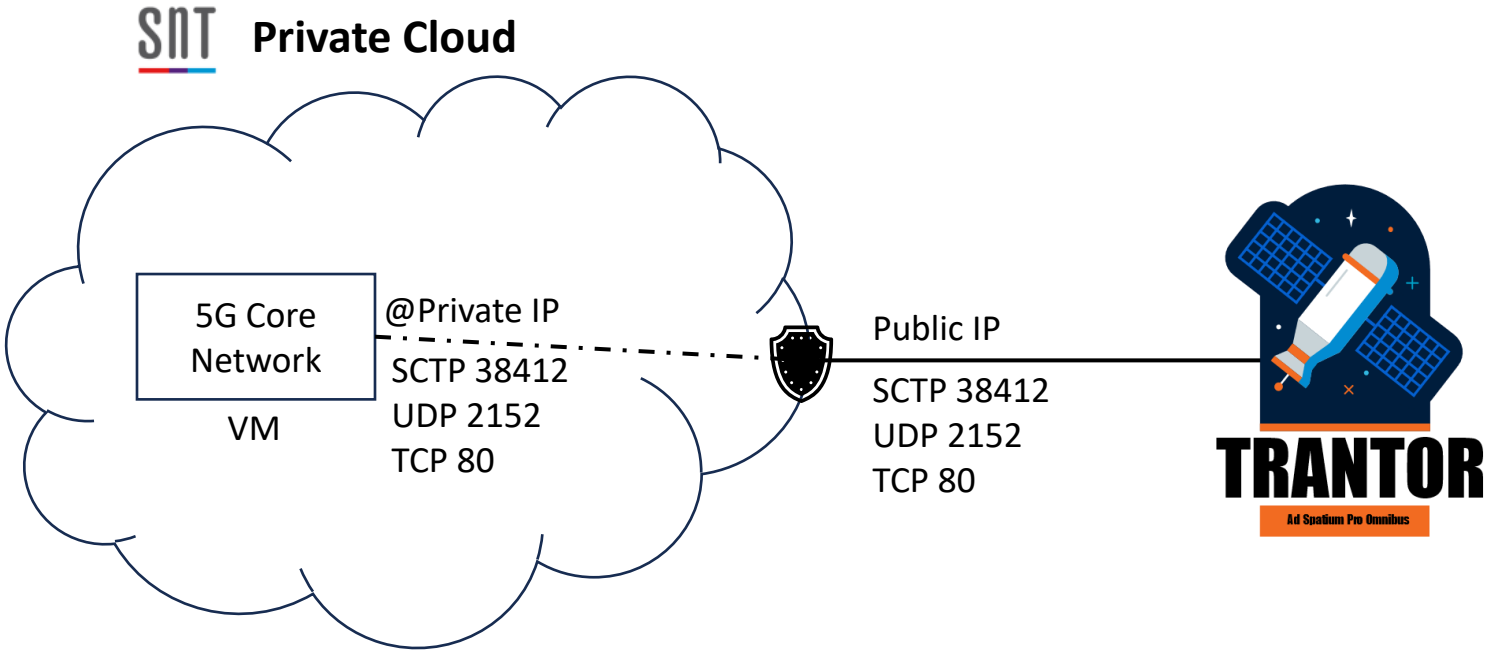
Realtime Metrics Monitoring

- Grafana

NG-RAN Testing

- Amarisoft gNB
- OAI 5G gNB
- srsRAN gNB

Core Network – Publicly Available



Status: Up and running

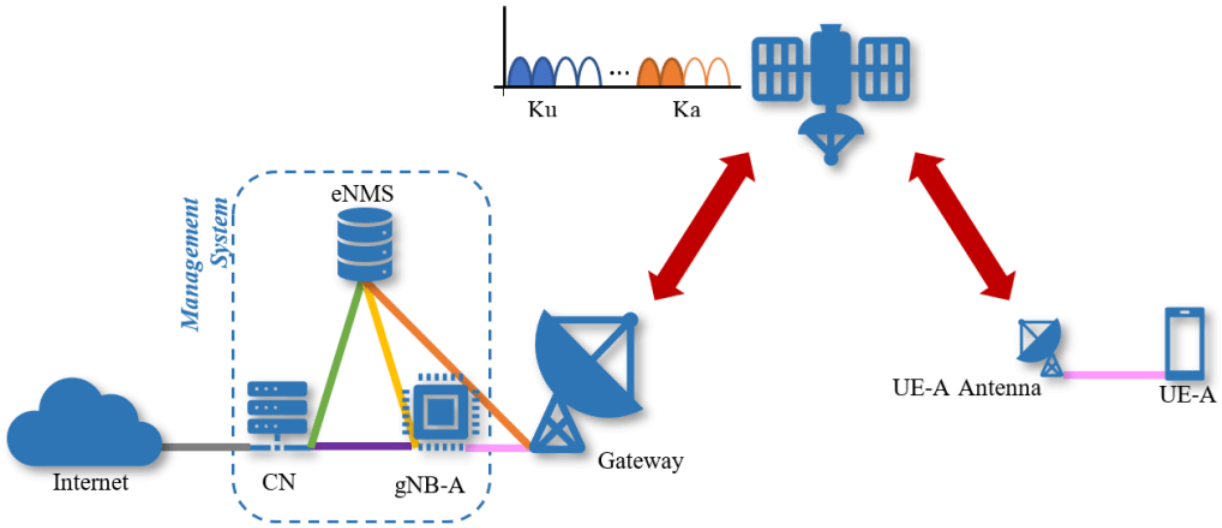
In order for partners to use the SNT Core Network, they will have to configure their tools/gNB to use it:

- AMF ➔ Public IP:38412/SCTP
- UPF ➔ 158.64.79.145:2152/UDP
- NEF ➔ 158.64.79.145:80/TCP

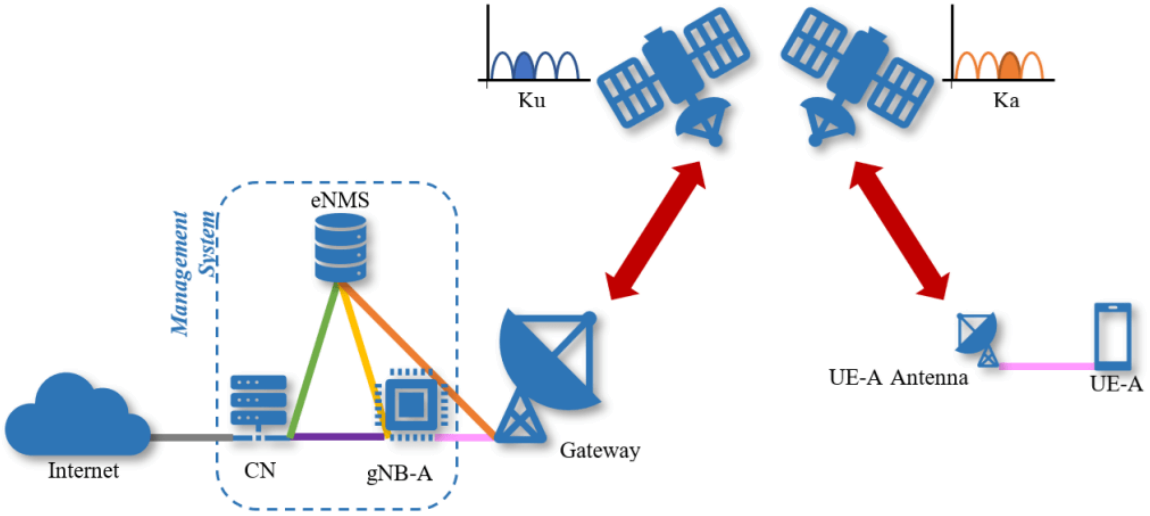
HEU TRANTOR & SNS ETHER

Multiorbit and multiband simultaneous connectivity

- 3D multilayer handover optimization in megaconstellations (via ISLs)
- Core Network NWDAF for real-time traffic monitoring, steering and routing



Carrier Aggregation

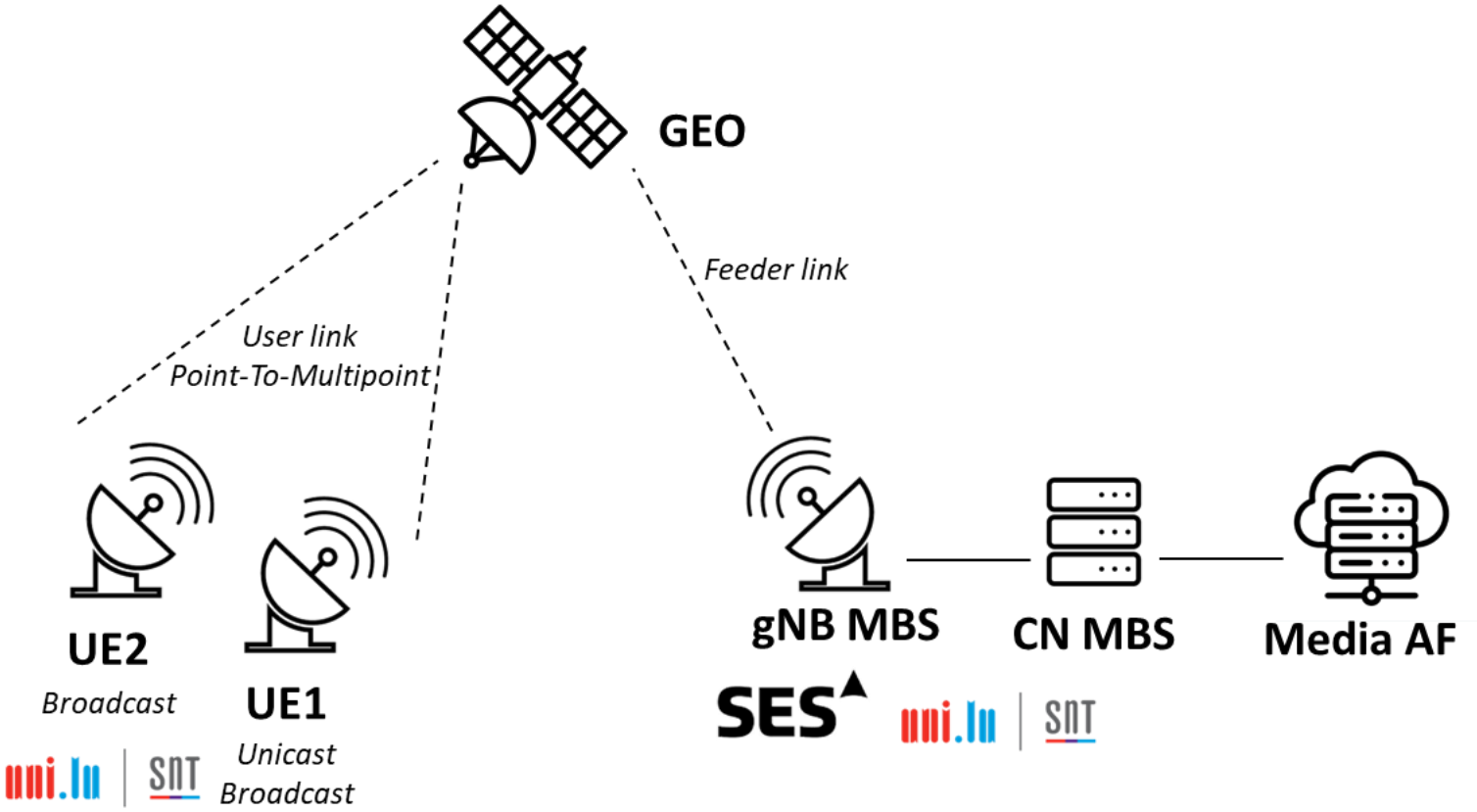


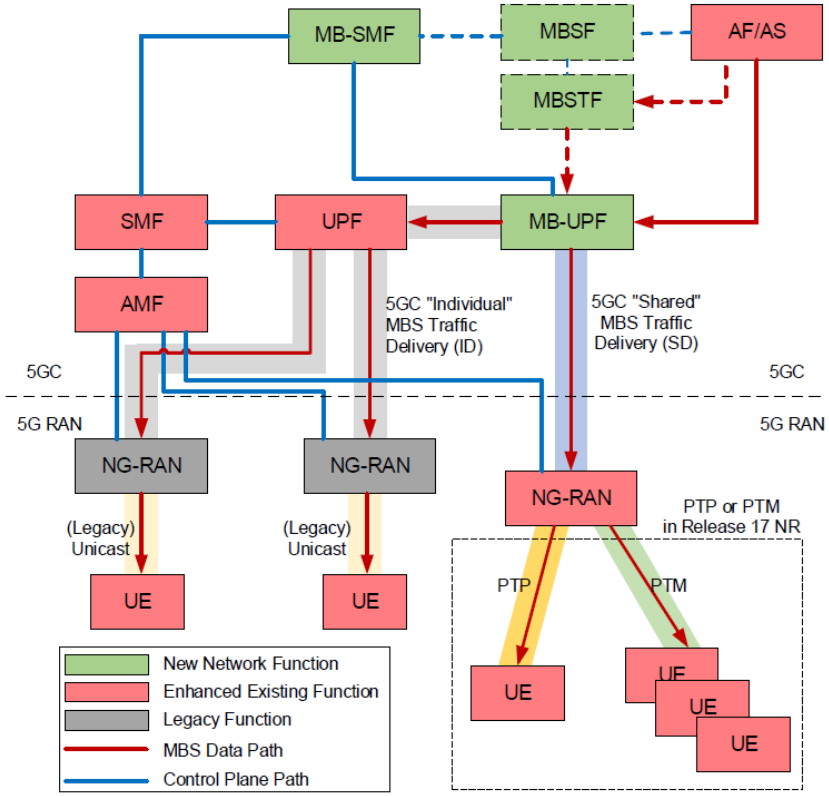
Dual Connectivity

ESA 5G-EMERGE

6G NTN MBS Over-The-Satellite with SES GEO satellite

- Demonstration of 5G-NTN Point-To-Multipoint Direct-to-Device Receive-Only Broadcast
- ESA 5G-EMERGE Phase 2 project (KO'24)



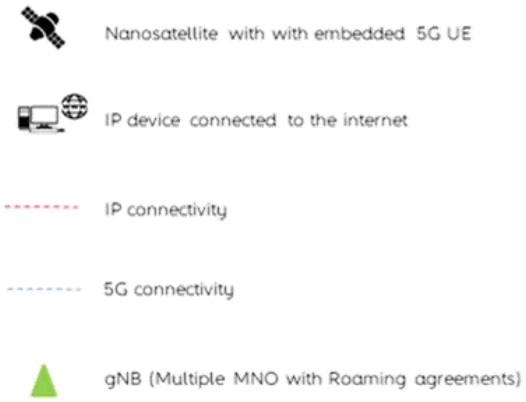


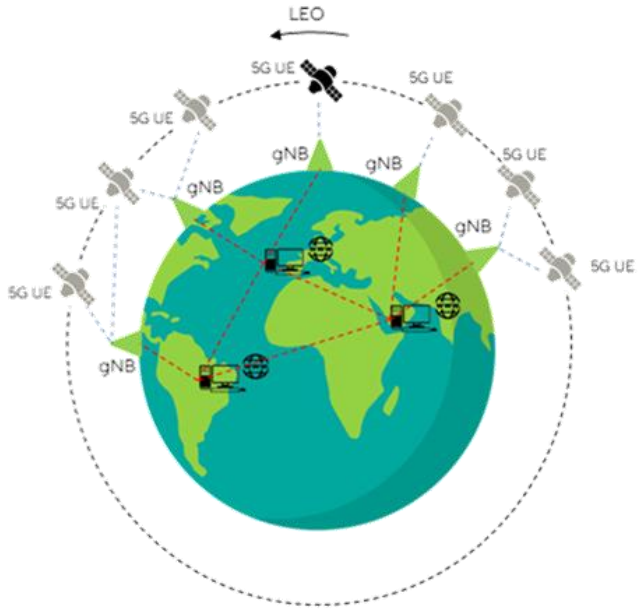
V. K. Shrivastava, S. Baek, and Y. Baek, "5G Evolution for Multicast and Broadcast Services in 3GPP Release 17

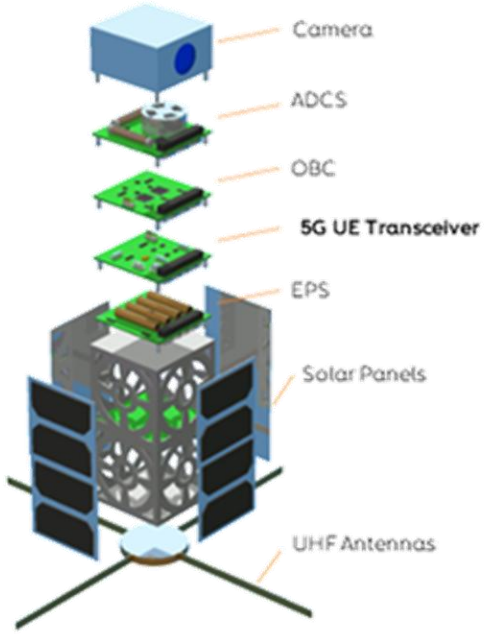
ESA 5G-Nanosatellite

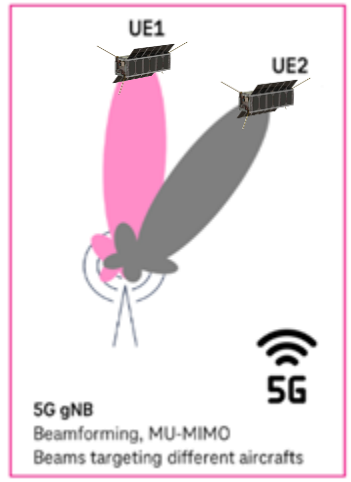
ESA Industry-driven project co-funded by Altice Labs

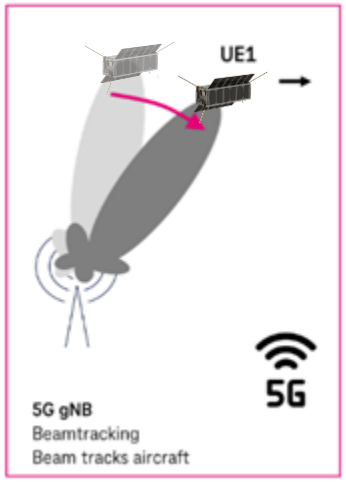
- Earth-observation missions generate huge amounts of data that needs to be downloaded from the satellites
- A network of dedicated 5G ground stations can provide high-bandwidth connectivity to thousands of satellites
- The 6GSPACE Lab is developing its own 5G terminal to be embarked in a 3U Cubesat Proof-of-Concept
- Project KO'24. Launch, operation and in-orbit validation are planned for 2026







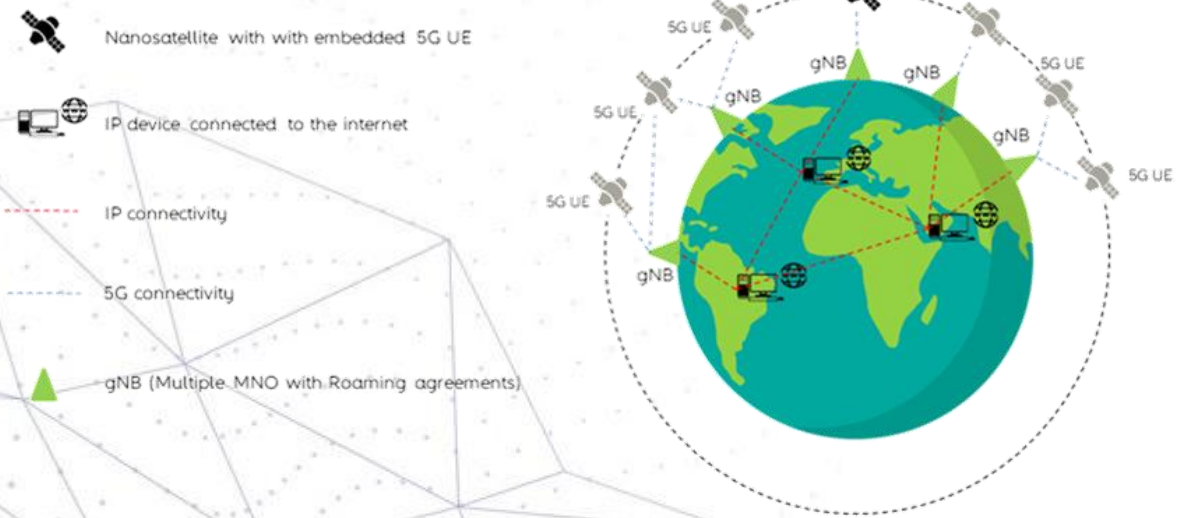


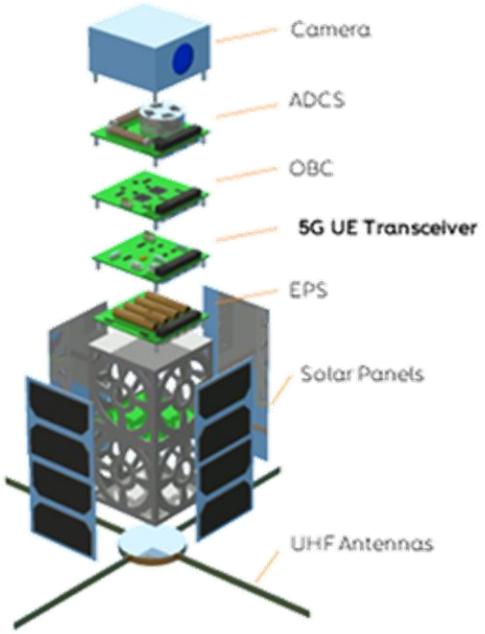


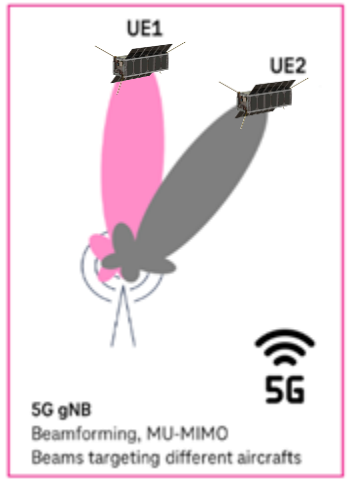
ESA 5G-Nanosatellite

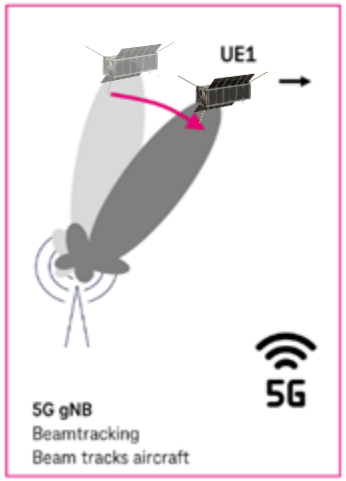
ESA Industry-driven project co-funded by Altice Labs

- Earth-observation missions generate huge amounts of data that needs to be downloaded from the satellites
- A network of dedicated 5G ground stations can provide high-bandwidth connectivity to thousands of satellites
- The 6GSPACE Lab is developing its own 5G terminal to be embarked in a 3U Cubesat Proof-of-Concept
- Project KO'24. Launch, operation and in-orbit validation are planned for 2027







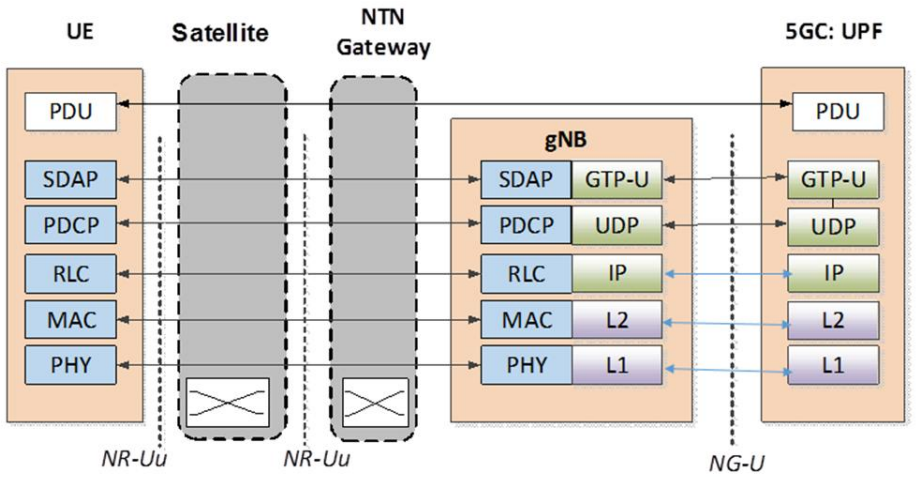


ESA 5G-GOA

OAI Extensions during 5G-GOA To Support NTN Features

Features broader than NTN, but necessary for NTN experimentation

- PHY Layer
  - Extend OAI rf-simulator to support simulation of long delay
  - Support for 5 MHz BW with 15 kHz SCS
  - Extended support for multiple bandwidth parts (BWP)
- MAC Layer
  - Support for Multi-UE
  - Implementation of real FDD Scheduling
  - Implementation of QoS scheduling
- Implementation of a new KPI GUI



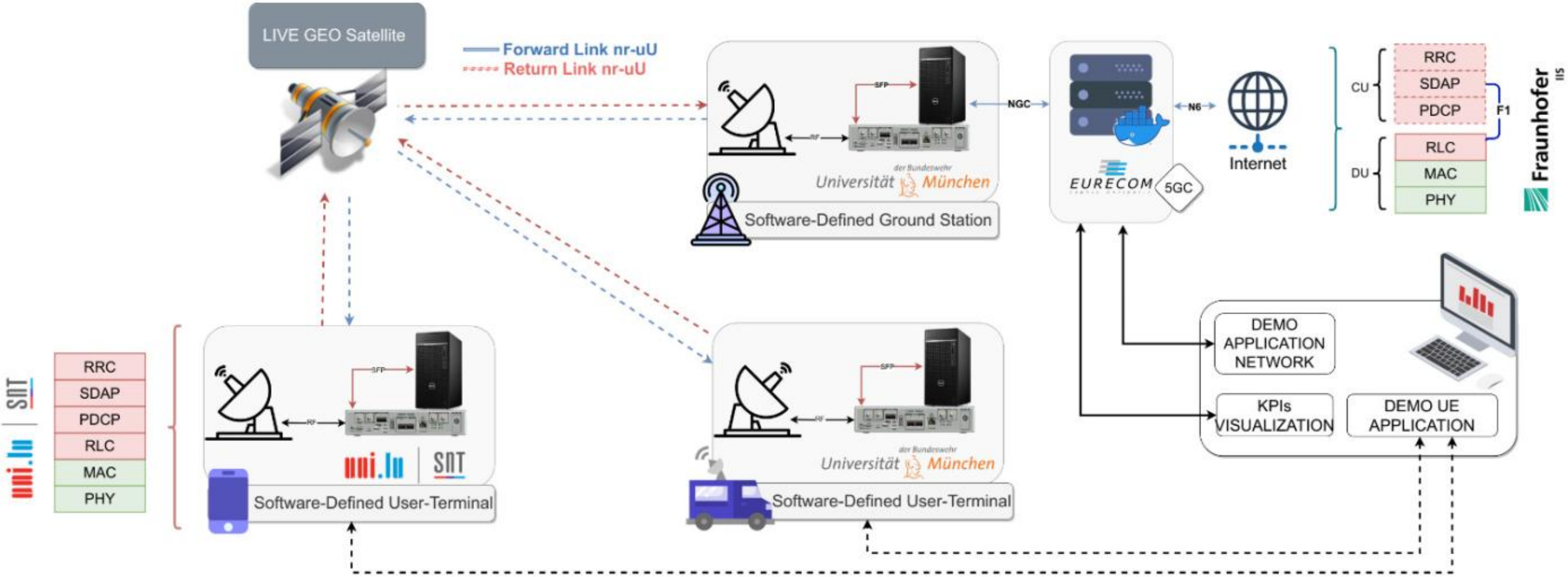
*3GPP TR 38.821 V16.1.0 (2021-05)

NTN specific feature extensions

- PHY Layer
  - Disabling HARQ at gNB and UE
  - Consider large delay for UL scheduling at gNB (FDD)
- MAC Layer
  - Adapting Uplink timing advance and RA procedure
- RLC Layer
  - Disable HARQ-ARQ interaction
  - Increase ARQ buffer size to cope with large GEO delay
  - Increase maximum Sequence Number value
- PDCP Layer
  - Increase discard timer for transmit SDU buffer
  - Increase t-reordering timer for receive PDU buffer
  - Increase size of transmit PDU buffer
- RRC Layer
  - Increase selected timers (T300, T301, T311)
- NAS Layer
  - No adaptations foreseen

ESA 5G-GOA

System setup



*S. Kumar et al., "OpenAirInterface as a platform for 5G-NTN Research and Experimentation", FNWF 2022, IEEE Future Networks World Forum, 12-14 October 2022, Montreal, Canada

ESA 5G-GOA

OTA Demo (Fall 2022)

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5G OAI UE

1.2 m dish

Ku-band
BUC + LNB

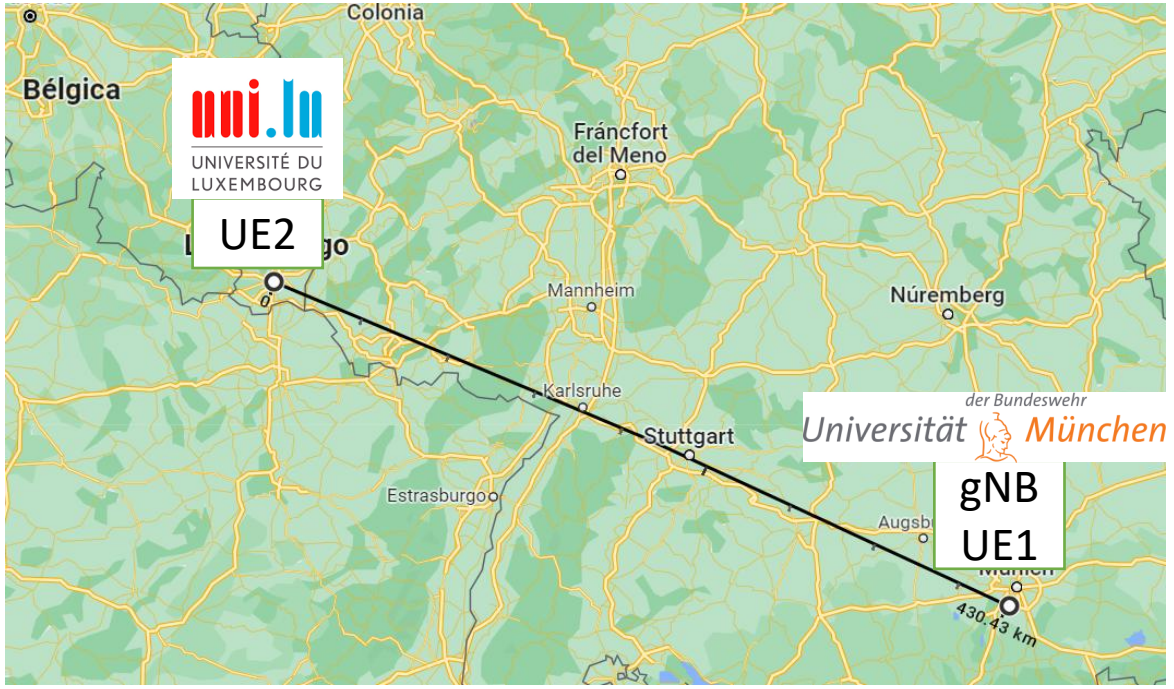
UNIVERSITÉ DU LUXEMBOURG

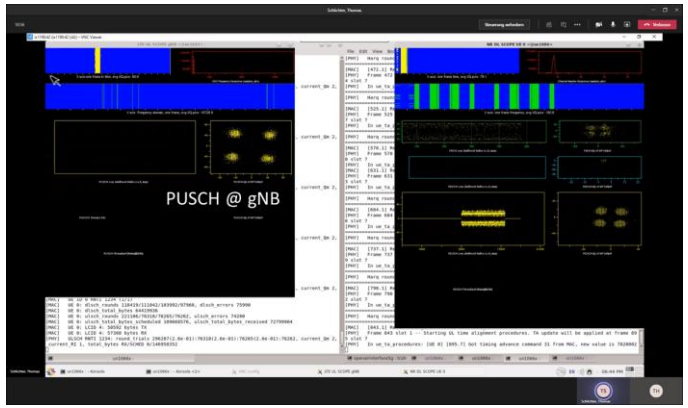
OAI GUI

Fraunhofer IIS

der Bundeswehr Universität München

Demo OTA locations





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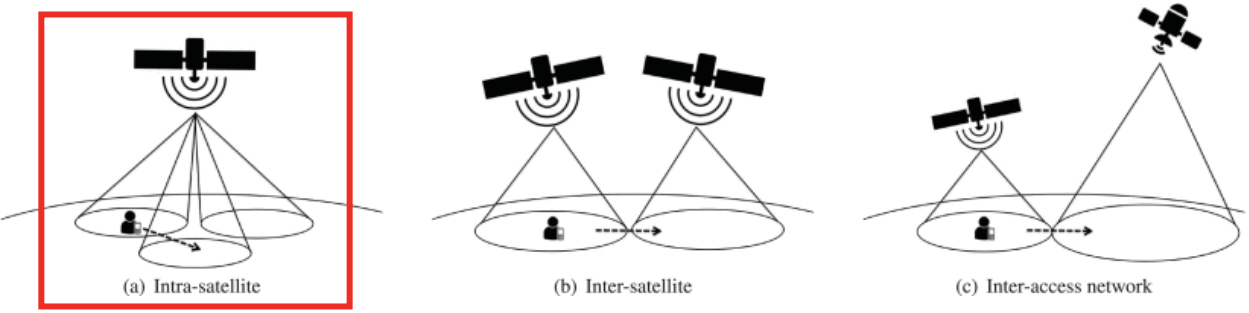
ESA 5G-LEO

OAI Extensions during 5G-LEO To Support NTN Features

Features broader than NTN, but necessary for NTN experimentation

- PHY and MAC Layer:
  - Continuous frequency offset compensation
  - SNR measurement and Channel State Information (CSI) Reporting
  - Uplink Power Control (Open loop & Closed loop)
  - Adaptive Modulation and Coding (AMC)
- Other
  - Extensions to the OAI gNB and UE KPI GUI



NTN specific feature extensions

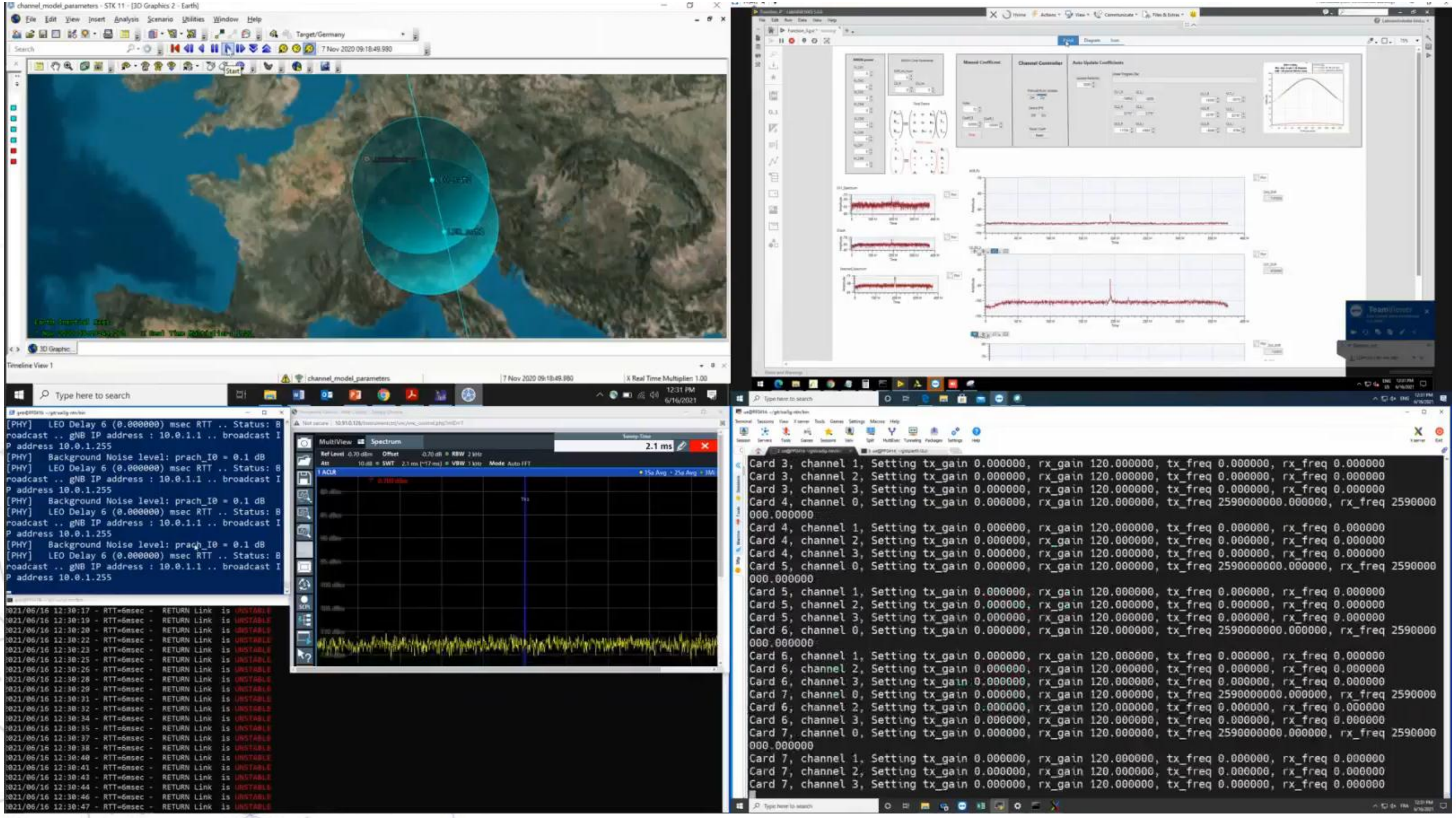
- PHY and MAC Layer
  - Adapted continuous timing drift compensation (and Doppler)
  - Support for up to 32 HARQ Processes (following 3GPP Release 17)
- RLC Layer
  - Increased t-ReassemblyTimer when HARQ is enabled
- PDCP Layer
  - Increased discardTimer at the transmit entity
  - Increased t-ReorderingTimer at the receive entity
  - Increased SDU buffer at the transmit entity
- RRC Layer
  - Increasing UE-timers and constants used by the UE when in RRC_CONNECTED, RRC_INACTIVE and RRC_IDLE state
  - Extending sr-Prohibit Timer
  - Adaptation of the basic 5G NR Handover procedure and paging protocols (for intrasatellite handover)

5G-SpaceLab Demo

Earth-orbiting Scenario: Small Satellites and NGSO Constellations

STK
Orbit

Chan.
Emul.



gNB +
Sat

UE
(SNR+
Mbps)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6G NTN AI-acceleration
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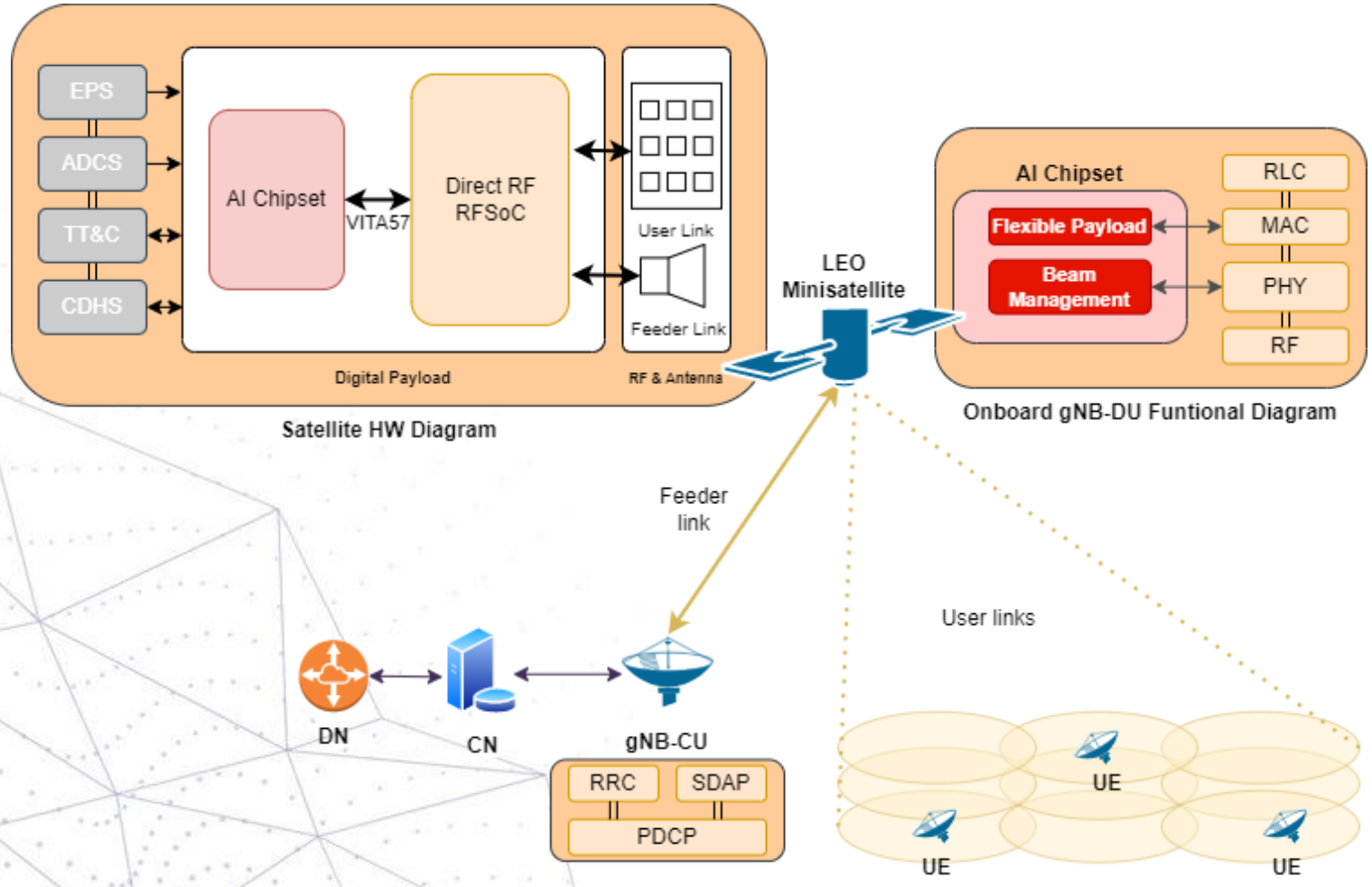
AI-acceleration for regenerative satellite payloads

AI-acceleration for MAC/PHY layers using AI chipsets

- AI chipsets: AMD Versal, Intel Loihi, NVIDIA Jetson
- ESA SPAICE, NEUROSAT, SAFARI (SatNEx) Projects



AI-Accelerated functionalities

- Scheduler (flexible payload)
- Beamforming
- PAPR & ACI reduction

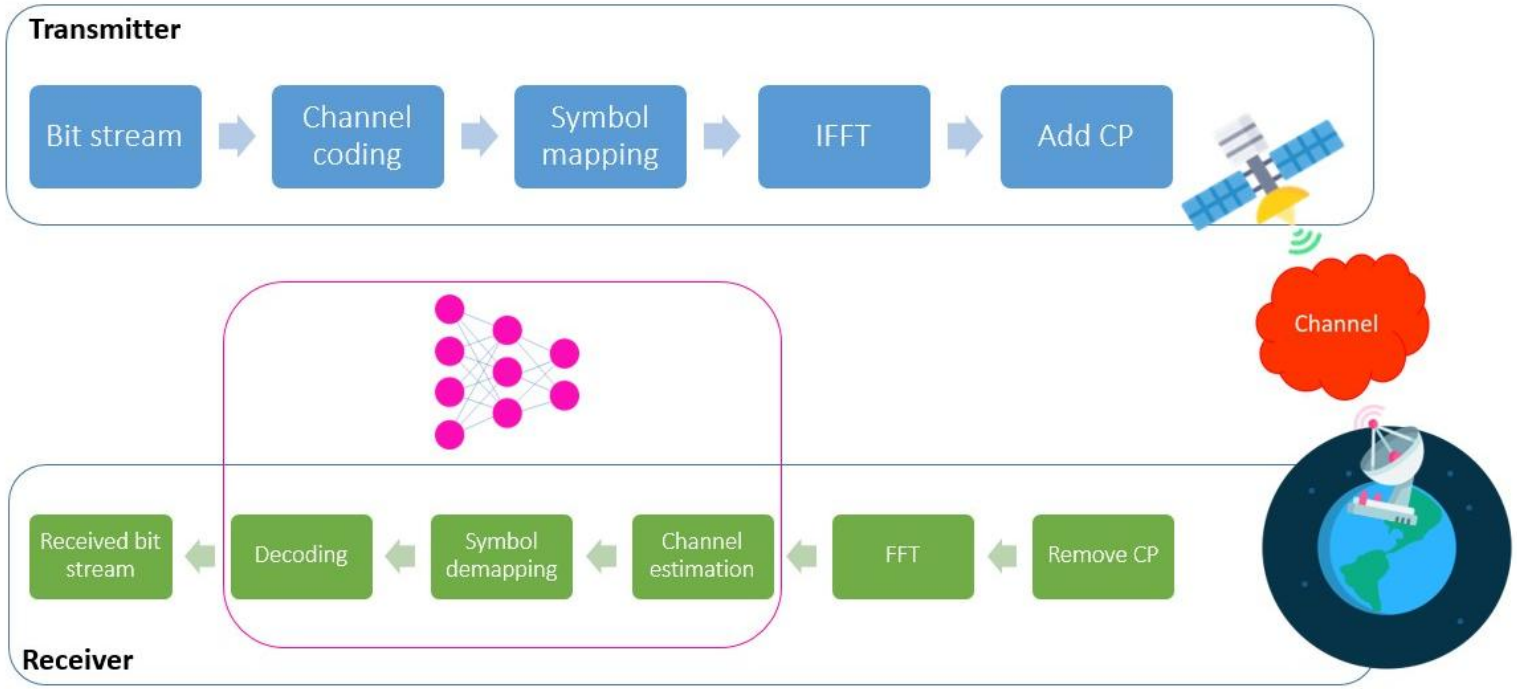
LEO MSS use cases

- Onboard LEO regenerative payload

AI-acceleration for 5G UEs

AI-acceleration for UE PHY layers using AI chipsets

- AI chipset: AMD Versal
- ESA TANNDEM project



AI-Accelerated functionalities

- Channel decoding
- Symbol demapping
- Channel estimation

LEO MSS use cases

- UE NTN D2D optimization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6G NTN Spectrum Sensing
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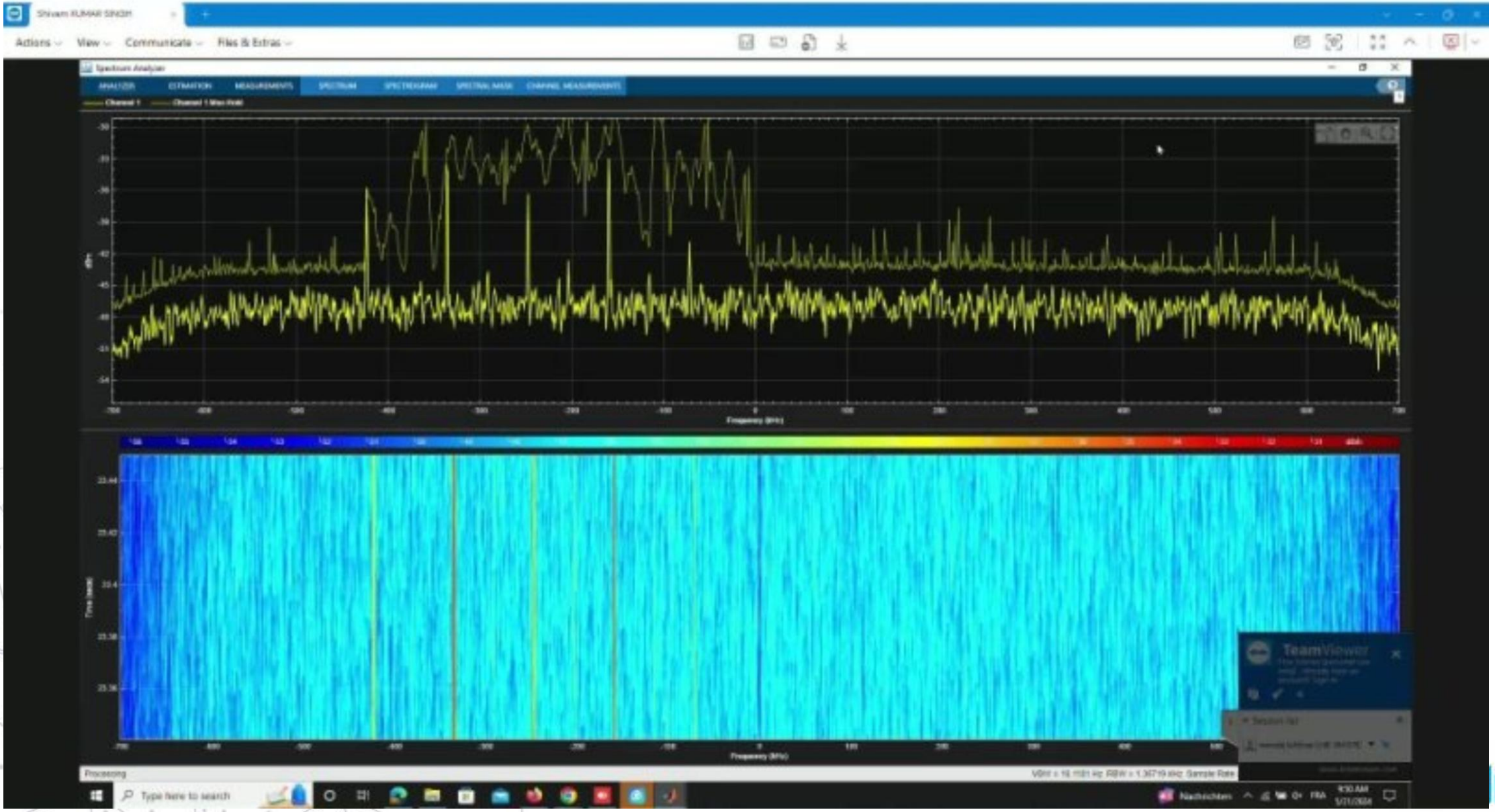
NGSO-Sense

PROTOTYPE FOR MEASURING NGSO SATELLITE NETWORK INTERFERENCE AND RADIOFREQUENCY CHARACTERISTICS

Dual-band Tracking Antenna for Spectrum sensing

NGSO-Sense


Actions
View
Communicate
Files & Extras
Spectrum Analyzer
ANALYZER
ESTIMATION
MEASUREMENTS
SPECTRUM
SPECTROGRAM
SPECTRAL MASK
CHANNEL MEASUREMENTS
Channel 1
Channel 1 Max Hold
dBm
Frequency (MHz)
Time (sec)
Frequency (MHz)
TeamViewer
Processing
Type here to search
Nachrichten
FRA
9:30 AM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Lunar 5G Proximity &
Edge Computing
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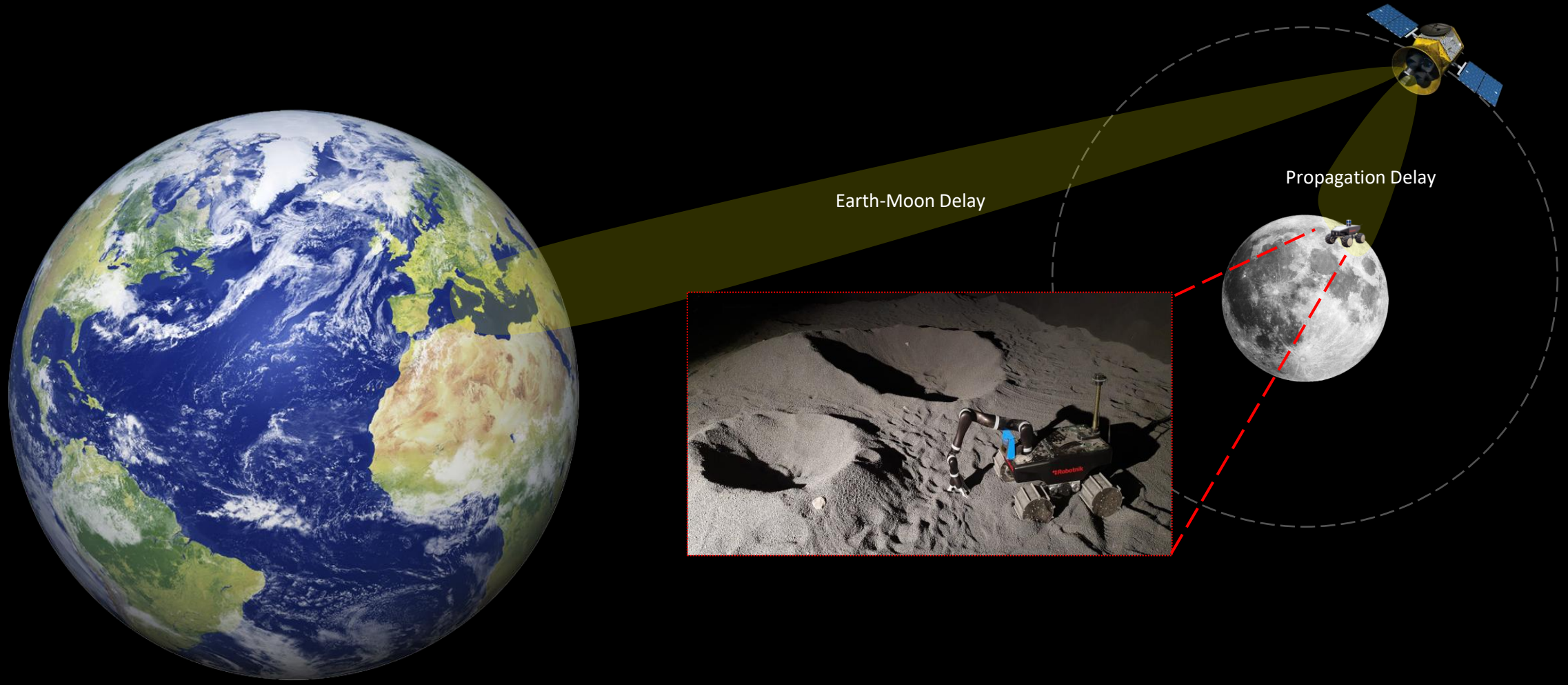
LLO Mission scenario



Teleoperator
Concurrent Design Facility
Core Network

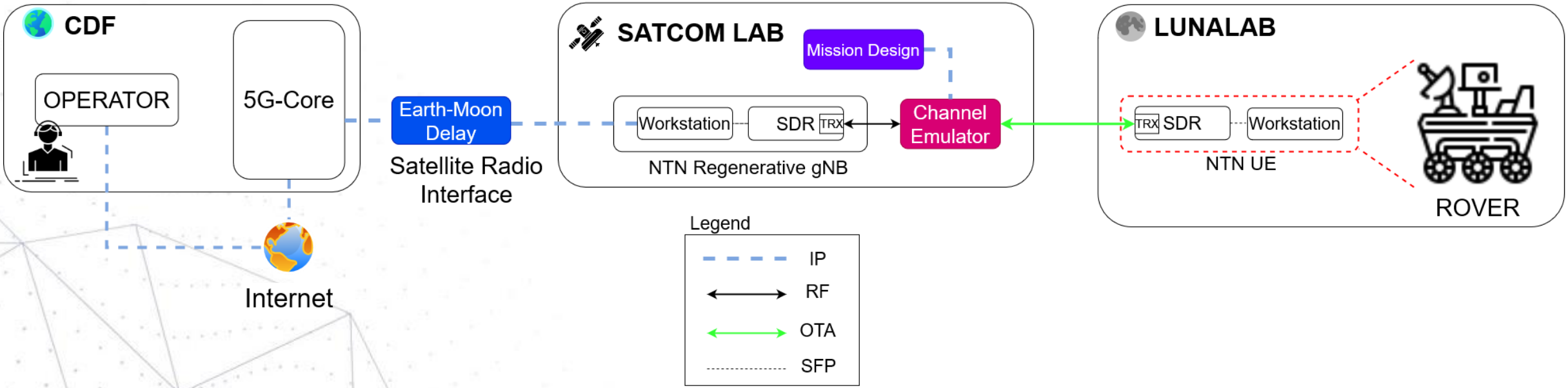
Earth-Moon delay

LLO Regenerative 5G-NR satellite

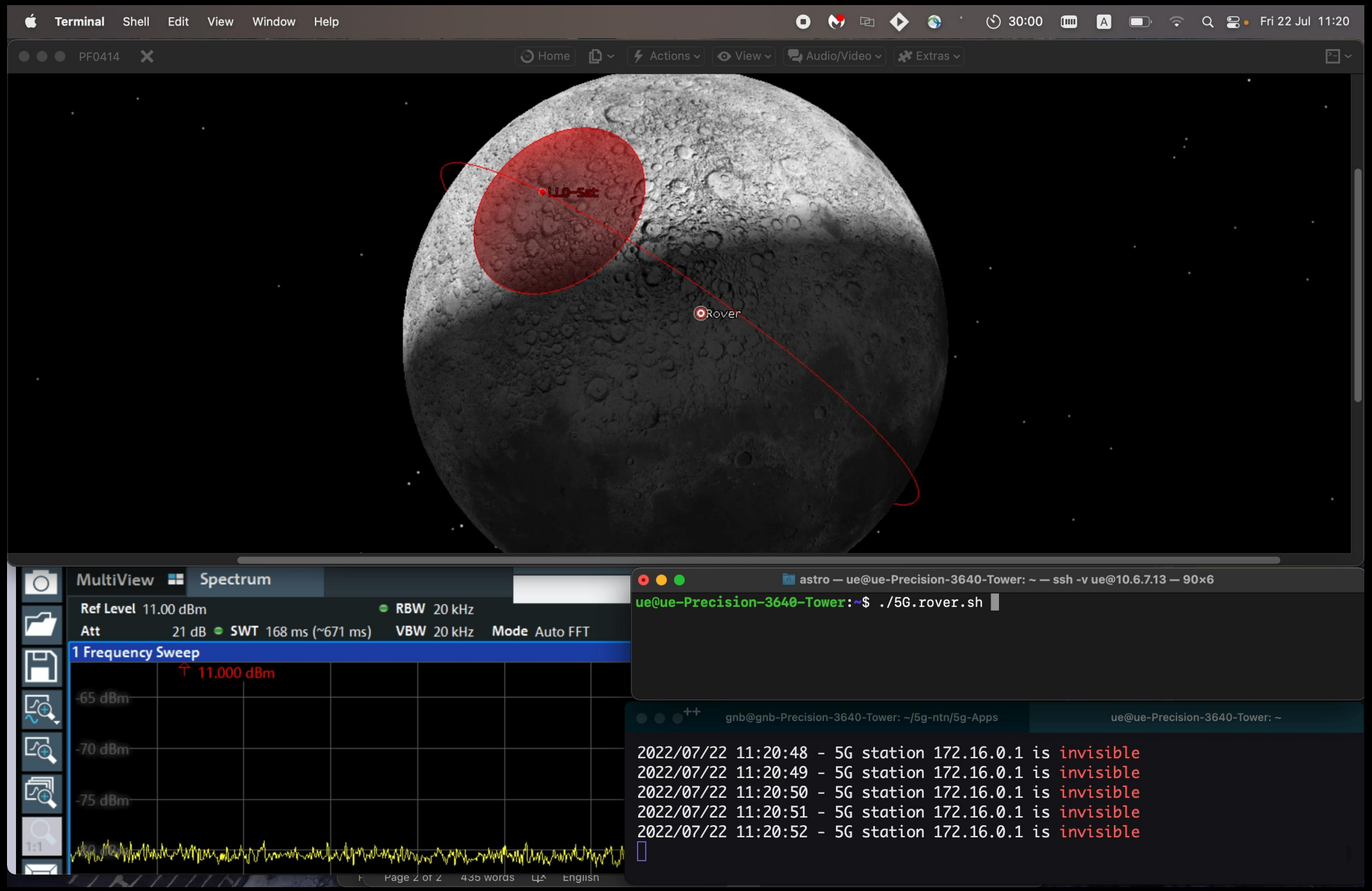
Propagation delay

ROVER

Functional architecture of scenario testbed

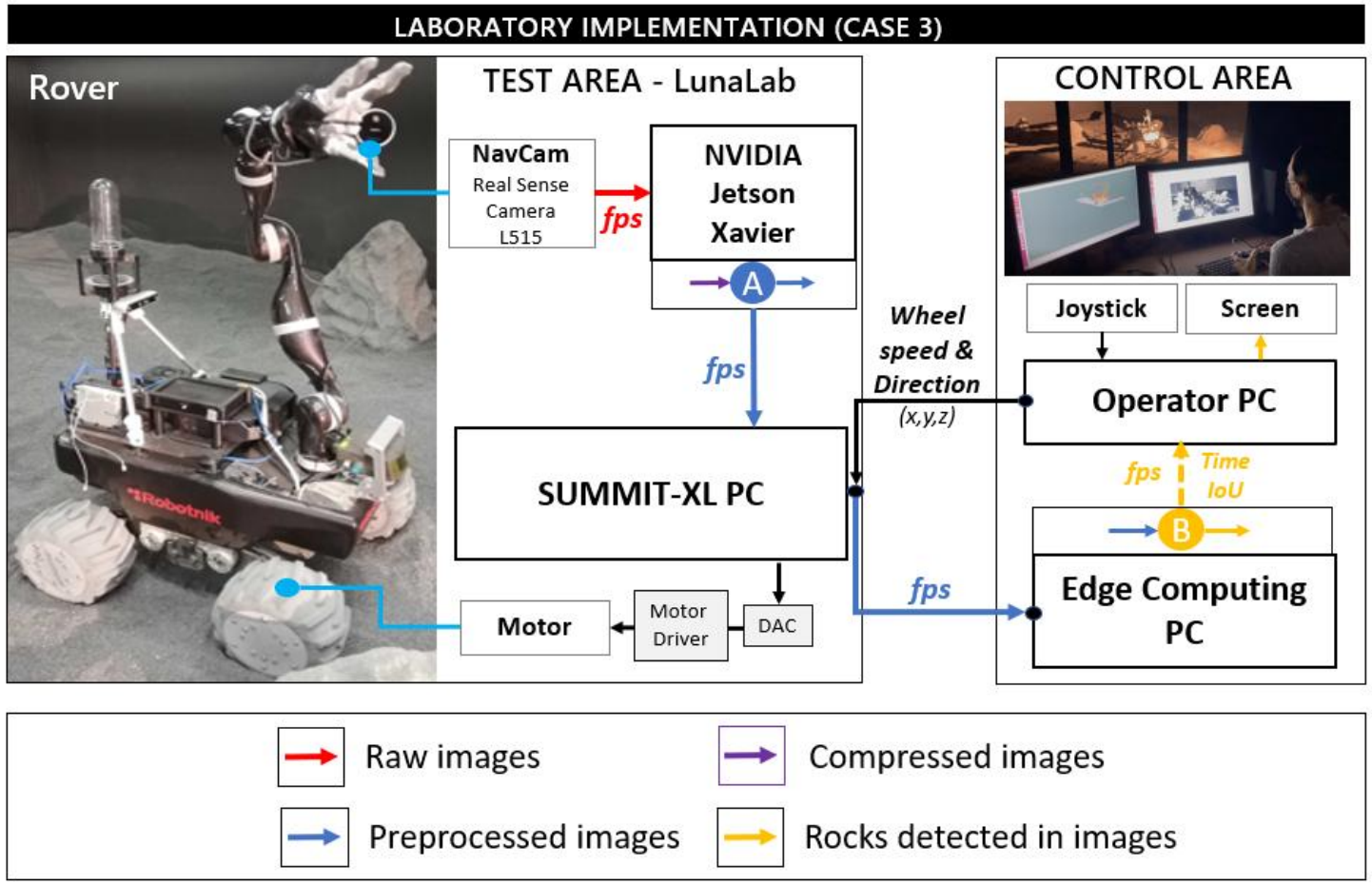


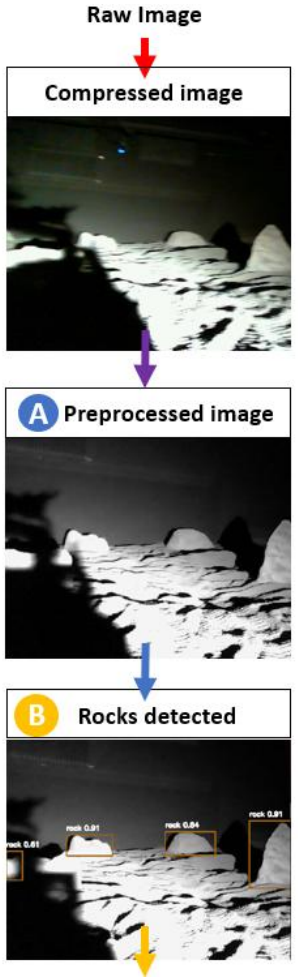
5G-NTN LLO Mission
Acces-Time: 48~sec



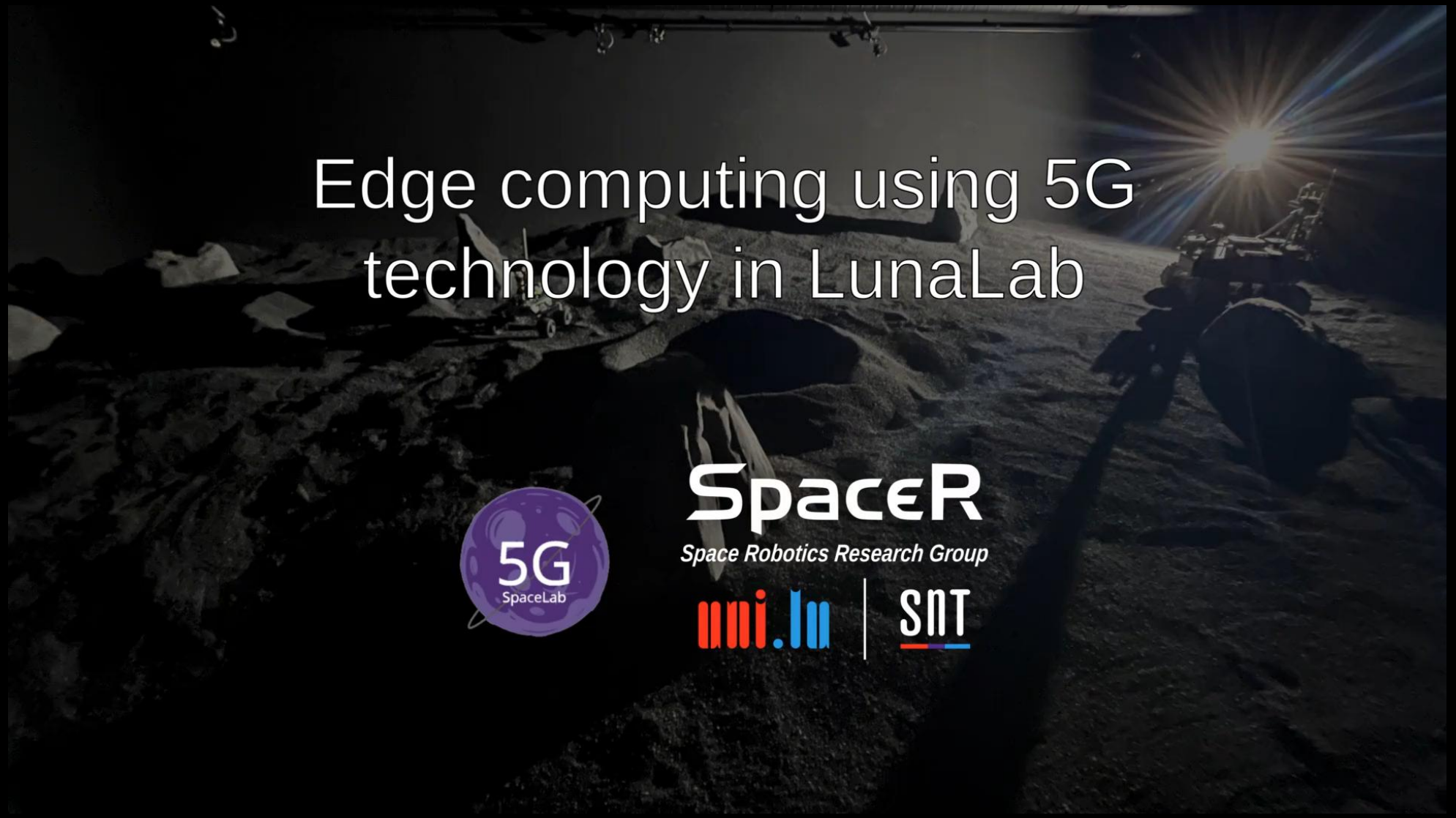
System Setup for Rock Recognition Algorithm

Preprocessing of the images in the NVIDIA Jetson Xavier and execution of YOLOv5 in the Edge Computing PC





Experiment Comparison (Qualitative)

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Actual situation for PNT service providers

- At this moment, the PNT services are offered via Global Navigation Space Services (GNSS)
- This could be **easily attacked** (jamming and spoofing techniques)
- Any disruption of these PNT services could be **catastrophic for the Critical National Infrastructures (CNI)** that rely on them

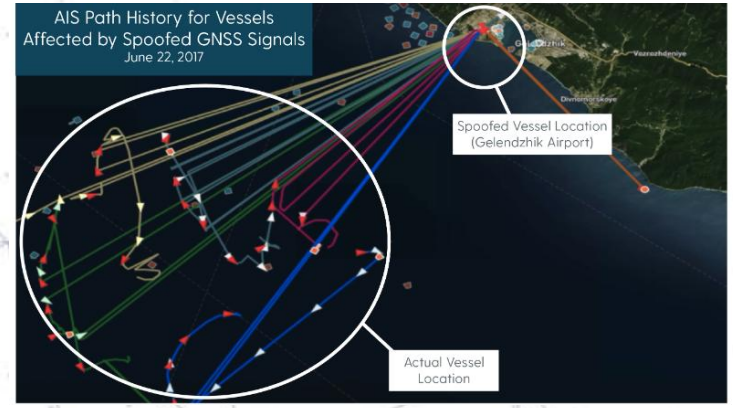


Fig. 1. Spoofed GNSS Signal in the Black Sea [1]

EASA
European Union Aviation Safety Agency

Safety Information Bulletin
Operations – ATM/ANS
SIB No.: 2022-02
Issued: 17 March 2022

Subject: **Global Navigation Satellite System Outage Leading to Navigation / Surveillance Degradation**

Ref. Publications:
None.

Applicability:
National Aviation Authorities (NAAs), Air Navigation Service Providers (ANSPs) and air operators.

Description:
In the current context of the Russian invasion of Ukraine, the issue of Global Navigation Satellite Systems (GNSS) jamming and/or possible spoofing has intensified in geographical areas surrounding the conflict zone and other areas.

Eurocontrol, Network of Analysts and open-source data reports analysed by EASA indicate that since 24 February 2022, there are four key geographical areas where GNSS spoofing and/or jamming has intensified, namely:

- Kaliningrad region, surrounding Baltic sea and neighbouring States;
- Eastern Finland;
- The Black Sea; and
- The Eastern Mediterranean area near Cyprus, Turkey, Lebanon, Syria and Israel, as well as Northern Iraq.

The effects of GNSS jamming and/or possible spoofing were observed by aircraft in various phases of their flights, in certain cases leading to re-routing or even to change the destination due to the inability to perform a safe landing procedure. Under the present conditions, it is not possible to predict GNSS outages and their effects. The magnitude of the issues generated by such outage would depend upon the extent of the area concerned, on the duration and on the phase of flight of the affected aircraft.

Fig. 2. Report about GNSS outage for flights surrounding Ukraine [2]

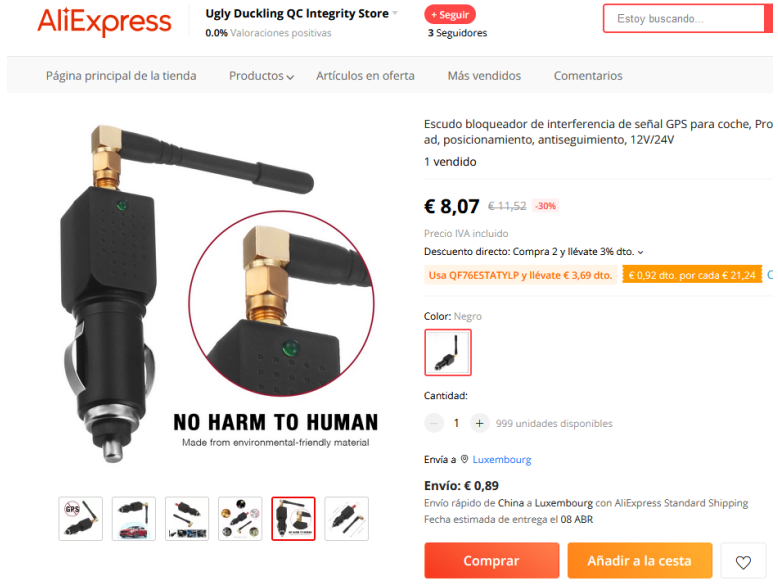


Fig. 3. GNSS jammer accessible by anyone for less than 10$

And the solution: Diversification of PNT sources

✓ Lowering the likelihood of a single-point failure

- ✓ 5G enables **joint communication** and **localization** into a single receiver
- ✓ **Integrity** of the signal can be **verified** with the use of the communication network.
- ✓ Terrestrial waveforms penetrate better inside buildings, therefore **indoor navigation** is possible
- ✓ Combined with satellite, the 5G PNT service **coverage** in rural areas is **better** than using only terrestrial systems

- ⚠ Increased complexity of the receiver
- ⚠ Terrestrial PNT has local/regional coverage only

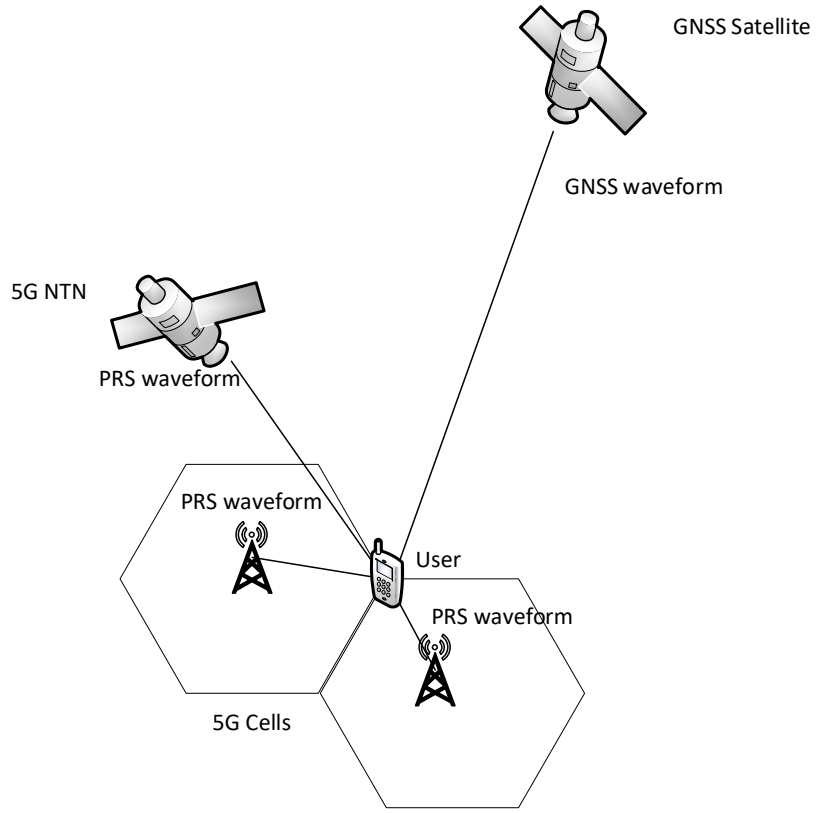


Fig. 4. Diversification of PNT sources

Interference analysis for a shared Resource Grid in an NTN scenario

Example of a shared Resource Grid between 4 transmitters

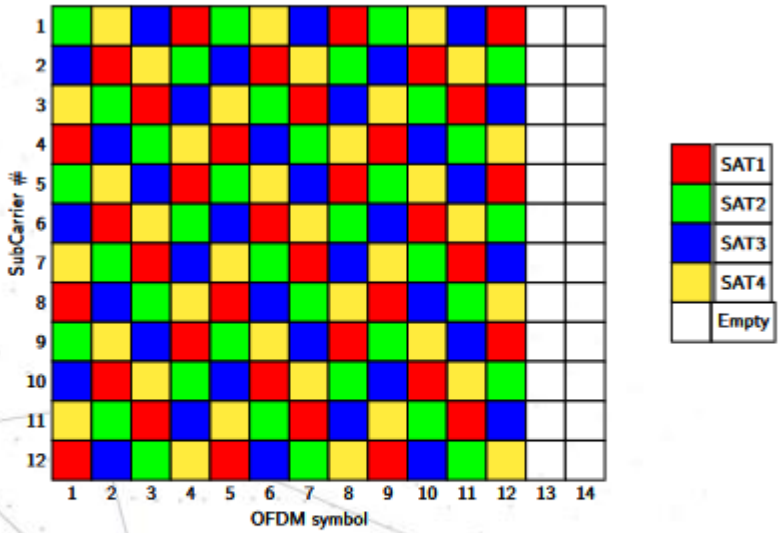


Figure: 5G PRS Resource Grid allocation. Size 1 Resource Block × 1 Slot

Differential delays and Dopplers between transmitters

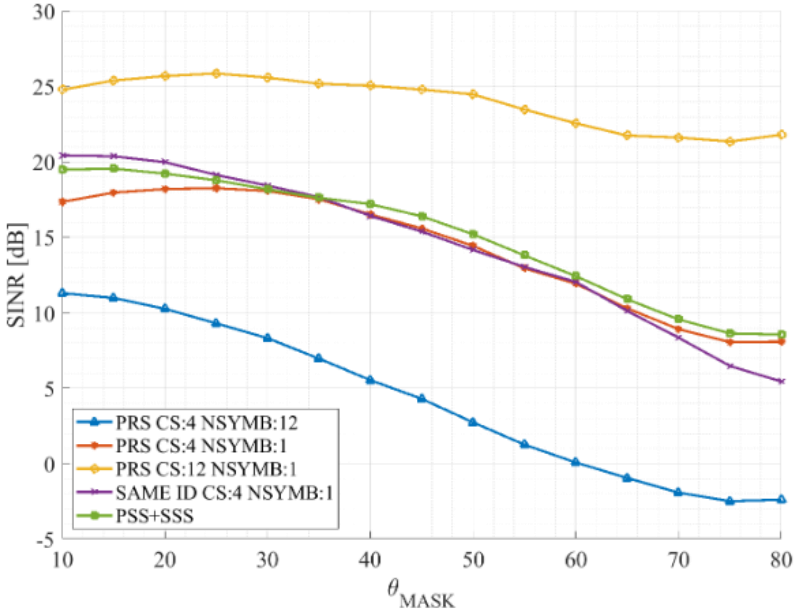


Figure 18: Received SINR for different θ_{MASK}

5G-LEON: RADIO POSITIONING TECHNOLOGIES FOR 5G SATELLITE NETWORKS

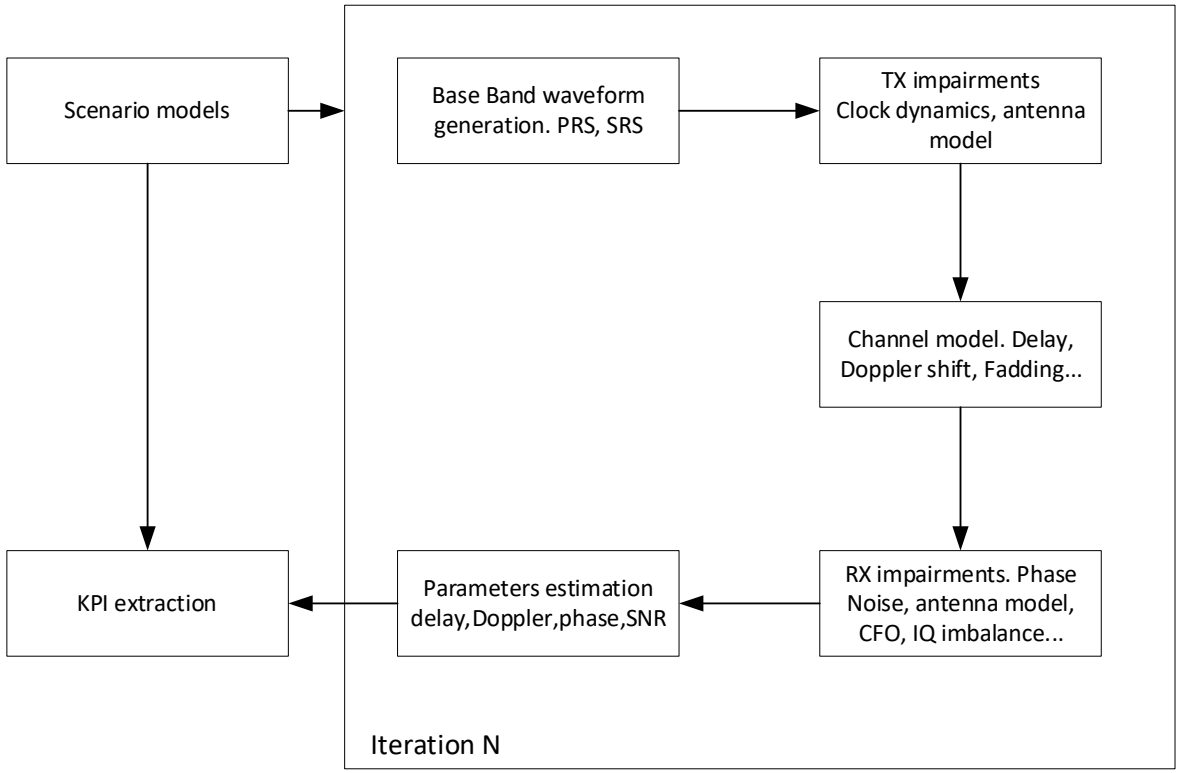
UniLu WP responsibilities:

- WP Leader of WP3300 and WP4200: Physical Layer Measurement Module

- WP Contributor to WP1300, WP2200, WP2300, WP3100 and WP5100

UniLu Main Tasks

- Develop the PHY layer measurement module. This module is responsible for obtaining the statistical distribution of the different parameters used for the position estimation (delay, doppler, phase, SNR,…) based on the transmitted waveform and the scenario.



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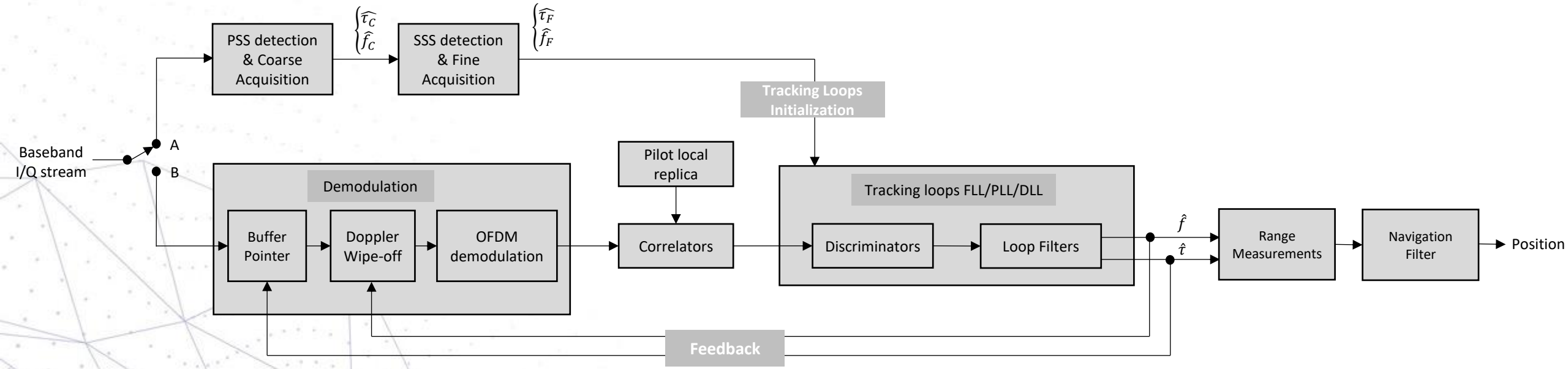


JCAS for 6G-NTN

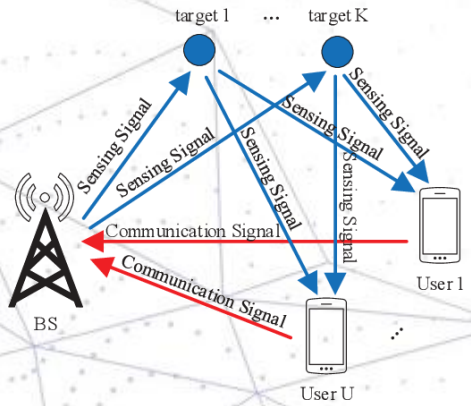
Funded by T-Labs (DE)

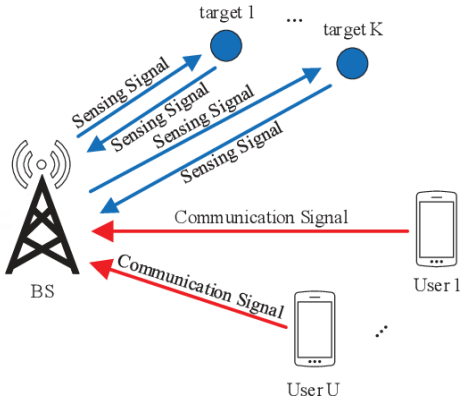
Objectives

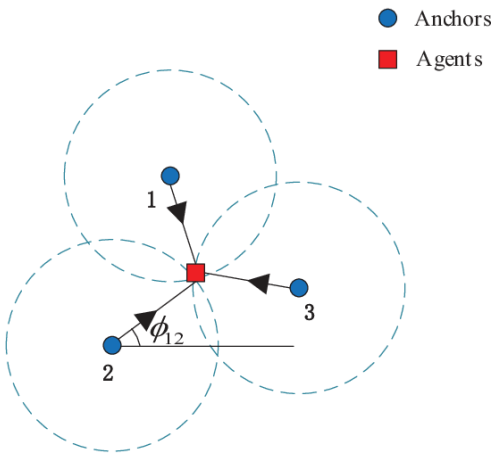
1) Conduct a Literature Review to Gain a Comprehensive Understanding of Existing JCAS Literature for NTN (not only)
2) Identify Relevant Use Cases and their Enabling Techniques/Technologies
3) Gather Information on Relevant Regulatory Requirements and Constraints

Use case classification

- **Channel-based parameters (Remote Sensing)**
  - Estimated parameters are external to the network
  - Prior knowledge or calibration at TX/RX (position/antenna/receiver)
- **Device-Based (Positioning, Navigation and Timing)**
  - Estimated parameters depend on the TX/RX connected to the network







Summary of research outputs and projects

Projects:

- 5G-LEON: RADIO POSITIONING TECHNOLOGIES FOR 5G SATELLITE NETWORKS, funded by ESA TDE program
- SATNEX WI Y3.3 LEO-PNT, funded by ESA
- JCAS for 6G-NTN, funded by T-labs, Berlin
- 5G-Sky: Interconnecting the Sky in 5G and Beyond – A Joint Communication and Control Approach, funded by FNR

Journals:

- S. E. Trevlakis et al., "Localization as a Key Enabler of 6G Wireless Systems: A Comprehensive Survey and an Outlook," in IEEE Open Journal of the Communications Society, vol. 4, pp. 2733-2801, 2023.
- Gonzalez-Garrido, Alejandro, Querol, Jorge, Chatzinotas, Symeon, “Interference analysis of Positioning Reference signals in 5G NTN” in IEEE Open Journal of the Communications Society, *Submitted. https://arxiv.org/abs/2401.09157*

Conferences:

- Gonzalez-Garrido, Alejandro, Querol, Jorge, Chatzinotas, Symeon, "Hybridization of GNSS and 5G Measurements for Assured Positioning, Navigation and Timing," *Proceedings of the 35th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS+ 2022)*, Denver, Colorado, September 2022, pp. 2377-2384. https://doi.org/10.33012/2022.18385
- A. Gonzalez-Garrido, J. Querol and S. Chatzinotas, "5G Positioning Reference Signal Configuration for Integrated Terrestrial/Non-Terrestrial Network Scenario," *2023 IEEE/ION Position, Location and Navigation Symposium (PLANS)*, Monterey, CA, USA, 2023, pp. 1136-1142, doi: 10.1109/PLANS53410.2023.10140024

Book chapter:

- Nguyen Diep N. 2022. *Enabling Technologies for Social Distancing : Fundamentals Concepts and Solutions*. London United Kingdom: Institution of Engineering and Technology. Retrieved January 16 2024 (https://doi.org/10.1049/PBTE104E).

Interdisciplinary Centre for Security, Reliability and Trust

Contact:

Jorge.Querol@uni.lu

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