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Evolving Non-Terrestrial Networks from 5G to 6G

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IEEE Future Networks Webinar

*"New Perspectives for the Integration of Terrestrial and Non-Terrestrial Networks
for 6G Systems"*

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Acknowledgements



Design and validate NTN's key technical, regulatory, and standardisation enablers for the integration of TN and NTN components into 6G, focusing on multidimensional network infrastructure, multi-constraint RANs, and multi-user terminals



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Deliver a fully integrated 5G-NTN autonomous system with novel self-adapting end-to-end connectivity models for enabling ubiquitous radio access



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Design a 3D multi-layered communication architecture for integrated T/NT networks, by designing advanced transmission technologies and conceiving innovative methodologies for the orchestration of communication and computational resources



<https://www.fondazione-restart.it/projects/s11-ita-ntn/>



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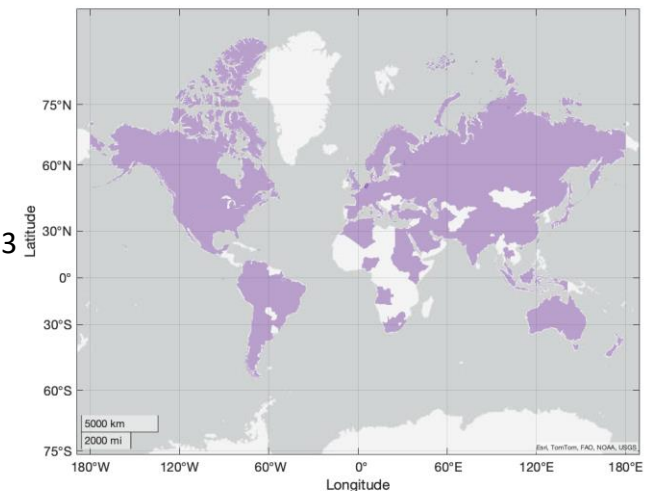
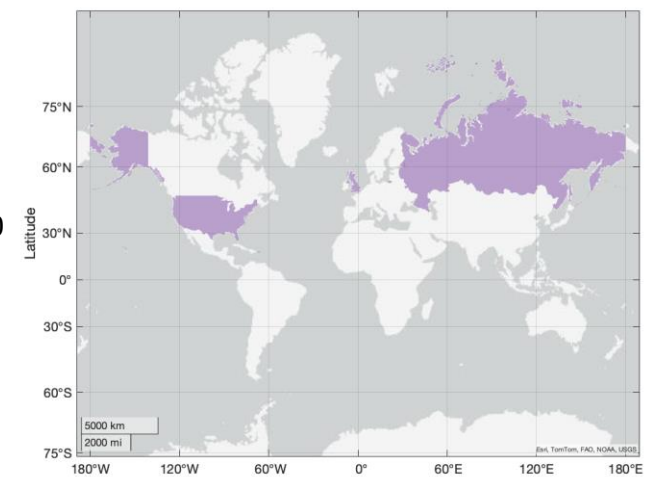
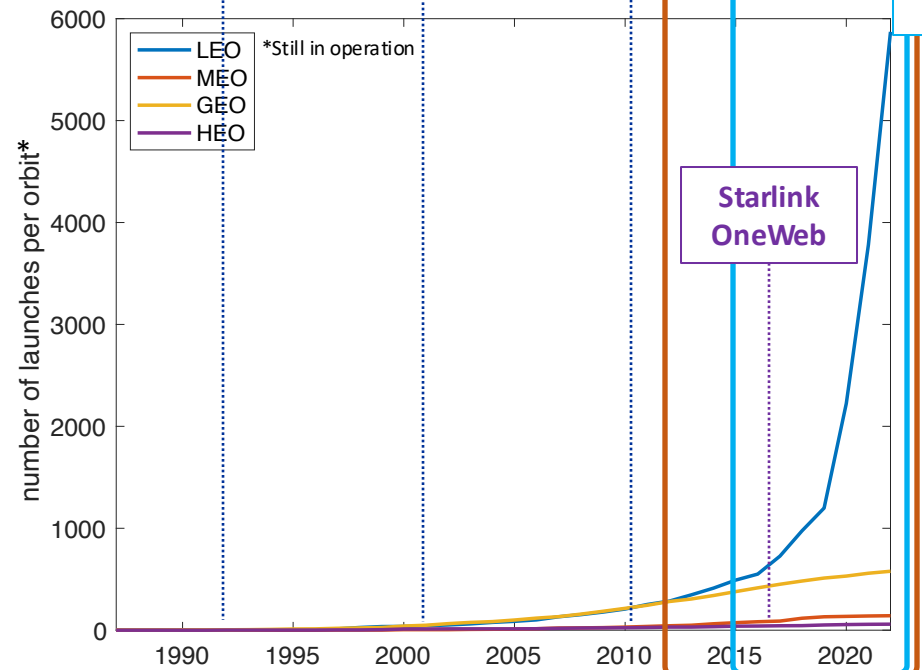
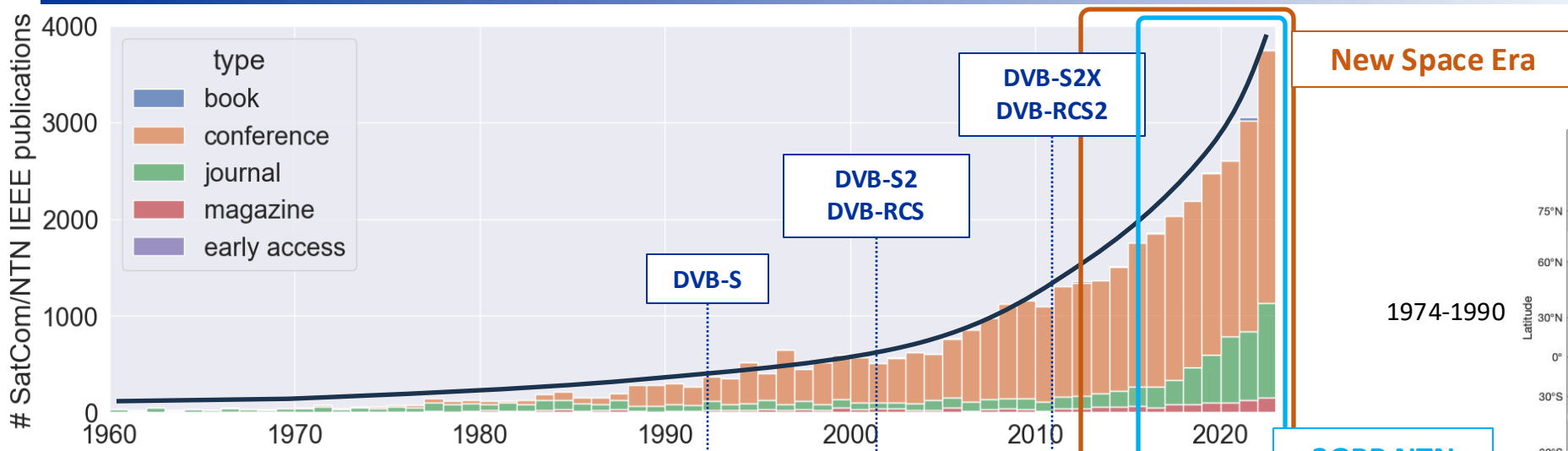


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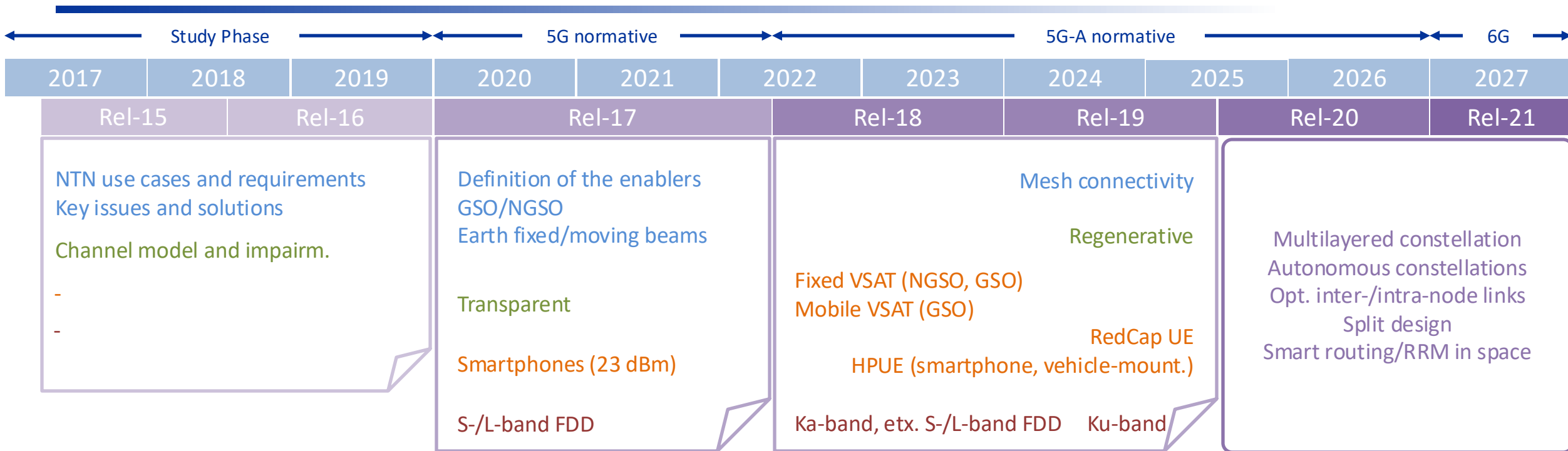


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From SatCom to NTN (nothing happens overnight)



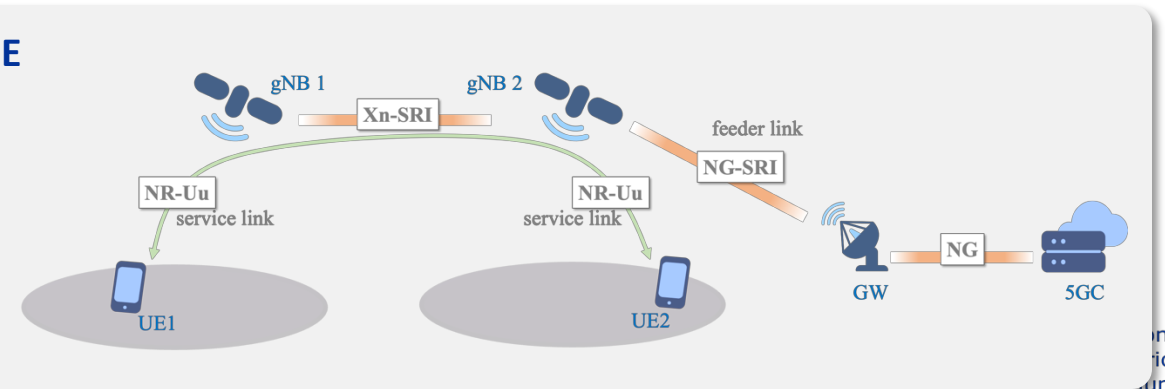
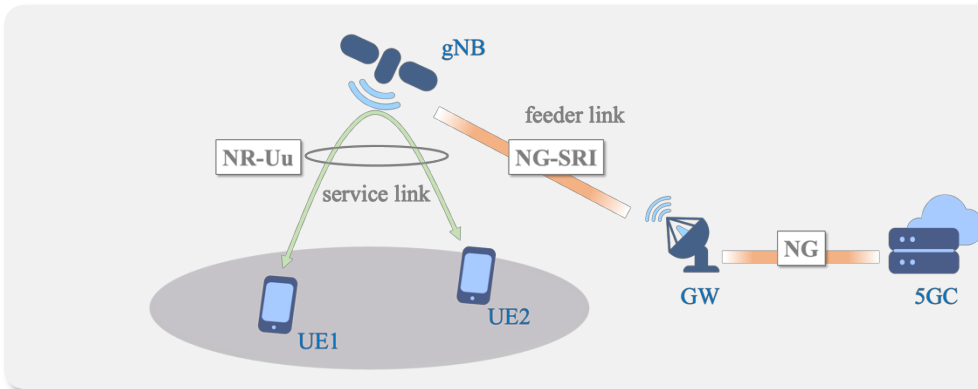
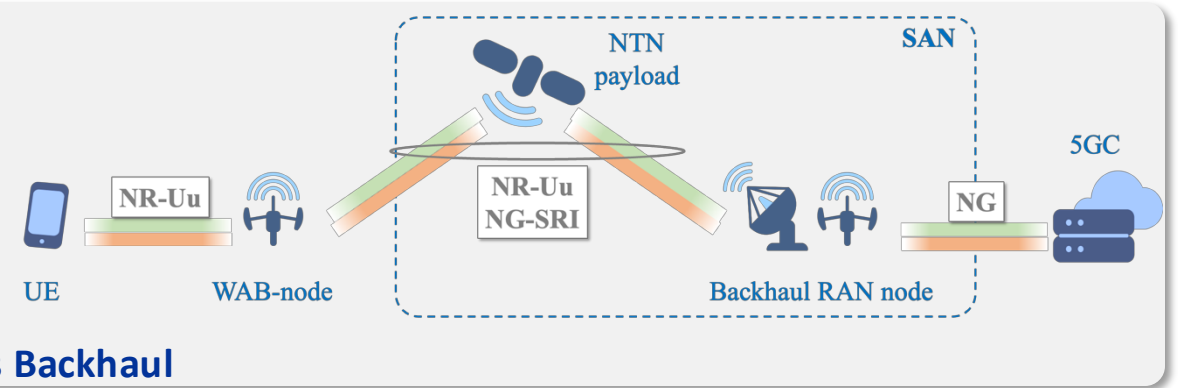
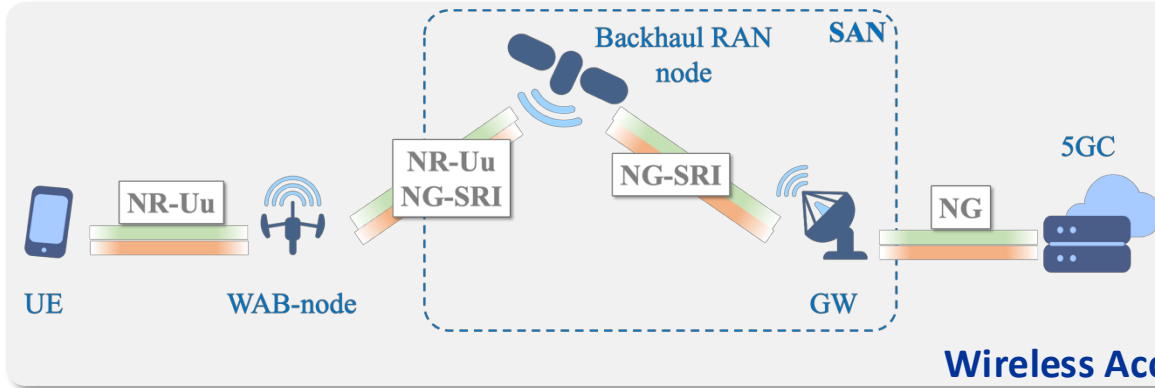
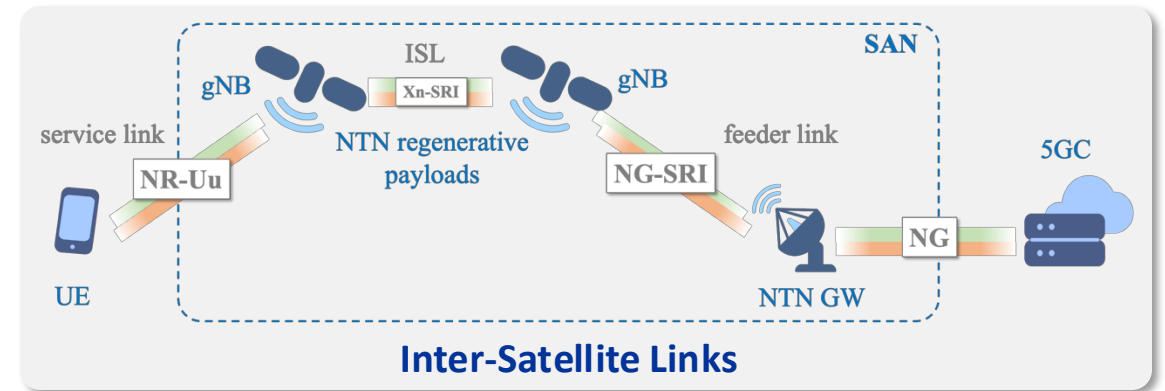
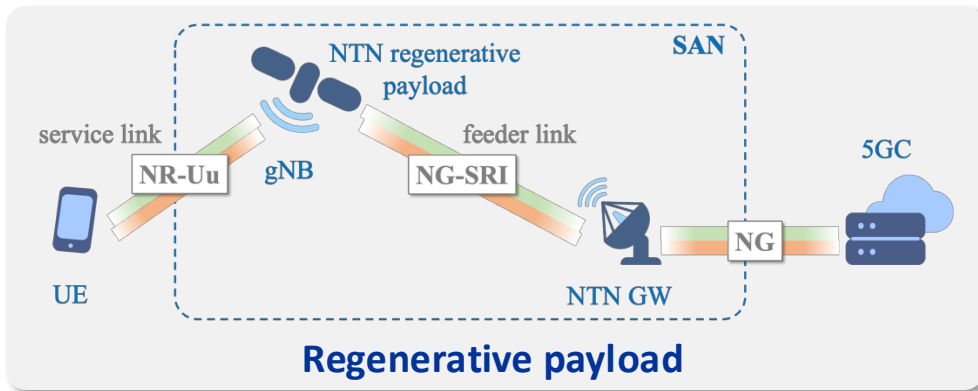
NTN roadmap



- System architecture
- RAN aspects
- Targeted terminals
- Spectrum

- Solutions for indirect connectivity: IAB → WAB
- Multi-Connectivity de-prioritised and not yet developed
- Functional split solutions most likely to flow into Rel. 20-21

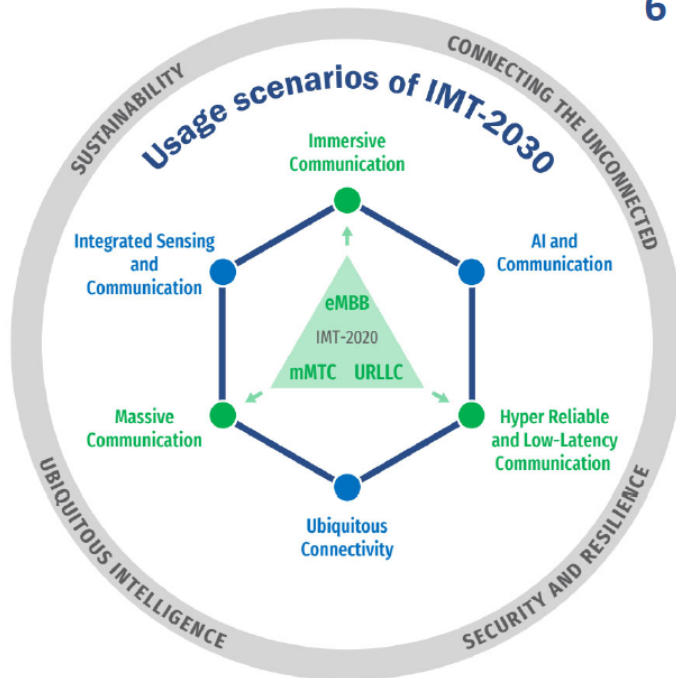
NTN Rel. 19: architecture evolution



6G: from integration to a native NTN component

ITU-R IMT-2030

6 Usage scenarios



So called "Wheel diagram"

Extension from IMT-2020 (5G)

eMBB → Immersive Communication

mMTC → Massive Communication

URLLC → HURLLC (Hyper Reliable & Low-Latency Communication)

New

Ubiquitous Connectivity

AI and Communication

Integrated Sensing and Communication

4 Overarching aspects:

act as design principles commonly applicable to all usage scenarios

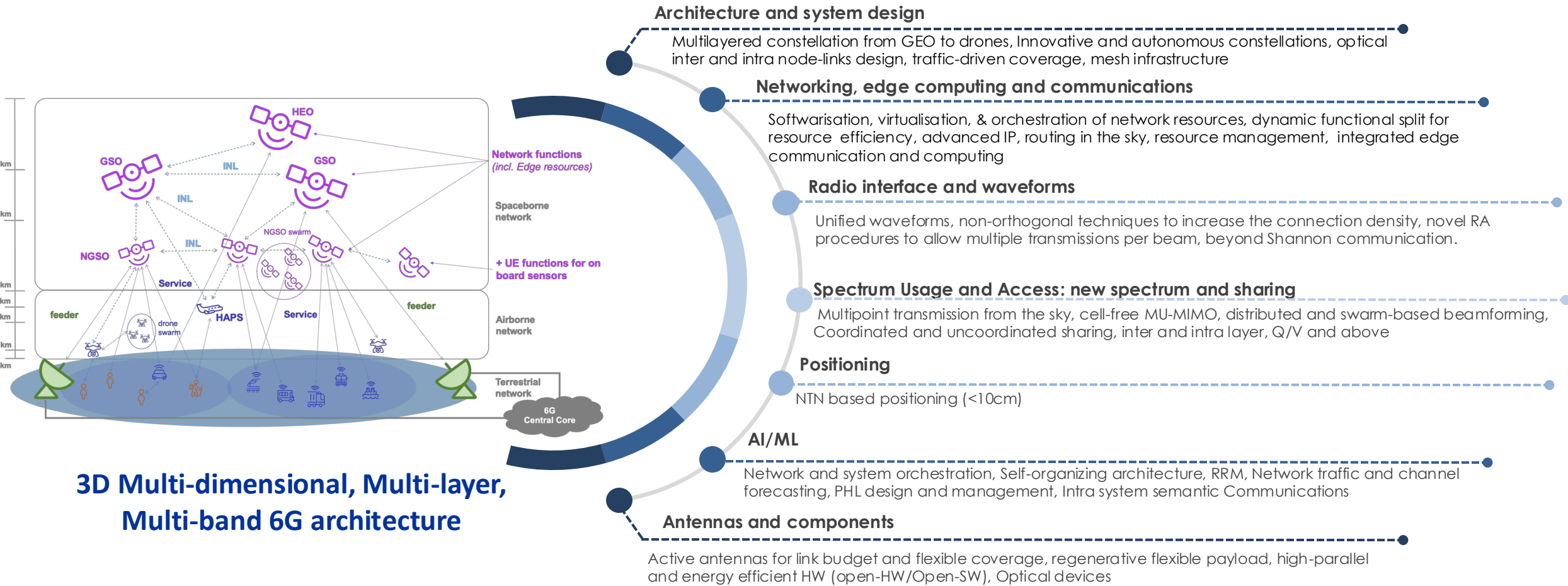
Sustainability, Connecting the unconnected,
Ubiquitous intelligence, Security/resilience

Source: <https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2030/Pages/default.aspx>

- August 2024: **New Study on 6G Use Cases and Service Requirements (FS_6G-REQ)**
 - identify the high-level principles and use cases, with potential requirements, for IMT-2030
- December 2024: **New Study on 6G Scenarios and Requirements**
 - investigate a candidate set of minimum technical performance requirements based on ITU-R M.2160

NTN will be pivotal to provide a **ubiquitous, continuous, flexible, and resilient infrastructure**

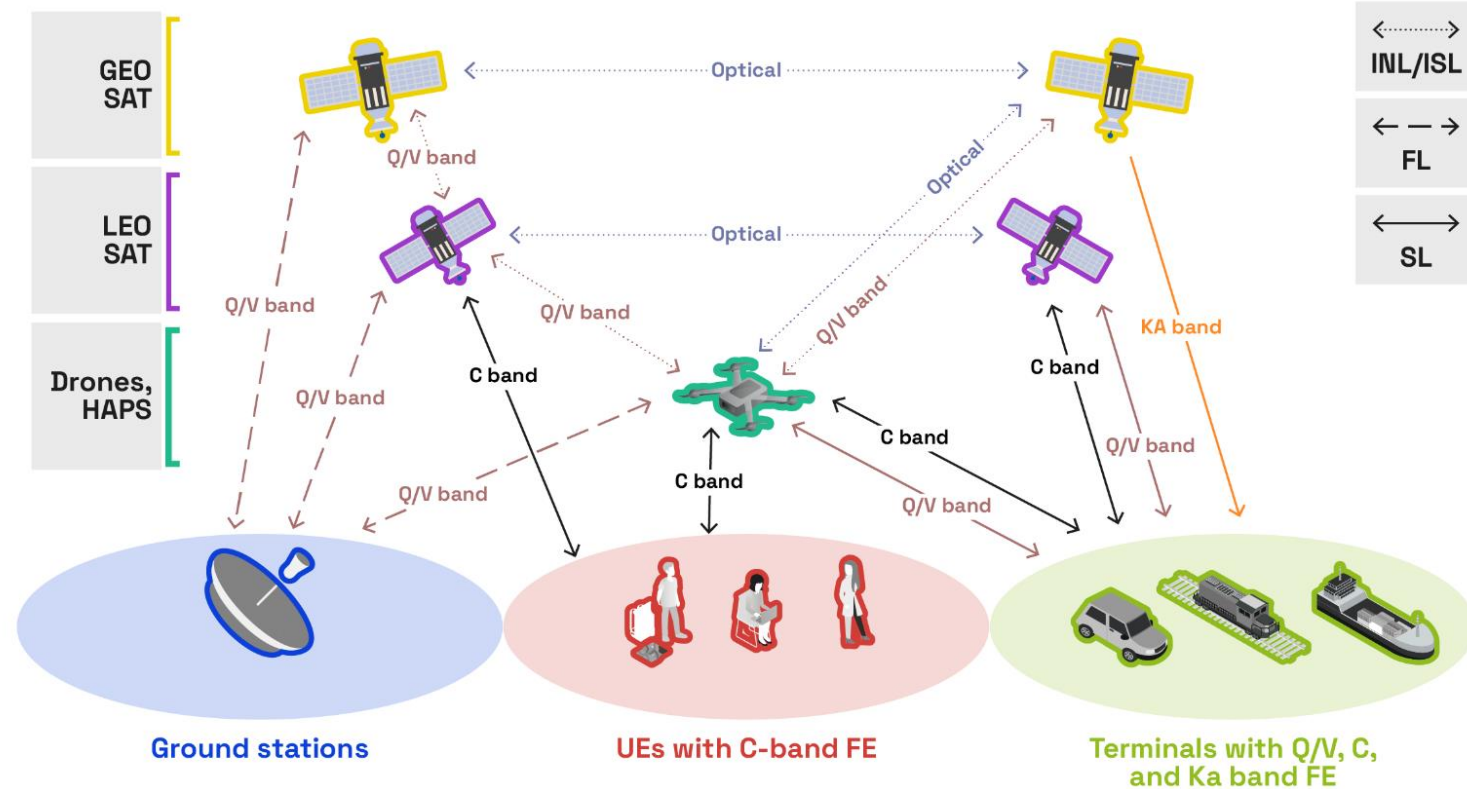
6G: from integration to a native NTN component



6G-NTN: multi-multilayer and multi-band 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 UE



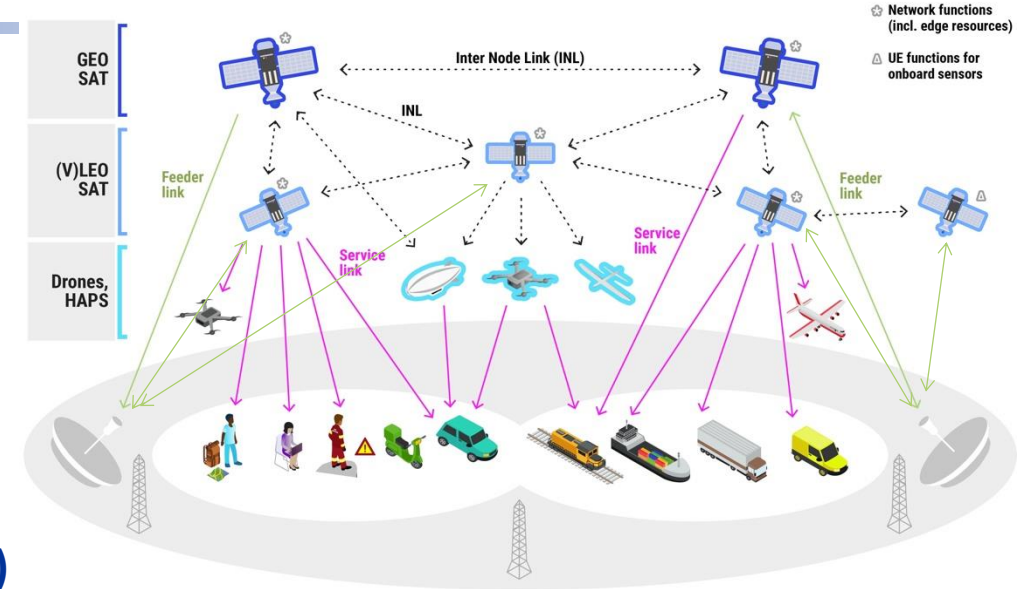
Flexible nodes “opportunistically” deployed

- HAPs or (heavy) drones
 - capacity to specific areas with no TN, *e.g.*, disaster/emergency
 - additional capacity for sudden traffic increase, *e.g.*, concerts, sport events w/wo TN coverage

6G-NTN: architectural solutions

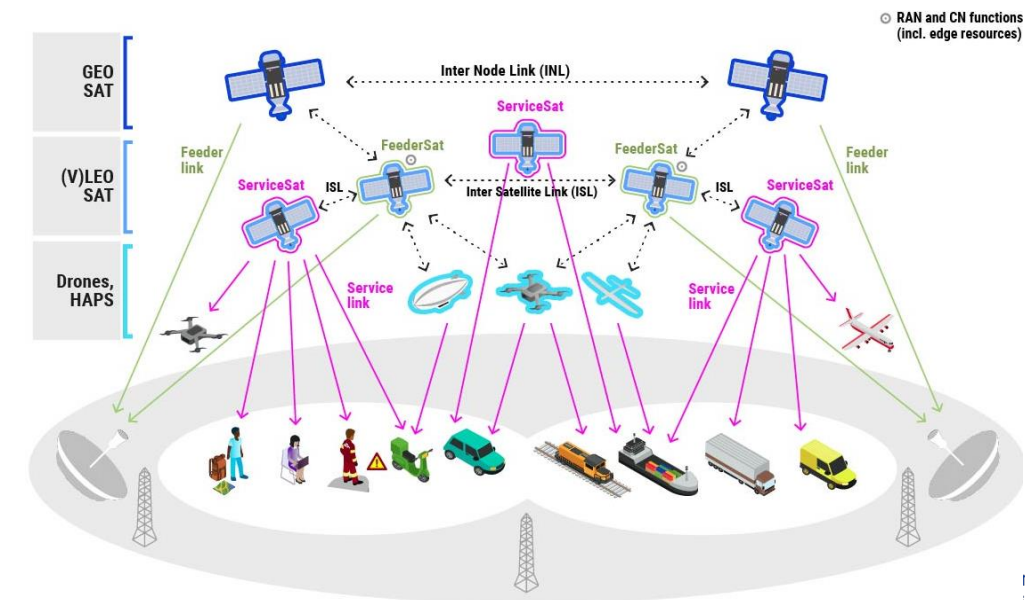
• Conventional architecture – homogeneous satellites

- 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 ISL 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 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 OISL 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	planes	sat/type	total sat
Conventional		47	27	-	1269
Distributed	Feeder	14	24	366	1635
	Service	47	27	1269	

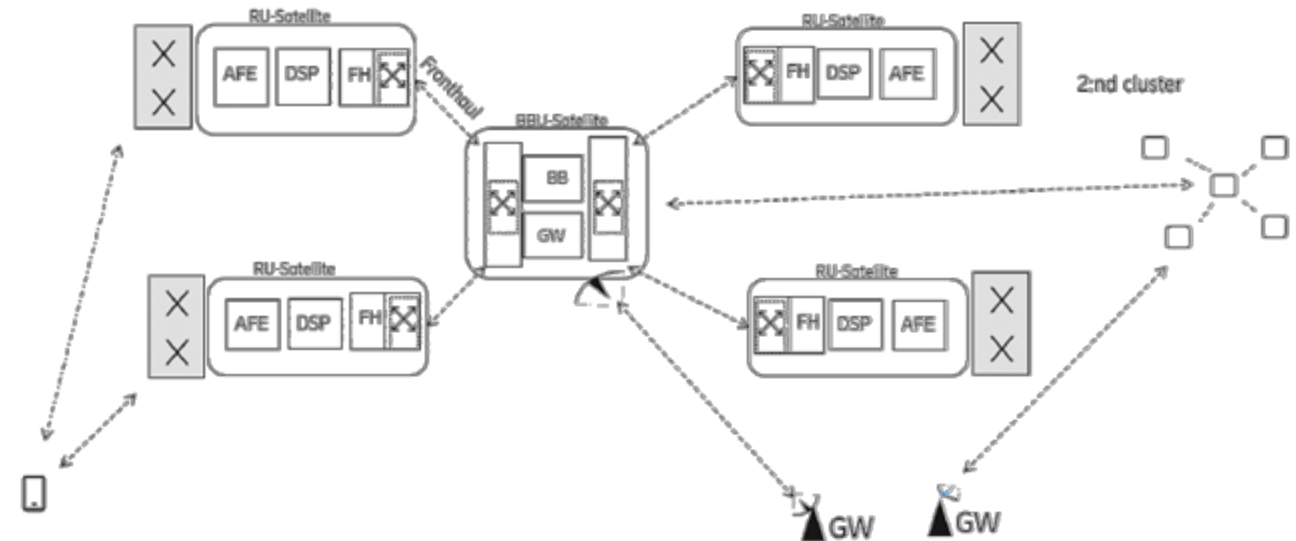
- Assumptions
 - altitude: 600 km
 - near-polar inclination (~87°)
 - 45° minimum user elevation angle
 - at least 1 satellite always in visibility
 - at least 10 s of overlap between 2 satellites
 - 2 constellations: C-band + Q/V-band
 - only for the service satellites
 - the feeder satellites are the same, with 8 ISLs

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

Distributed architecture: considerations

- Platform sizing
 - RAN functional split in space (feeder/service satellite)
 - optimization of power budget and payloads volume
 - Feeder satellites w/o power amplifiers for user link → power/volume available for computation
 - Service satellites lower computational load → smaller platform, higher power for user link power amplifiers, antennas, etc.

- Example of functional split in a distributed architecture: Lower Layer Split
 - Service satellites (1269)
 - analog and digital front-ends, receiver beamforming, CP removal, FFT transforms
 - Feeder satellites (366 sat)
 - up to CN functionalities



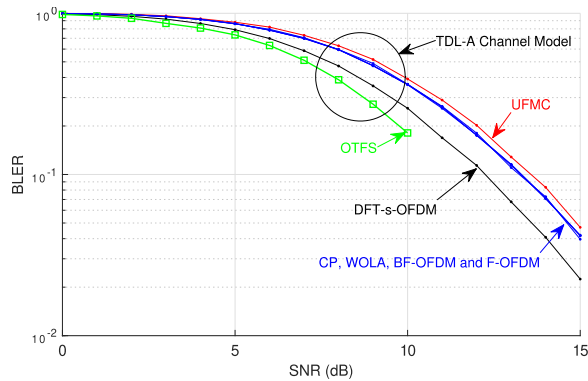
Source: SNS JU Project 6G-NTN, D3.5 "Architectural Solutions," March. 2024.

6G-NTN: radio interface design drivers

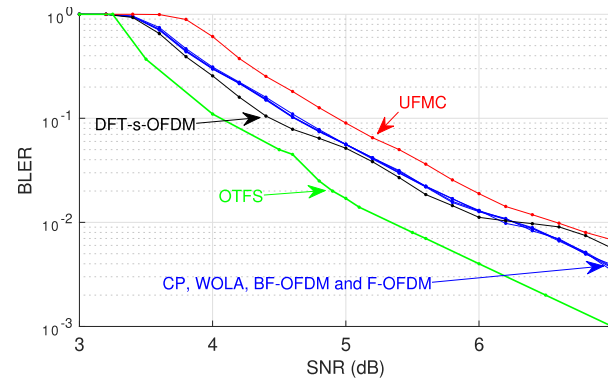
Radio interface design drivers	Rationale
Multi carrier waveform enhancements	Relaxed synchronization requirements (GNSS-free operations) Downlink PAPR reduction for spectral efficiency maximization in simplified platform (single channel HPA)
Advanced modulation, coding and multiple access schemes	Low SNR regimes enabling the support of challenging radio link conditions, <i>e.g.</i> , light indoor
Design flexible UL/DL framing structure	Flexibility for frame structure adaptation to satellite orbit, frequency range, etc. 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 robust synchronization, access procedures, and positioning	GNSS free operation, support reliable network-based solution for Positioning, Navigation and Timing services (<10cm)
Support of broadcast and multicast	Leverage large coverage area of satellites (multilayered architecture)
Support for AI driven radio resource control	Dynamic optimization of the radio interface configuration (<i>e.g.</i> , 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?

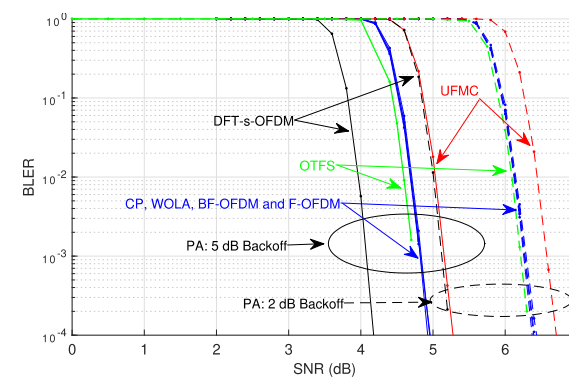
- Potential new/adapted waveforms addressing NTN features, *e.g.*,
 - CP-OFDM, DFT-s-OFDM, WOLA-OFDM, OTFS, BF-OFDM, UFMC, F-OFDM



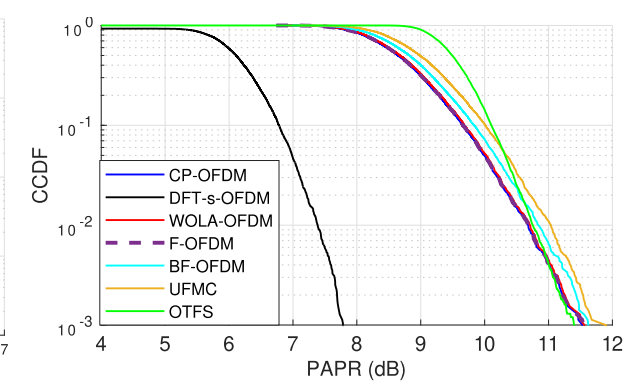
C band, NTN-TDL-A



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 Al, '6G NTN in C and Q/V-Bands: Link Budget Analysis and Waveforms Performance' – Globecom 2024

6G NTN standardisation: an educated guess

- Potential objectives
 - connectivity in areas not covered by TN
 - improving the coverage performance of direct connectivity, possibly in light indoor conditions
 - reducing the energy consumption through smart TN-NTN routing
 - higher accuracy positioning services beyond TN coverage
 - deterministic and lower delays through interconnected nodes at very low altitudes

new waveforms with flexible channel bandwidth and low PAPR

- extend the link margin (e.g., light indoor)
- support ISAC
- support NOMA in high density scenarios

definition of **new/enhanced radio procedures** to support new architectures and technologies

definition of **advanced routing protocols** in multi-dimensional networks, with variable inter-node conditions

AI-driven RRM supporting NTN-TN spectrum sharing solutions

support TN/NTN and NTN/NTN **Multi-Connectivity**

support of **functional split architectures** across the feeder link and on INLs

Conclusions

- **TN/NTN native unification in 6G**
- **Evolutionary and revolutionary technologies** are needed to achieve a true **fully unified 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
- **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)
 - ...



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