THE 6G-NTN PROJECT

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6G Horizons: Synergies for a Connected Future
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Outline

- Project overview
- 6G-NTN Rationale
- Selected project outcomes
  - Satellite Architecture: a new sustainable paradigm
- Key Takeaways

Project Facts and figures

6GNTN

- **Addressing call**: "SNS-2022-STREAM-B-01-03: Communication Infrastructure Technologies and Devices"
- **Project duration**: 1 January 2023 - 31 December 2025
- **Targeted TRL**: 2 – 4
- **Total budget**: 4Meuro
- **Overall objective**: **Research and develop** innovative **technical**, **regulatory**, and **standardization enablers** needed to ensure the full-fledge integration of the **NTN component into the 6G system**.
- **Contact Points: Alessandro Vanelli-Coralli,** Project Coordinator (UniBo), **Nicolas Chuberre,** Technical Manager (TAS-F), **Sandro Scalise,** Innovation Manager (DLR), **Monique Calisti**, Communication & Dissemination Manager (MAR)

Ambition

to **develop the 6G NTN component** concept and **drive its standardization** phase in 3GPP 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 RATIONALE

NTN IS THE NEW COMMUNICATION FRONTIER IN 6G

Rationale of NTN in 6G

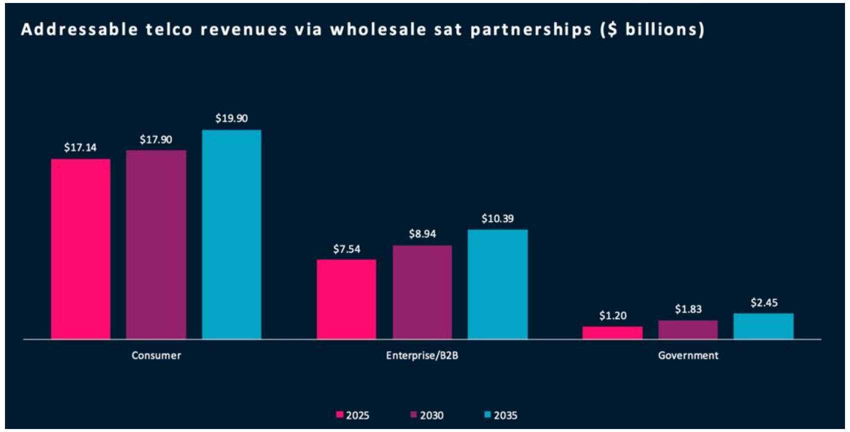
MWC ’25: GSMA Intelligence Report

- NTN Global market will count up to 3% of telco total revenues (~30B$) in the next 10 years
  - Ubiquitous coverage and service continuity
  - Consumer, Enterprise and Government markets

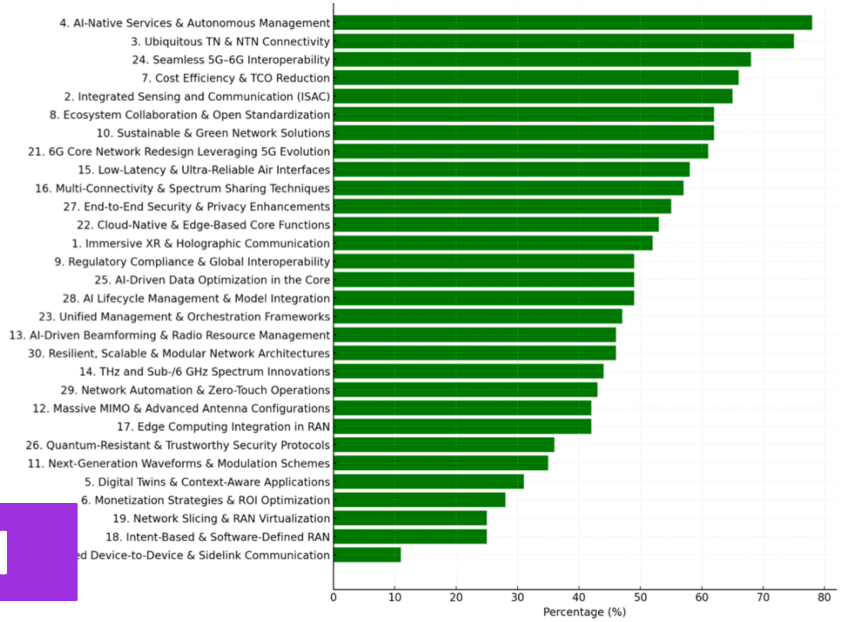
3GPP 6G Workshop (Incheon, SK) – March 10-11, 2025

- 1800 attendees (750 in person)
- 230 contributions
  - NTN in 75% of them
  - AI in 78% of them
- NTN is second only to AI, and right after it

NTN is an integral part of 6G and not any more a vertical

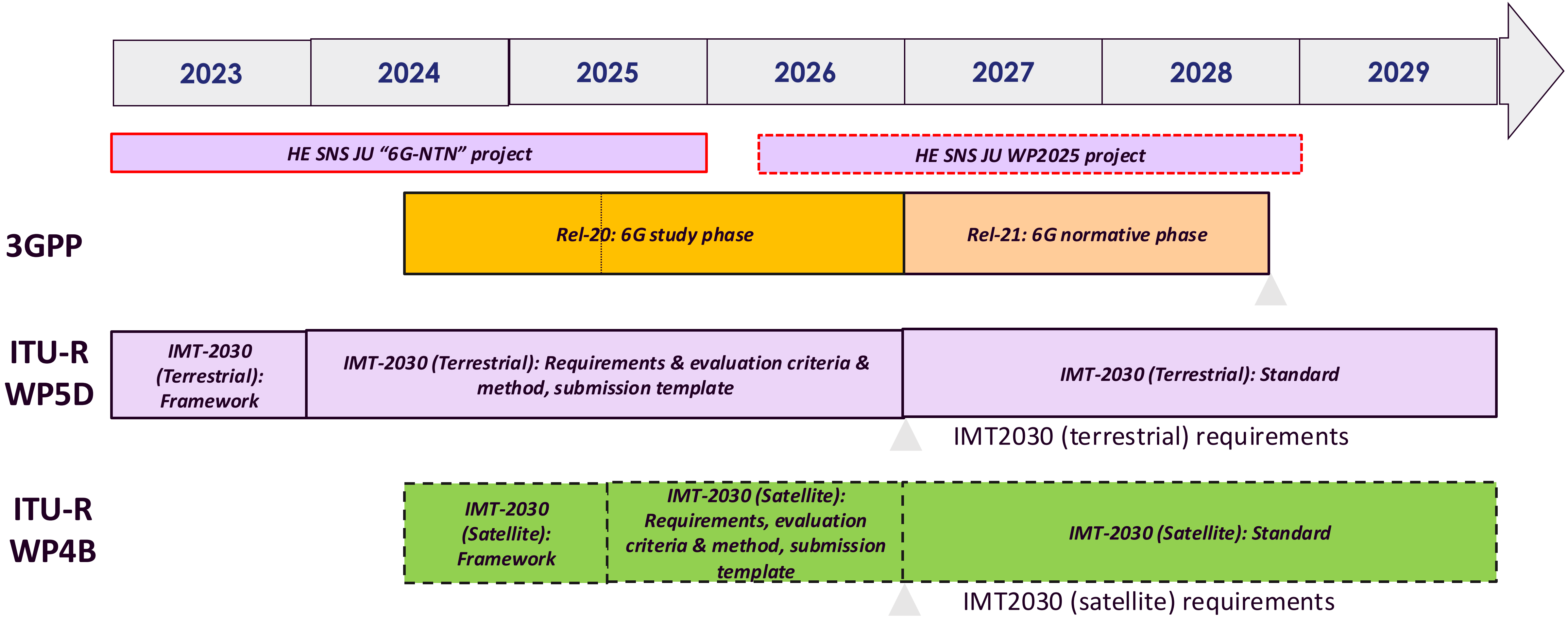


Source: GSMA Intelligence MWC2025, Satellite and NTN Summit



Source: APEX Standard , https://apexstandards.com/6gws.pdf?ref=NLT2

3GPP 6G timeline and 6G-NTN



6G-NTN

Project Outcomes

Project Outcomes

Use cases

- Definition of use cases, service, and system requirements

Architecture

- New architecture paradigm
- Constellation design and sizing
- Small factor antennas for Q/V and C band vehicle/drone mounted terminals

Radio Interface

- Waveform analysis beyond CP-OFDM for RAN integration from day 1
- GNSS free operations and NTN based PNT with high accuracy
- Low SNR range for light indoor coverage

Spectrum

- C and Q/V bands coexistence

THE NTN ARCHITECTURE

A NEW SUSTAINABLE INFRASTRUCTURE PARADIGM FOR 6G NTN

Multi-multilayer & multiband 6G architecture

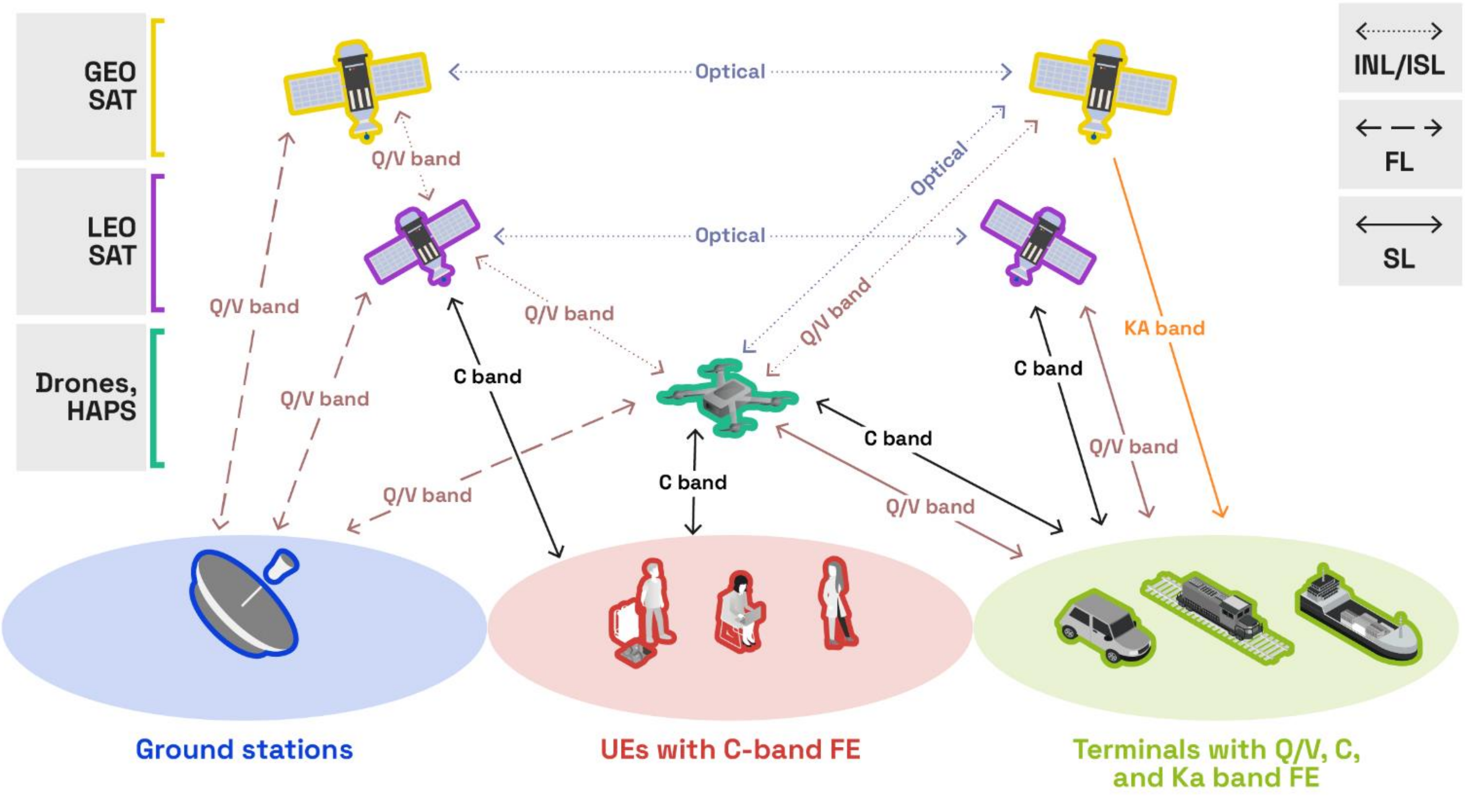
Deterministic nodes with fixed and predictable orbits

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

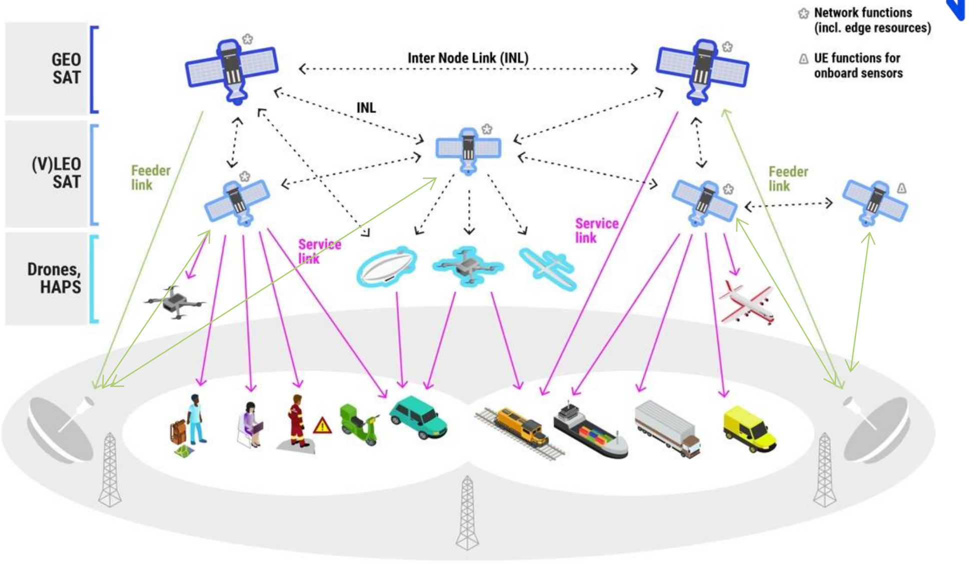
HAPs or drones (heavy drones)

- 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

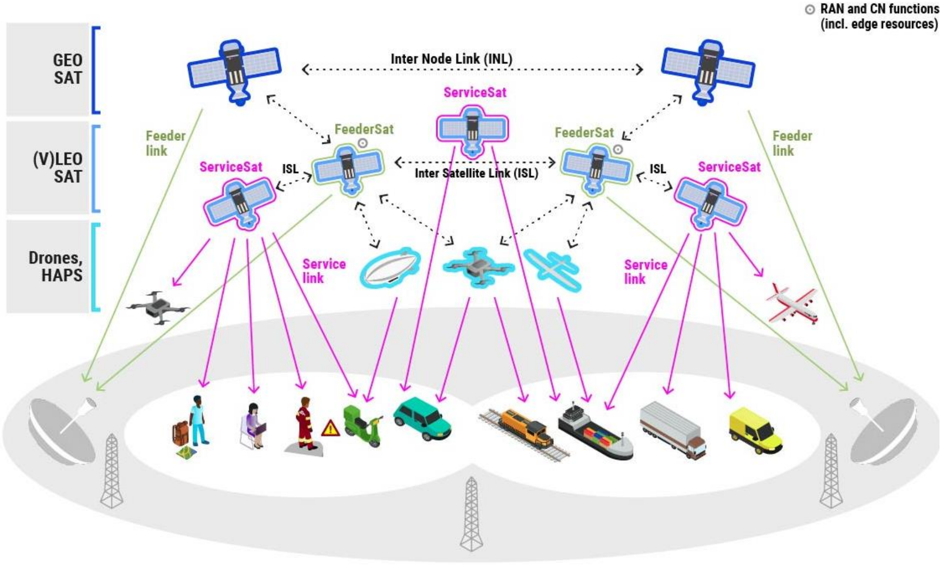
Conventional architecture – homogeneous satellites

- 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 functionalities (Edge computing in space)



Distributed architecture – heterogeneous nodes (same altitude)

- Feeder Nodes with higher computational capabilities
  - 2 Feeder links to GW / no user link to UE
  - 4 OISLs to 4 service nodes
  - 2 OISLs to 2 feeder nodes
  - 1 Ka-band payload for the ISL 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

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

The distributed architecture allows a better infrastructure sustainability thanks to a flexible C-SWaP trade-off and a limited number of satellites

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

KEY TAKEAWAYS

Key Takeaways

NTN is recognized as a **fundamental component of 6G** to provide **ubiquituous and continuous** services

Making NTN happening requires **international cooperation** and **open standard** to enable **sustainable, global and shared infrastructures**

The 6G-NTN Project is developing innovative **technical**, **regulatory**, and **standardization** enablers ensuring **full-fledge integration** of a su stainable **NTN component into the 6G from day 1**

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, adaptivity, multitennancy
- Routing in space for resilience, security, cost reduction (ground segment simplification), load balancing
- Mesh architecture for resiliency

Evolutionary and revolutionary 6G air interface technologies needed **for integration from day 1**

- Flexible and natively integrated waveforms
- GNSS free operation
- Efficient Spectrum Access and new spectrum
- Light indoor operations, e.g., improved link budget, extended/additional coding schemes
- NTN based positioning

Components Development is key

- 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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BACKUP SLIDES

THE 6G-NTN USE CASES

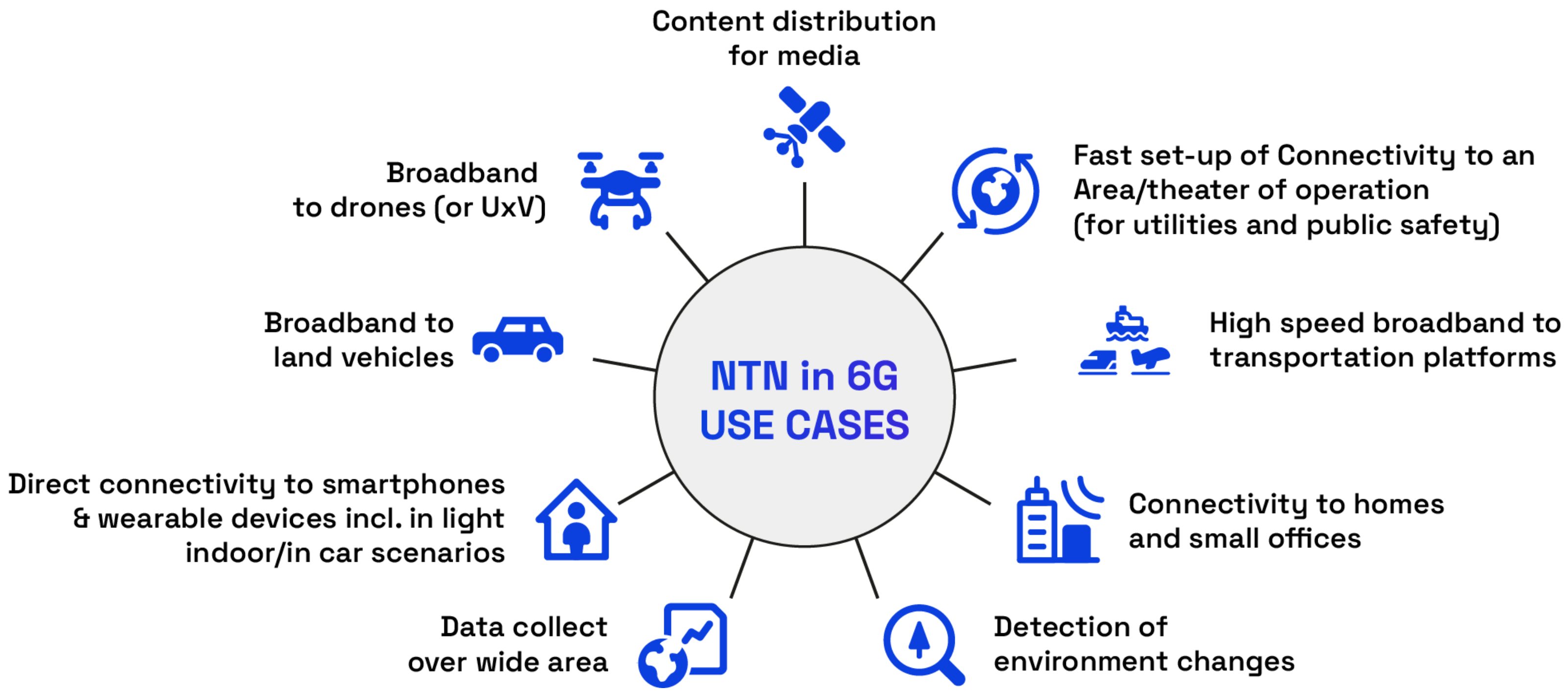
EVERYTHING STARTS FROM USERS

Use cases: from 3GPP use cases to 6G-NTN

Primary focus on coverage extension & Backhauling → Key interest for enh. Direct to device

mono-connectivity → Enh. multi-connectivity / true service versatility

Mobility mostly in idle mode or roaming → Seamless mobility in connected mode as a critical enabler



Use Cases	User	Service Expectations	Network configuration & mobility scenarios	UE Types
UC1: **Maritime Coverage** for search and rescue coast guard intervention	•Vessel Operator •UAV-Controller •Pilot	•Critical Comm. •Realtime control •Telemetry Data	•Tactical Bubble •Direct UE to UE via sat	•Handheld Prof •Mounted Maritime •Large drones
UC2: **Autonomous power line inspection** using drones	•Autonomous Drone •UAV-Controller	•Realtime control •Telemetry Data	•Private TN – NTN •NTN via HAPS	•Drone •Large Drones
UC3: **Urban air mobility**	•UAV-Controller.	•Realtime control •Edge network services •Broadcast •3D-Location	•TN - NTN info. exchange •Direct UE to UE via sat •NTN via HAPS	•Drone
UC4: **Adaptation to PPDR** or Temporary Events,	•First responder. •Ambulance	•Critical Comm. •Broadcast •Location, 3D-Location	•Tactical Bubble •Direct UE to UE via sat •NTN via HAPS / a. node	•Handheld Prof. •Mounted Vehicular •Drone •Large Drones
UC5: **Consumer Handheld** and **PNT** in Remote Areas	•Private user	•Emergency Call •Broadcast •Location	•Cross-border mobility	•Handheld Cons.
UC6: **Continuous Bi-directional** in High Mobility	•Passenger •Driver	•Conference (video) Call •Emergency Call •Broadcast	•Cross-border mobility	•Handheld Consumer •Mounted Vehicular
UC7: **Direct (Mesh) Communications** over satellite	•Private user •First responder	•Emergency Call •Broadcast •Location	•Direct UE to UE via sat	•Handheld Cons. •Handheld Prof.

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 TERMINALS

COST EFFECTIVENESS AND EFFICIENCY: LOW C-SWAP

Terminal Characteristics in C and Q/V (low Swap)

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

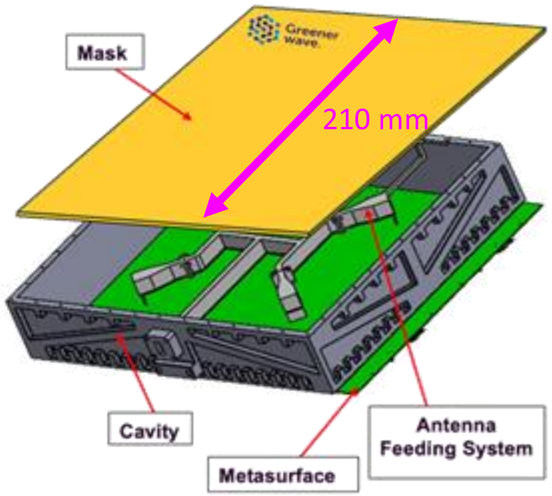
Q/V band terminal antenna design

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

- Two novel active beamformer based antenna for terminals in Q and V bands.
- 20x20 prototypes antennas
- 10x10 design based on 20x20 measurements and characterizations



6G-NTN AIR INTERFACE

NTN CHARACTERISTICS FROM DAY 1

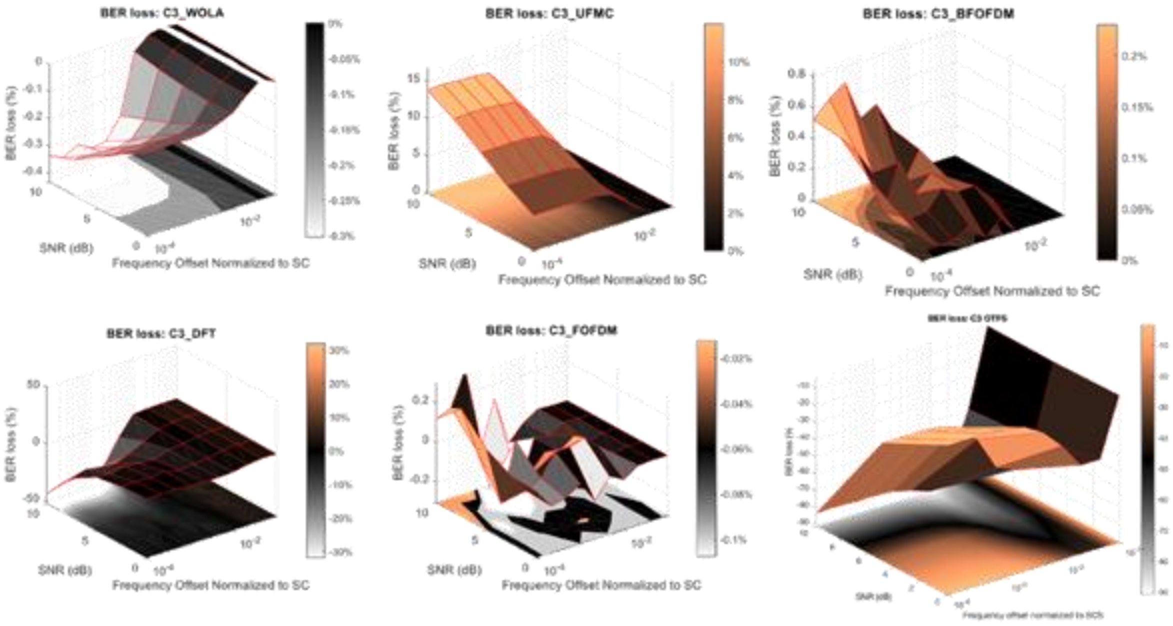
Beyond CP-OFDM: Waveform comparison [1/2]

- Seven candidate waveforms:
  - CP-OFDM
  - WOLA-OFDM
  - DFT-s-OFDM
  - UFMC
  - BF-OFDM
  - F-OFDM
  - OTFS

- Comparison of the waveforms under different impairments:
  - Phase noise
  - HPA Non linearities (in both C and Q/V bands)
  - Fading channels
  - Residual frequency synchronization errors
  - Residual timing synchronization errors

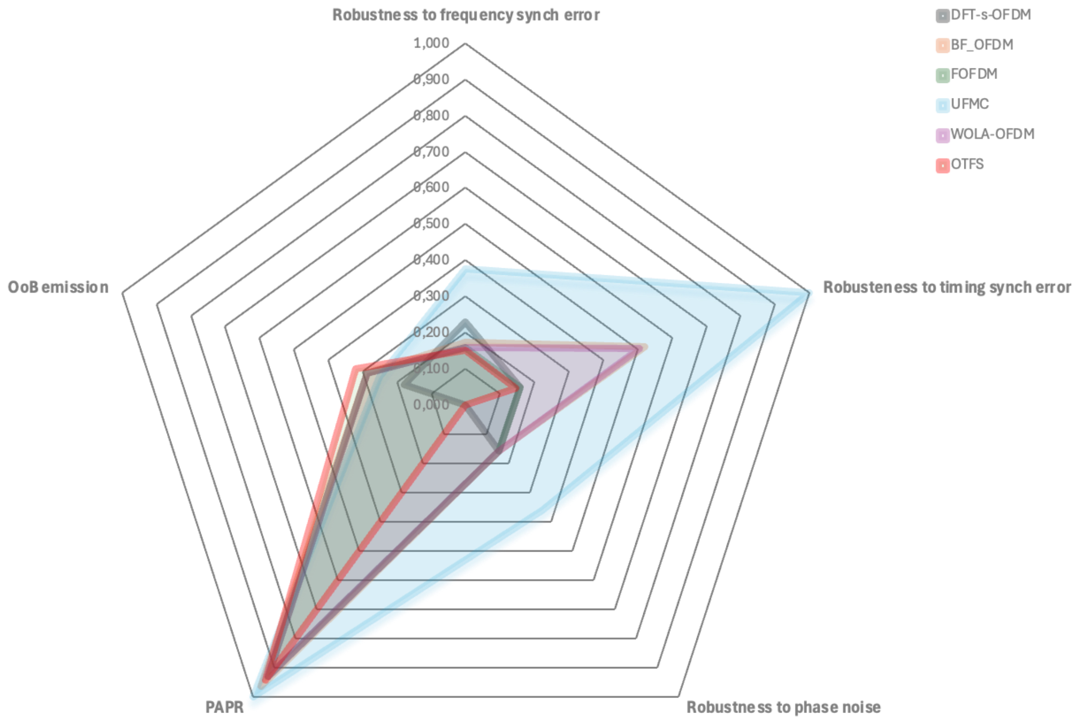
BER loss:

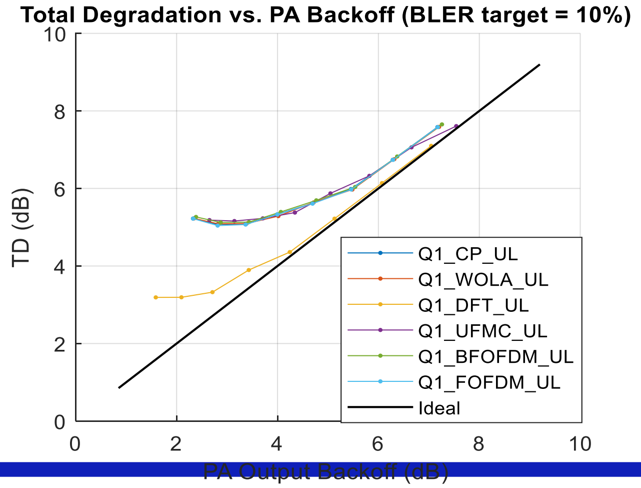
$$\left(\frac{BER_{waveform} - BER_{CP-OFDM}}{BER_{CP-OFDM}}\right) \times 100$$



Beyond CP-OFDM: Waveform comparison [2/2]

- The radar chart takes into account the worst-case scenario
  - E.g., the robustness to frequency synch errors at the highest considered frequency offset
- The lowest the area of the chart, the highest the performance
- Other two KPIs will be considered:
  - Robustness to frequency selectivity channel
  - The total degradation incurred due to the nonlinear distortions





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 Architecture

Distributed Architecture Overview

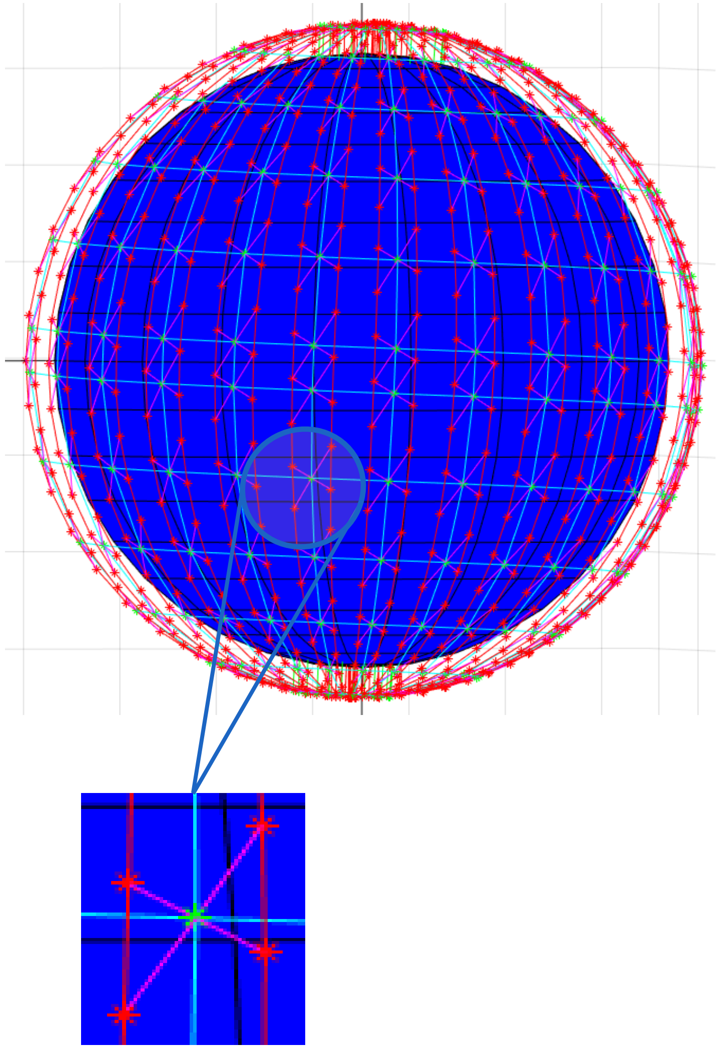
Distributed Architechture

Service layer (red stars)

- Smaller/lighter platforms providing link between the users and the feeder layer
- Each service satellite connects to one and only one feeder satellite

Feeder layer (green stars)

- Larger/heavier platforms providing link between the service layer and the ground stations
- Each feeder satellite
  - connects to 4 service satellites via OINLs (magenta line)
  - is connected to other four feeder satellites via OINLs (cyan lines)

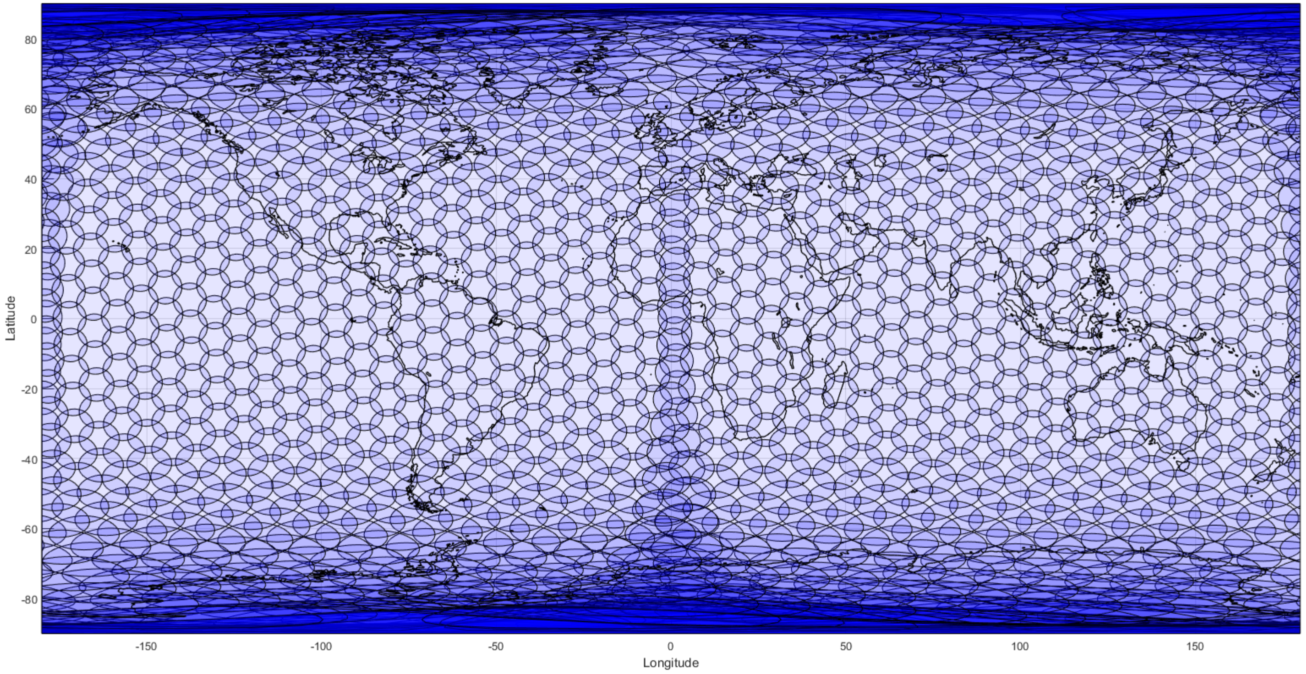


Source: SNS JU Project 6G-NTN, D3.5 "Architectural Solutions," March. 2024.

Distributed Architechture – Service Layer
(smaller platform, user link only, no feeder link)

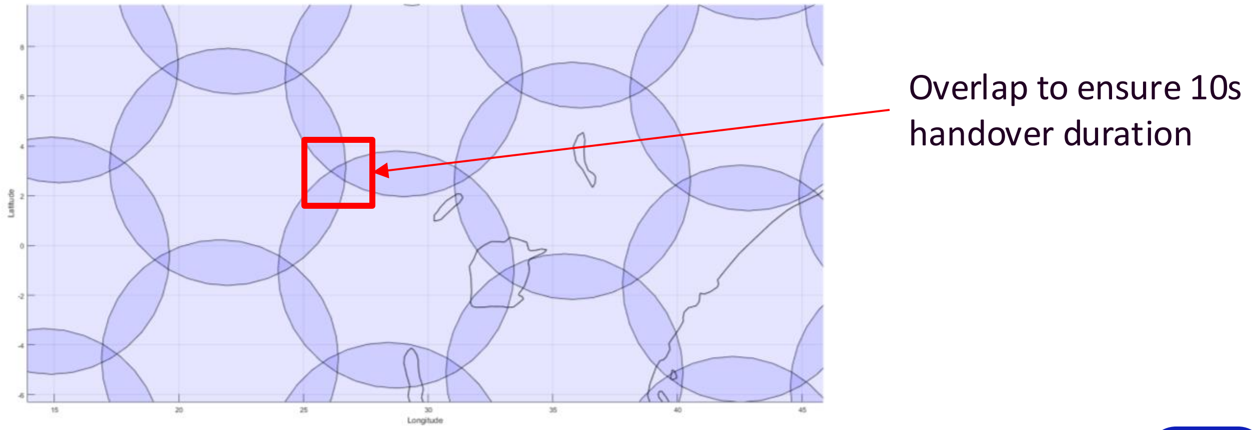
Service layer constellation

- 600km altitude
- 45° min user elevation
- Near-polar inclination (~87°) for global coverage
- 1 satellite always visible
- Minimum 10s handover between satellites
- 27 planes, 47 sats per plane
- 1269 sats total



Results in:

- Max Relative Velocity (user) of 4.9km/s
- Max Slant Range (user) of 815km



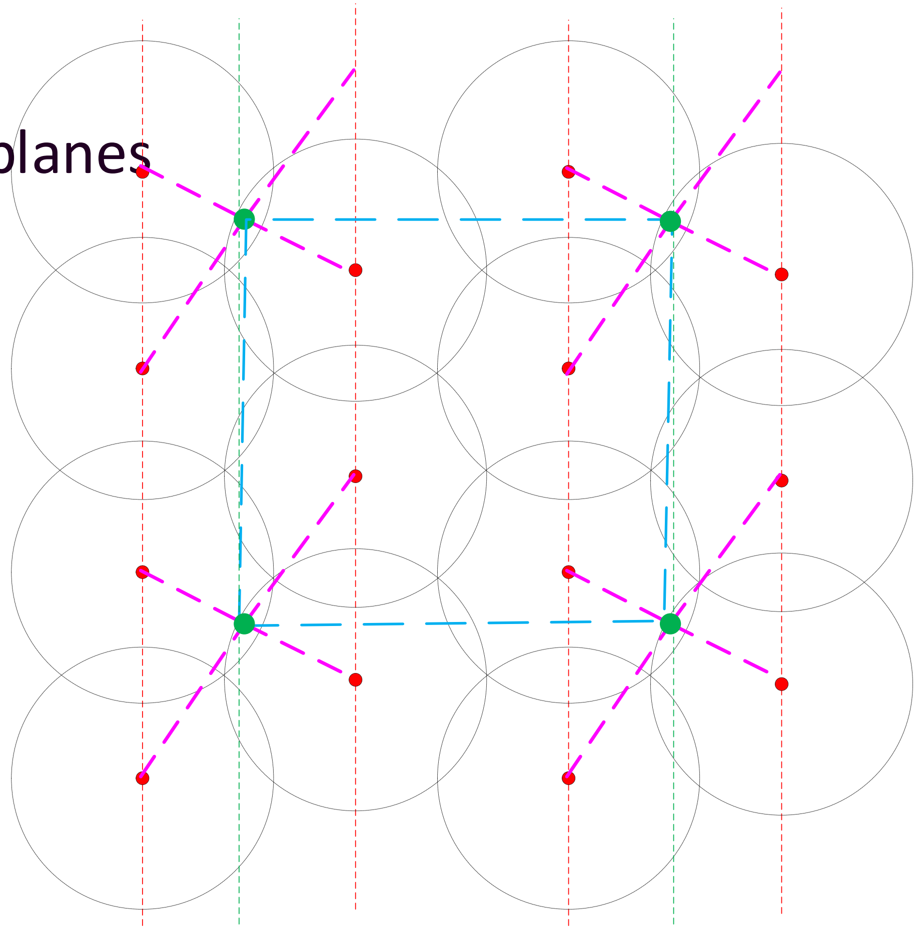
Source: SNS JU Project 6G-NTN, D3.5 "Architectural Solutions," March. 2024.

Distributed Architechture – Feeder Layer (larger platform, feeder link only, no user link)

Selected Optimal Constellation Configuration:

- 600km altitude
- Near-polar inclination (~87°)
- feeder plane between two service satellite planes
- 14 planes, 24 sats per plane
- 336 feeder satellites

Red: service sats
Green: feeder sats
Magenta: service-feeder OISL
Cyan: feeder-feeder OISL.

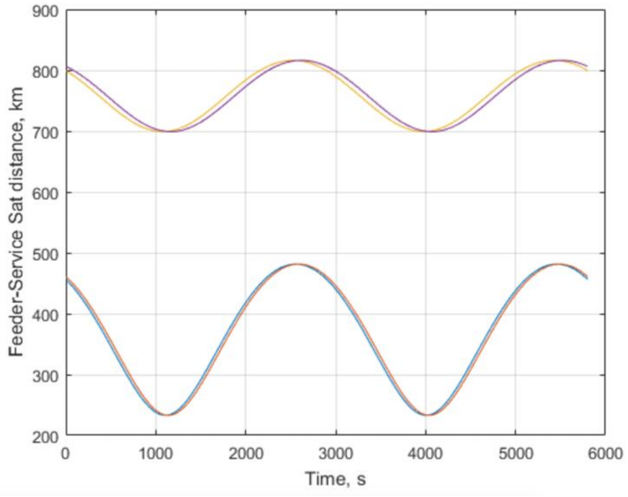


Source: SNS JU Project 6G-NTN, D3.5 "Architectural Solutions," March. 2024.

Feeder – Service satellites distance

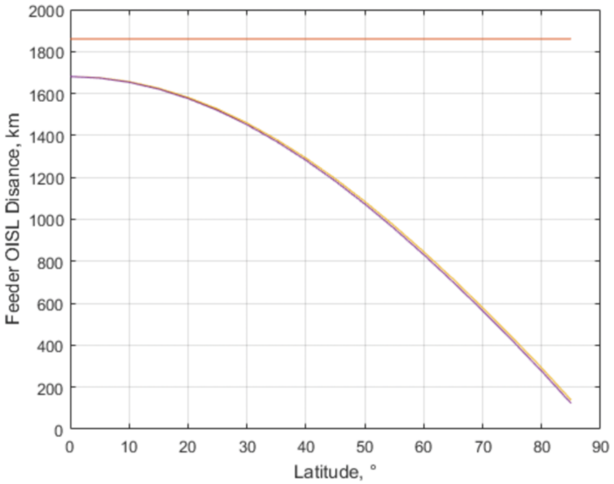
Feeder to service satellite distance

- between 700km and 800km for the two further service satellites
- between 250km and 500km for the closer two service satellites



Feeder to feeder satellite distance

- About 2000 km for same plane satellites
- From about 1700 km to 100 km for different planes satellites



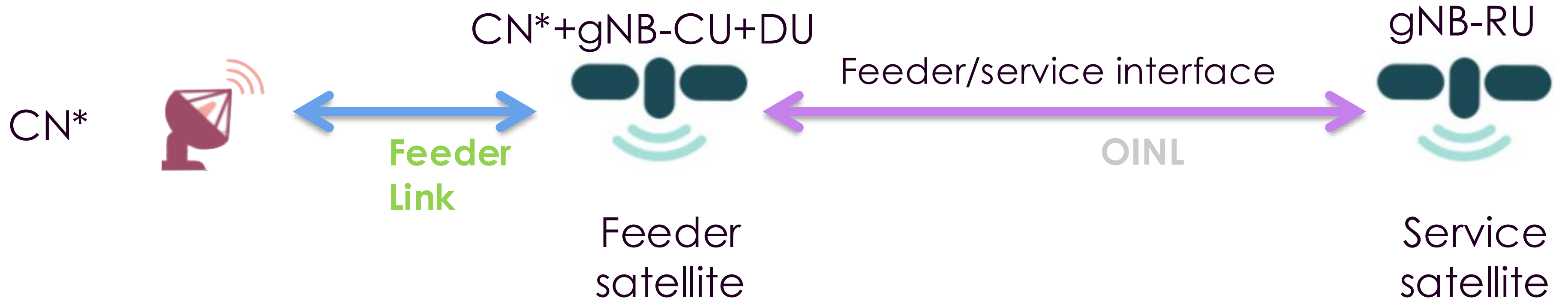
Source: SNS JU Project 6G-NTN, D3.5 "Architectural Solutions," March. 2024.

Distributed architecture: considerations (1/2)

Optimization of power budget and payloads volume between service and feeder platforms

- Feeder satellites w/o user link and fewer→ power/volume available for computation and feeder connection,larger optical terminal
- Service satellites w/o feeder link and numerous → power/volume for user link only, smaller platform, smaller Otical terminal (smaller distance and capacity)

RAN functional split in space (feeder/service satellite)

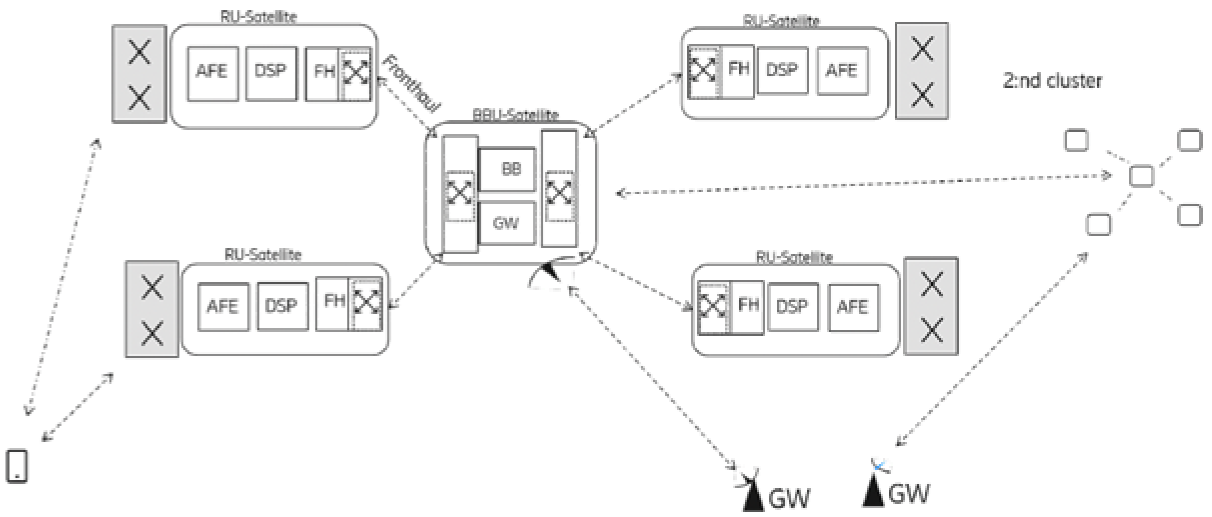


Source: SNS JU Project 6G-NTN, D3.5 "Architectural Solutions," March. 2024.

Distributed architecture: considerations (2/2)

Example of functional split in the distributed architecture: Lower Layer Split

- Service satellites (1269)
  - analog and digital front-ends, receiver beamforming, CP removal, FFT transforms
- Feeder satellites (366 sat)
  - From mmse to CN functionalities



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

Radio interface design drivers	Rationale
Multi carrier waveform enhancements	**Relaxed synchronization requirements** (GNSS free operations) Downlink **PAPR reduction** for spectral efficiency maximization in simplified platform
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. …
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 **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
Spectrum sharing between TN and NTN	Efficiency, coverage, integration
Joint communication and sensing	Provide low to medium resolution **sensing capabilities** directly from **waveform design**.

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