# THE 6G-NTN PROJECT

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# Outline

- The 6G-NTN project
- Use cases
- Research areas
  - Architecture
  - Terminals
  - Air interface
  - AI driven design and validation of data enhanced RIC for 6G NTN
- Impact
- Takeaways

# Project Facts and figures

- **Addressing call**: "[SNS-2022-STREAM-B-01-03: Communication Infrastructure Technologies and Devices]"
- **Overall goal**: Develop an NTN component fully integrated with the 6G infrastructure able to provide enhanced Mobile BroadBand (eMBB) and Ultra Reliable Low Latency (URLL) services to vertical industries and consumers terminals in outdoor and light indoor conditions.
- **Targeted TRL**: 2 - 4
- **Duration**: 36 months
- **Project kick-off**: 1 January 2023
- **Alessandro Vanelli-Coralli,** Project Coordinator (UniBo), **Nicolas Chuberre,** Technical Manager (TAS-F), **Sandro Scalise,** Innovation Manager (DLR), **Monique Calisti**, Communication & Dissemination Manager (MAR)

6G-NTN project ambition is to **develop the 6G NTN component** concept and **drive its standardization** phase in 3GPP as part of Rel-20+

# Project Consortium

## Disclaimer

**Views and opinions expressed are those of the Author only** and do not necessarily reflect those of the European Union nor those of the Projects' Partners. Neither the European Union, the Projects' Partners, nor the granting authorities can be held responsible for them.

## 6G-NTN at a glance

6GNTN

**Research** and **develop** innovative **technical**, **regulatory**, and **standardization enablers** needed to ensure the full-fledge integration of the **NTN** component into the **6G** system for **vertical industries** and **consumer market**, promoting the European Industrial leadership in the sector .

# Project Concept

6GNTN

Unification of the Terrestrial and Non-Terrestrial components on the basis of the following key enabling technologies

- sustainable and resilient 3D multi-layered network architecture.
- low Earth orbiting space segment.
- software defined payload adapted to each orbits and spectrum.
- flexible waveform supporting terrestrial and non-terrestrial deployments.
- support of smart phones and small factor vehicle/drone mounted terminals (with prime focus on the antenna solutions).
- use of new spectrum (i.e., C and Q/V bands) in coexistence with the terrestrial network component.
- high accuracy and reliable positioning solution.

# 6G-NTN High Level objectives

6GNTN

## OBJ 1

- Identify the **target service and operational requirements** for 6G NTN component

## OBJ 2

- Design/sizing of a **3D NTN** to meet the target user requirements

## OBJ 3

- Design trade-off and assessment of **compact terminals targeted by the 3D NTN component**

## OBJ 4

- Design flexible **software defined payload** across flying platforms and frequency bands

## OBJ 5

- Design **key characteristics/features of a flexible waveform** for 6G's integrated radio access network

## OBJ 6

- Design and evaluation of **AI data-enhanced multi-orbit multi-connectivity radio intelligent controller**

## OBJ 7

- Design and development of **dynamic orchestration of Virtual Network Functions** in a 3D network for 6G

## OBJ 8

- Design a **reliable and accurate positioning function** for the 6G system with a precision below 10 cm

## OBJ 9

- Design **enabling features for spectrum usage optimisation** between the different network nodes

## OBJ 10

- Maximise the **impact of 6G-NTN** and strengthening Europe's industrial leadership in the sector

# Project use cases [2/2]

| Use Cases (defined in WP2.1) | User | Service Expectations | Network Usage Expectations | UE Types | Handheld Consumer | Handheld Professional | Mounted Maritime | Mounted Vehicular | Drone | Other Aeral Vehicle |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | UE Characteristics | Geometry, Lifecycle, Operational Conditions, Environment, Mobility | | | | | |
| **UC1: Maritime Coverage for search and rescue coast guard intervention** | • Vessel Op.<br>• UAV-Contr.<br>• Pilot | • Critical Comm.<br>• Realtime control<br>• Telemetry Data | • Tactical Bubble<br>• Direct UE to UE via sat | → | | X | X | | | X |
| **UC2: Autonomous power line inspection using drones** | • Aut. Drone<br>• UAV-Contr. | • Realtime control<br>• Telemetry Data | • Private TN – NTN<br>• NTN via HAPS | → | | | | | X | X |
| **UC3:Urban air mobility** | • UAV-Contr. | • Realtime control<br>• Edge network services<br>• Broadcast<br>• 3D-Location | • TN - NTN info. exchange<br>• Direct UE to UE via sat<br>• NTN via HAPS | → | | | | | X | |
| **UC4: Adaptation to PPDR or Temporary Events,** | • First resp.<br>• Ambulance | • Critical Comm.<br>• Broadcast<br>• Location, 3D-Location | • Tactical Bubble<br>• Direct UE to UE via sat<br>• NTN via HAPS / a. node | → | | X | | X | X | X |
| **UC5: Consumer Handheld Connectivity and Positioning in Remote Areas** | • Priv. user | • Emergency Call<br>• Broadcast<br>• Location | • Cross-border mobility | → | X | | | | | |
| **UC6: Continuous Bi-directional Data Streams in High Mobility** | • Passenger<br>• Driver | • Conference (video) Call<br>• Emergency Call<br>• Broadcast | • Cross-border mobility | → | X | | | X | | |
| **UC7: Direct Communication over Satellites.** | • Priv. user<br>• First resp. | • Emergency Call<br>• Broadcast<br>• Location | • Direct UE to UE via sat | → | X | X | | | | |

Use cases and requirements defined jointly with the Advisory Board: **Volkswagen Infotainment, BMW, Bosch, SWR, Thales Group, SBB, EDF, Synctechno, Erillisverkot, French Ministry of Interior, NCAI**

# 6G NTN Architecture

# Multi-multilayer & multiband 6G architecture

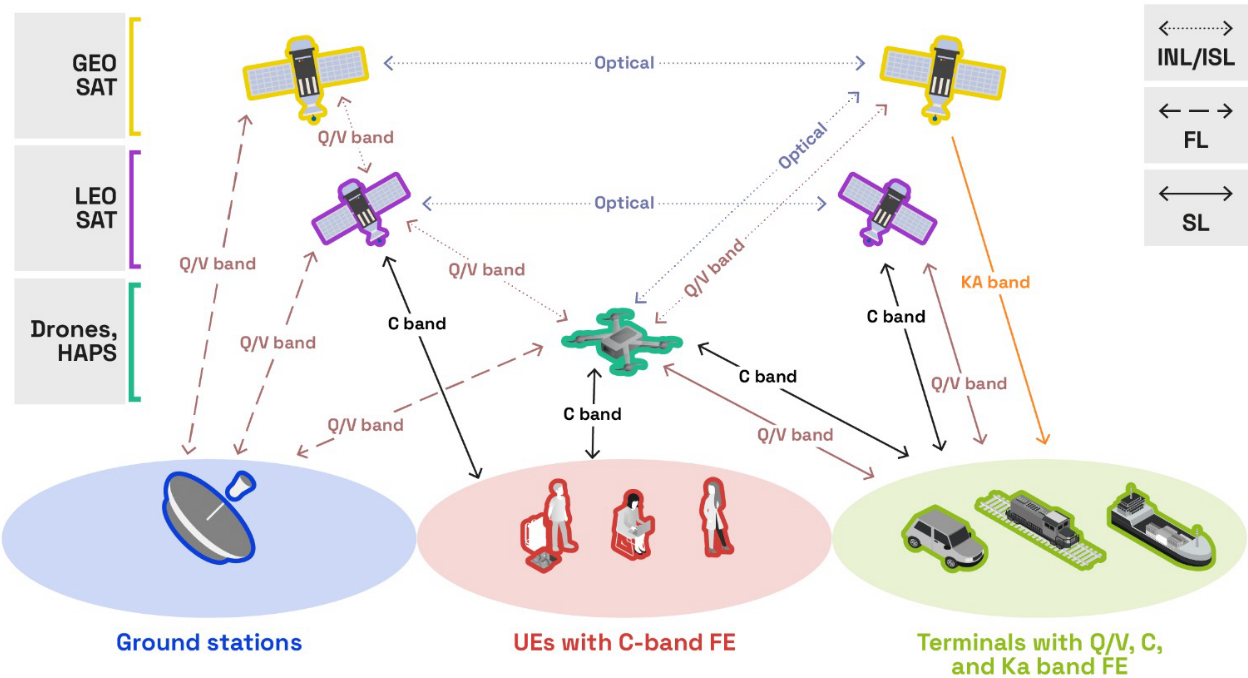
## Deterministic nodes with fixed and predictable orbits

### GSO platforms

- broadcast & multicast for fixed ground stations
- broadband access, e.g., backup coverage or complementary capacity for
- hot spots (latency tolerant)
- non-delay sensitive traffic offloading from the NGSO.
- control and management planes to the NGSO in case of no feeder links / ground segment
- Backup in case of lower constellations failures

### NGSO platforms

- broadband access to handhelds and VSAT-like UEs




## Flexible nodes “opportunistically” deployed

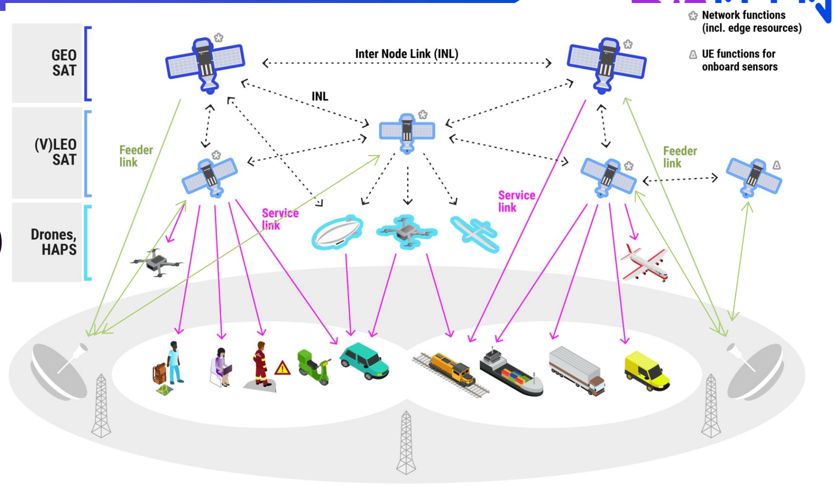
### HAPs or drones (heavy drones)

- capacity to specific areas with no TN, e.g., disaster, emergency, etc
- additional capacity for sudden traffic increase e.g., concerts, sport events w/wo TN coverage

# 6G NTN Architectural solutions

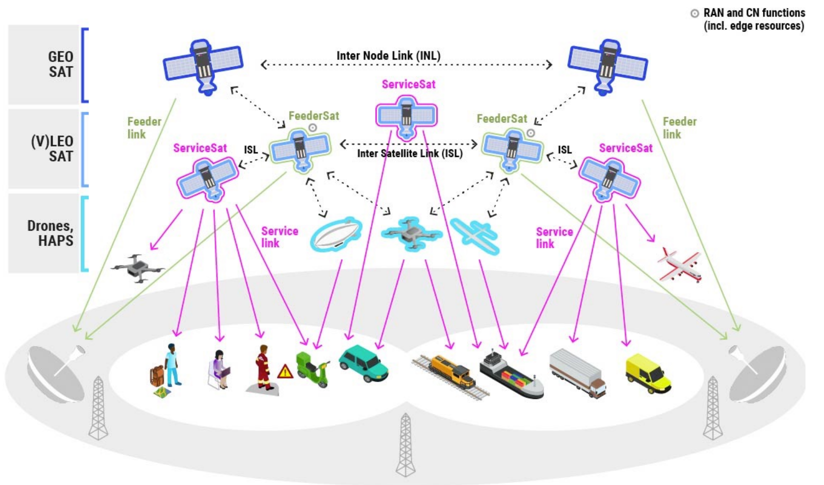
## Conventional architecture – homogeneous satellites

- All satellites have the same functionalities
  - User link to UEs (multibeam)
  - 2 feeder links (redundancy and/or seamless ground station handover)
  - 4 OISL to 4 adjacent satellites (same and adjacent orbital planes)
  - 1 Ka-band payload for the INL to GEO satellites
  - all RAN and, possibly, some CN functionalities




## Distributed architecture – heterogeneous nodes (same altitude)

- Feeder Nodes with higher computational capabilities
  - 2 Feeder links to GW / no user link to UE
  - 4 OINLs to 4 service nodes
  - 2 OINLs to 2 feeder nodes
  - 1 Ka-band payload for the INL to GEO satellites
  - Most of RAN/CN functionalities
- Service Nodes with lower computational capabilities
  - User link to UEs (multibeam) / no feeder link to GW
  - 1 OINL to 1 feeder node
  - Minimum RAN functionalities (RU)




Source: SNS JU Project 6G-NTN, D3.5 "Architectural Solutions," March. 2024.

# Architecture sizing: example

6GNTN

| Architecture | | Sat/ planes | # of planes | # of sat per type | Total # of sat |
|---|---|---|---|---|---|
| Conventional | | 47 | 27 | - | 1269 |
| Distributed | Feeder | 14 | 24 | 366 | 1635 |
| | Service | 47 | 27 | 1269 | |

## Assumptions

- Altitude: 600 km
- Near-polar inclination (~87°)
- 45° min user elevation angle
- At least 1 satellite always visible
- At least 10 s of overlap between 2 satellites
- 2 constellations 1 for C-band and 1 for Q/V band

Source: SNS JU Project 6G-NTN, D3.5 "Architectural Solutions," March. 2024.

# 6G-NTN Terminals

# Objective

The objective is to design and evaluate low C-SWaP (Cost Size Weight and Power) user terminals

| UE type | Communication characteristics | Terminal type | RF characteristic | Frequency band |
|---|---|---|---|---|
| **Handheld** | narrowband | classical integrated front end on handheld | typ. NF=9 Gain : -3dBi, Tx=23 dBm | Sub 6GHz<br><br>S and L band |
| **Professional handheld** | Narrowband<br><br>medium | Enhanced RF front end | typ. NF=7 Gain : -3dBi, Tx=26 dBm | Sub 6GHz<br><br>C band |
| **Drone; car** (small mounted UE) | medium | Enhanced Rf and antenna | typ. NF=7 Gain : 0 dBi, Tx =26 dBm | Sub 6GHz<br><br>C band |
| **Drone, train vessel** (mounted UE) | wideband | Enhanced RF and improved noise figure performance | typ. NF=5; Tx =25,5 dBm | Q/V band |
| **Drone, train vessel** (mounted UE) | Ultra-wideband | Enhanced RF and extreme noise figure performance | typ. NF=4; Tx =28 dBm | Q/V band |

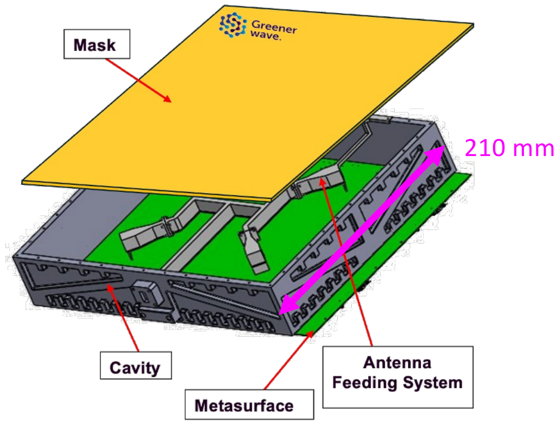
# Outcomes

## CHALLENGES

| Challenge | Description |
|---|---|
| High-frequency signal losses | Greater signal attenuation due to absorption |
| Material and fabrication precision | High frequencies demand precise fabrication tolerances as small imperfections can lead to significant performance degradation. |
| Size reduction and compact designs | Smaller wavelengths require compact antenna designs, which are difficult to achieve while maintaining performance and efficiency. |
| Dielectric and conductor losses | Dielectric and conductive materials face higher losses at Q and V-band frequencies, necessitating careful material selection. |
| Thermal management | High-frequency electronics generate more heat, making effective thermal management necessary. |
| Bandwidth requirements | Achieving wide bandwidth is challenging due to the narrow operational bands and high data rate demands. |
| Integration and beamforming | More complex signal processing and circuit design required for the antenna and beamforming at these high frequencies. |
| Electromagnetic interference (EMI) | Increased susceptibility to interference from nearby systems and components operating in adjacent frequency bands. |
| Measurement and testing challenges | Testing and characterizing antennas at high frequencies require specialized, costly equipment and calibration techniques. |

## OUTCOMES & MEASURES

- Two novel active beamformer based antenna for terminals in Q and V bands.
- Power consumption and Bill of Material (BOM) of the ultra-small aperture terminals.
- Architecture and technologies for the RF front-end.



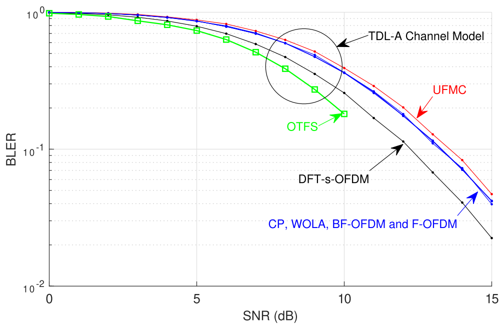
# 6G-NTN Air Interface

| Radio interface design drivers | Rationale |
| --- | --- |
| Multi carrier waveform enhancements | **Relaxed synchronization requirements** (GNSS free operations)<br>Downlink **PAPR reduction** for spectral efficiency maximization in simplified platform (single channel HPA) |
| Advanced modulation, coding and multiple access schemes | **Low SNR regimes** enabling the support of challenging radio link conditions, e.g., light indoor. |
| Design flexible UL/DL framing structure | Flexibility **for frame structure adaptation** to satellite orbit, frequency range, etc. …<br>Overhead reduction (limited multi-paths conditions ) |
| TDD support | **Unpaired spectrum** may be allocated to NTN (LEO/vLEO platform) |
| Full duplex | **Spectrum usage** maximization |
| Reference signals for positioning | Support **reliable network-based solution** for Positioning, **Navigation and Timing** (PNT) services (<10cm). |
| Support of broadcast and multicast | Leverage **large coverage area** of satellites (multilayered architecture) |
| Support for Artificial Intelligence driven radio resource control | **dynamic optimization** of the **radio interface** configuration (e.g. Modulation, coding, power, signal occupancy, interleaving depth, HARQ) according to the radio link conditions |
| Spectrum sharing between TN and NTN | Co-channel spectrum sharing between TN and NTN. |
| Joint communication and sensing | Provide low to medium resolution **sensing capabilities** directly integrated into the **waveform design**. |

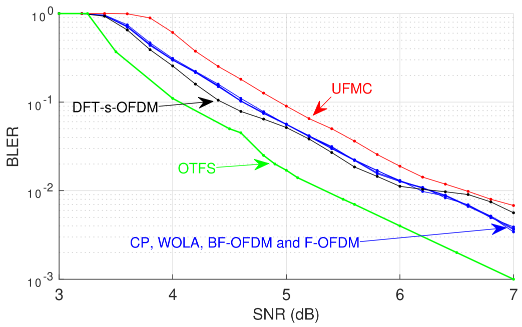
# Waveform: evolution or revolution?

## Potential new/adapted waveforms addressing NTN features, e.g.,

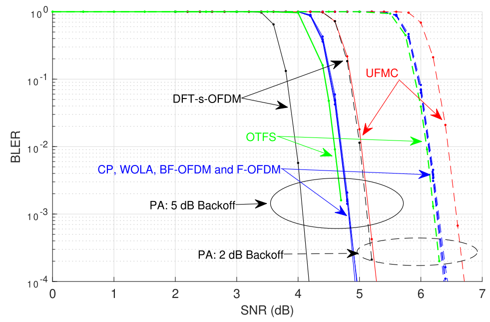
- CP-OFDM, DFT-s-OFDM, WOLA-OFDM, OTFS, BF-OFDM, UFMC, F-OFDM



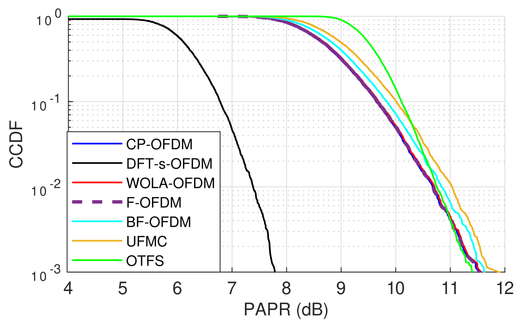

C band, NTN-TDL-A




Q/V band, PN




Q/V band, IBO = 2 and 5 dB




PAPR

- DFT-s-OFDM shows better performance when HPA is implemented because of its reduced PAPR
- PN strongly impacts the performance of all the waveforms
- Higher robustness of OTFS to PN and multipath. Higher receiver complexity
- Assumption: no receiver optimization… yet

*Source: Amatetti et All, '6G NTN in C and Q/V-Bands: Link Budget Analysis and Waveforms Performance' – Globecom 2024*

# 6G-NTN AI DRIVEN DESIGN AND VALIDATION OF DATA ENHANCED RIC FOR 6G NTN

# Objective

6G NTN RIC mechanism for the Radio Resource Management of the overall NTN systems ranging from:

- From large-scale temporal configurations (e.g., orbital spectrum assignments, bandwidth parts, etc)
- To low scale temporal radio adaptations (e.g., number of resource blocks per terminal, user-beam association)

# RIC network functions

## Identified potential RIC resource network functions intended to optimize:

| Function | Scope |
|---|---|
| Traffic offloading | To balance the load between TN and NTN depending on the dynamic user traffic i.e. by off-loading traffic to NTN. |
| Fractional Frequency Reuse | To maximize the overall offered system capacity and the spectrum utilization. |
| Traffic Prediction and NTN Radio Optimization | Considering the full integration between TN and NTN and the latency constraints for many potential services, the future traffic volume and trends prediction in different sub-networks or geographical areas will facilitate the proactive planning for scaling the network infrastructure. |
| Link Quality Prediction | To improve the efficiency during NTN mobility, an AI-based mechanism is considered to predict the UE's radio channel condition in the time-and-spatial domain |

# 6G-NTN IMPACT

## DISSEMINATION AND STANDARDIZATION

# Communication and Dissemination KPIs

6GNTN

- **25'000+ unique visitors** to the project website
- **3'700+ LinkedIn followers**
- **17 Deliverables published**
- **15+ scientific publications**
- **2 workshops** organized
- Publication of **6G NTN White Paper** and contribution to **6G-IA Vision White Paper**
- Multiple **standards contributions** to **3GPP** and **ETSI**



*6G-NTN project has received funding from the Smart Networks and Services Joint Undertaking (SNS JU) under the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101096479. This work has received funding from the Swiss State Secretariat for Education, Research and Innovation (SERI).*

# Key Takeaways

# Key Takeaways

**Evolutionary and revolutionary technologies** are needed to achieve a true **fully integrated** 6G **air interface**

- Flexible and natively integrated waveforms
- Networking, edge computing and communications
- Efficient Spectrum Access and new spectrum
- GNSS free operation
- Light indoor operations, e.g., improved link budget, extended/additional coding schemes
- AI based NTN and NTN supported AI
- New constellations

**Megaconstellations represent a sustainability** (financial/environmental) **challenge**: smart and sustainable design paradigms needed e.g., **distributed architecture**

- Functional split in space
- Software defined regenerative payload for flexibility and adaptivity
- Routing in space for resilience, security, cost reduction (ground segment simplification), load balancing
- Mesh architecture

**Components** need to be addressed

- Antennas, e.g., VSAT type at Q/V band
- Optical ISL
- Computational platform for SW defined payload, AI support, etc. (open HW/Open SW)

# THANK YOU

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