Technology Management Wireless

5G NTN TAKES FLIGHT: 5G NON-TERRESTRIAL NETWORKS EVOLVING TOWARDS 6G

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Make ideas real

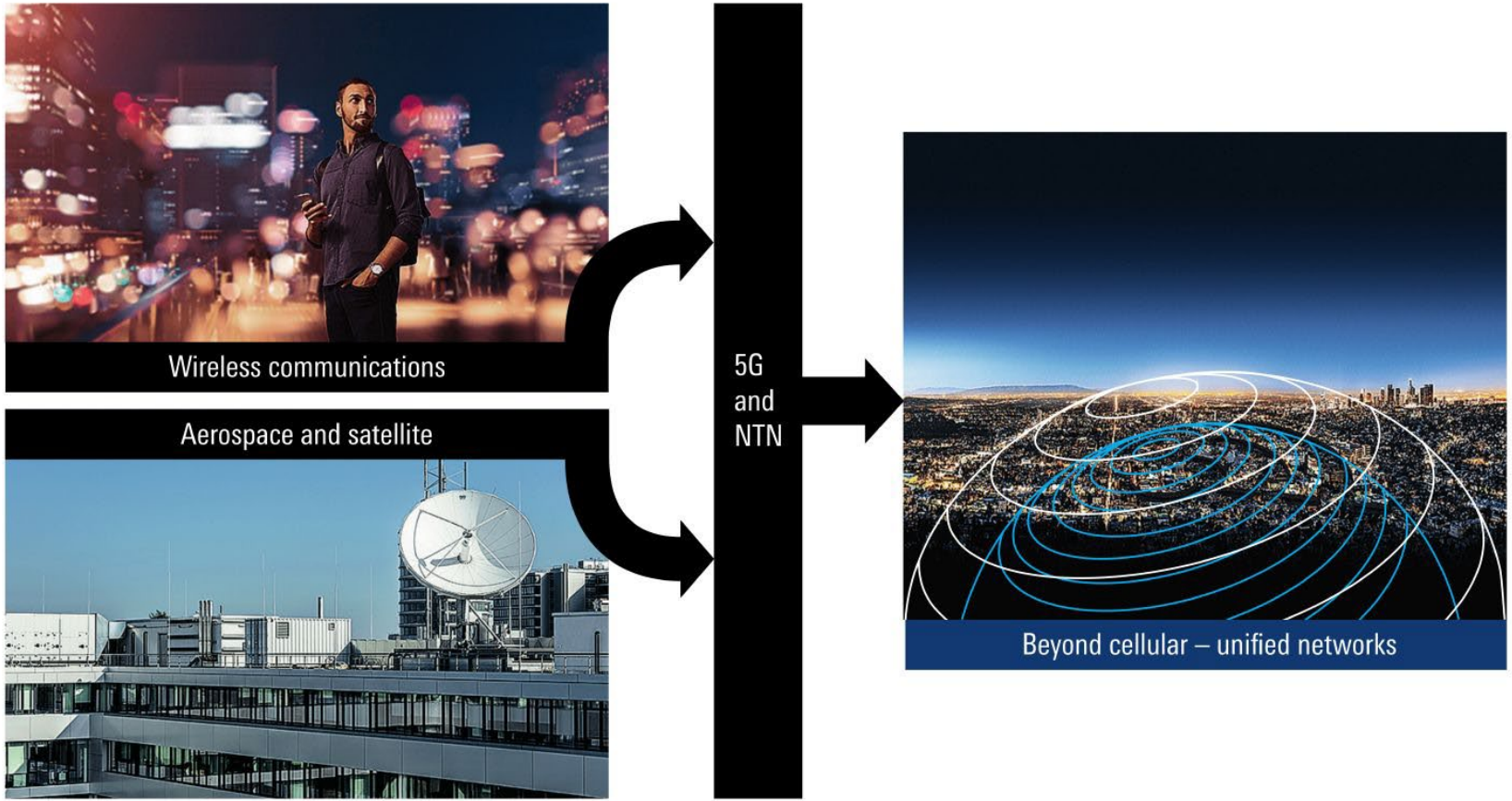
AGENDA

- Introduction and motivation
- Commercial NewSpace constellations
- NTN frequency and architecture aspects
- NTN RF aspects and challenges
- NTN procedures and protocol updates
- NTN evolution – outlook

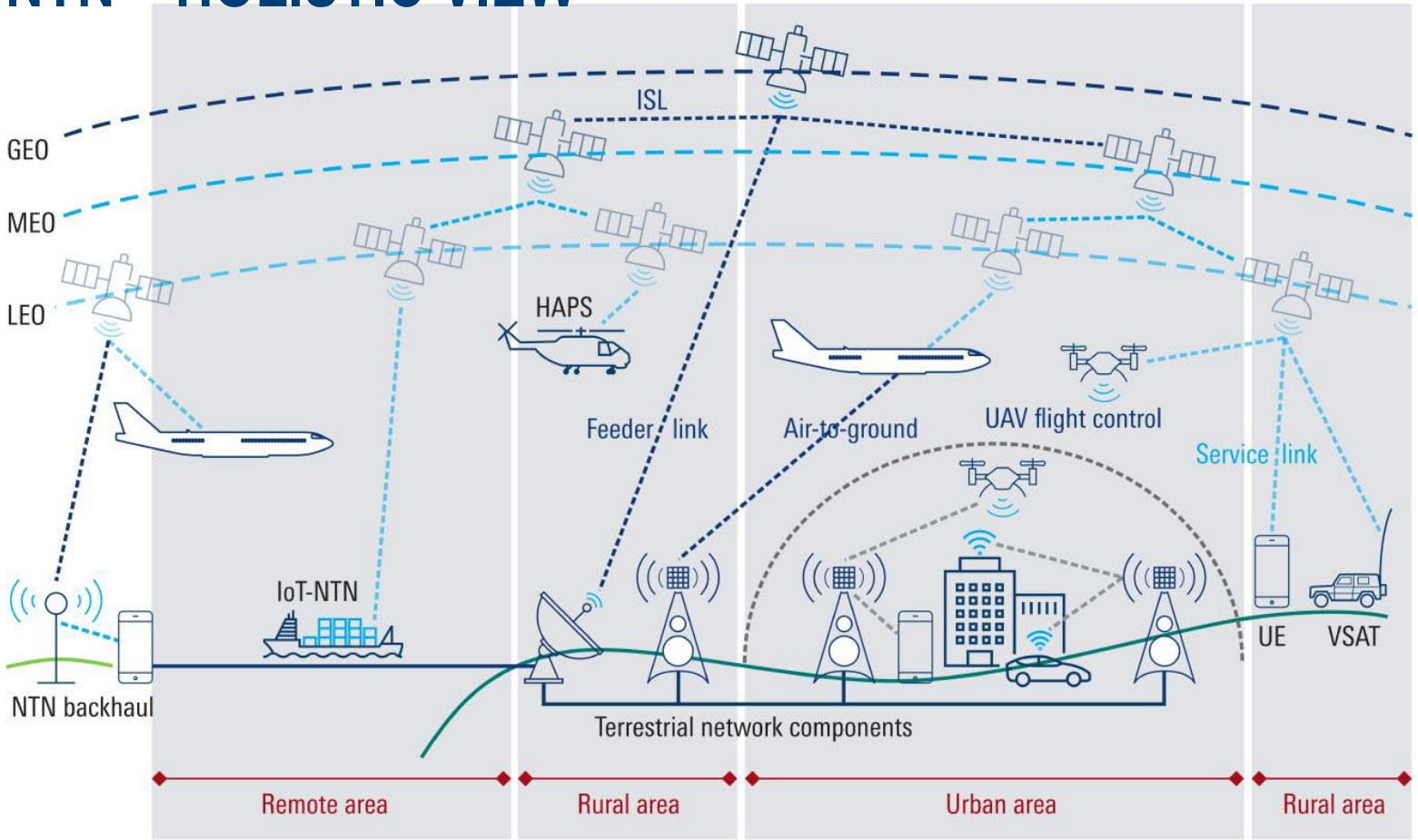
Non-terrestrial networks (NTN)

5G NTN INTRODUCTION AND MOTIVATION

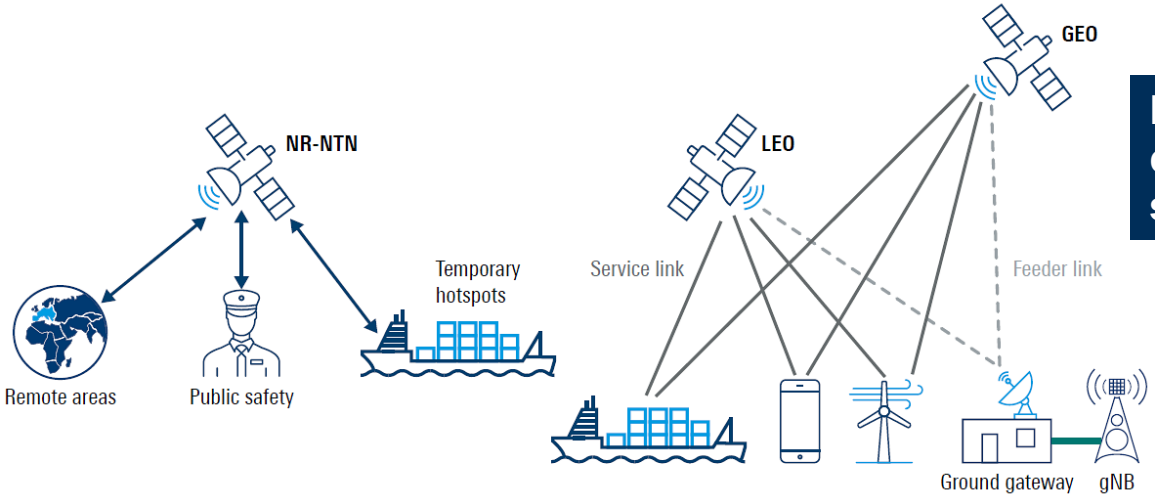
CONVERGENCE BETWEEN AEROSPACE AND WIRELESS ECOSYSTEMS



5G NTN – HOLISTIC VIEW

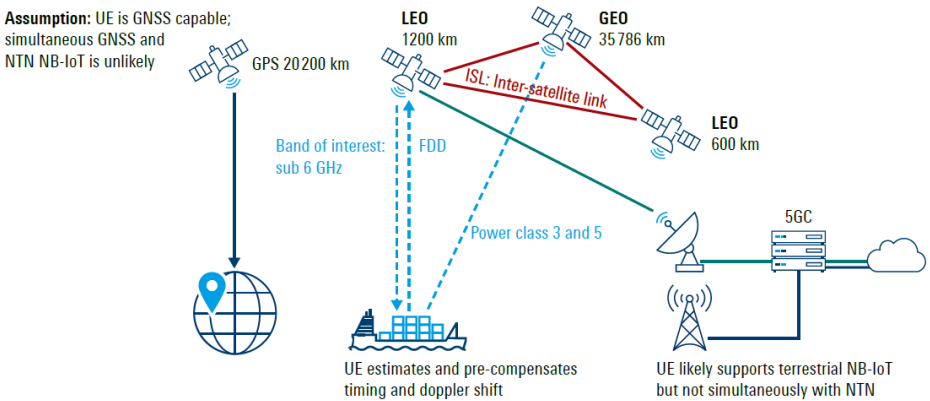


5G NTN TWO FACETS: NR-NTN AND IoT-NTN

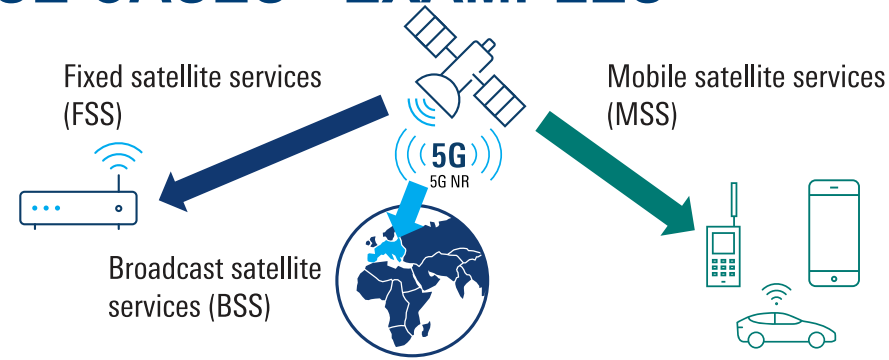


NR-NTN: enabling 5G connectivity via satellites

IoT-NTN: enabling IoT connectivity via satellites



5G NTN USE CASES - EXAMPLES



3GPP use case categories:

- **Service continuity**
- **Service ubiquity**
- **Service scalability**

Urban	Rural	Remote	Isolated
Overlay and traffic offload, hotspot on demand, network resilience and emergency, fixed wireless access	Network resilience and emergency, fixed wireless access, wide area connectivity, public protection and desaster relief (PPDR)	Network resilience, backhaul, PPDR and emergency, wide area connectivity	Aeronautical, maritime, remote hotspots, PPDR and emergency

NewSpace CONSTELLATIONS

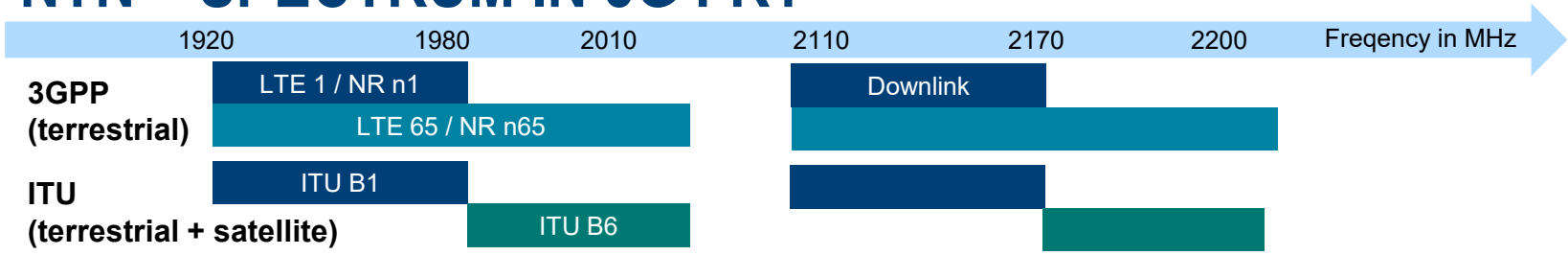
5G NTN will not be the „only“ satellite constellation in space ☺

Constellation	Lightspeed	Starlink	OneWeb	Kuiper
Operator	Telesat	SpaceX	OneWeb	Amazon
Country	Canada	USA	UK	USA
Owner	New Telesat (Loral Skynet, Public Sector Pension Investment Board of Canada)	Elon Musk	British Crown, Indian Bharti Company, Softbank, Hughes Network	Jeff Bezos
Budget	$5 billion	N.A., > $10 billion	N.A., approx. several $billion	$10 billion
Target customer	industrial consumers: aeronautical, maritime, enterprise, telecom and government networks	broadband internet, consumer market, military, governments	broadband internet, consumer market	broadband internet, consumer market
Manufacturer of satellites	TAS France	SpaceX	OneWeb Satellites (Airbus and OneWeb)	N.A.
Number of satellites (current estimate)	298 satellites in six polar orbits, 11 satellites on 20 orbits close to the equator	phase 1: 1584, phase 2: 2824, phase 3: 30000	650, then 1980, finally 6372	3236

Non-terrestrial networks (NTN)

5G NTN FREQUENCY ASPECTS & ARCHITECTURE

NTN – SPECTRUM IN 5G FR1



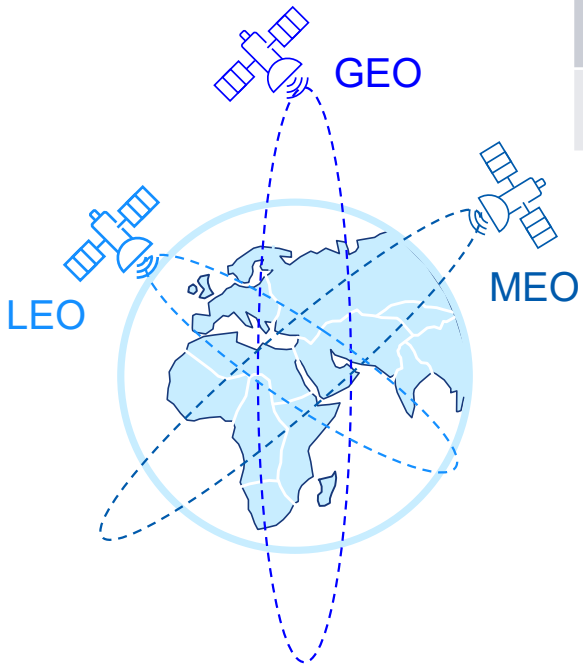
3GPP, first NTN bands for S and L-band

NTN band #	Uplink	Downlink	Duplex
n256	1980 – 2010 MHz	2170 – 2200 MHz	FDD
n255	1626.5 – 1660.5 MHz	1525 – 1559 MHz	FDD

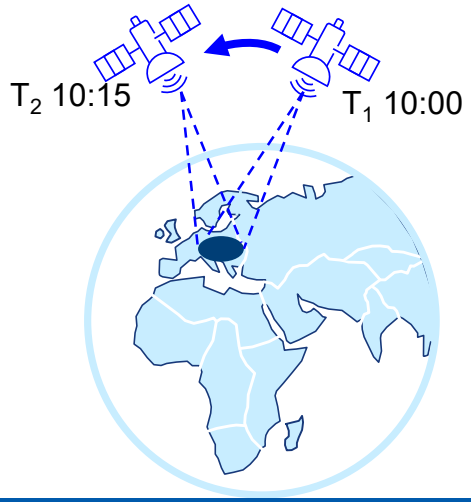
3GPP, bandwidth and subcarrier spacing for NTN bands + #RB

NTN band #	SCS (kHz)	5 MHz	10 MHz	15 MHz	20 MHz
256	15	Yes	Yes	Yes	Yes
	30		Yes	Yes	Yes
	60		Yes	Yes	Yes
255	15	Yes	Yes	Yes	Yes
	30		Yes	Yes	Yes
	60	N/A	Yes	Yes	Yes
		#RB	#RB	#RB	#RB
Max. transmission bandwidth configuration	15	25	52	79	106
	30	11	24	38	51
	60	N/A	11	18	24

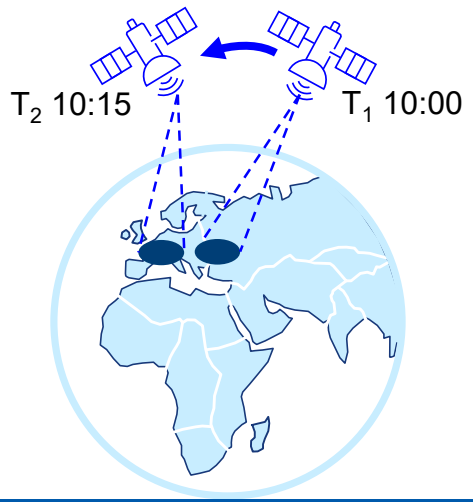
5G NTN: CONSTELLATIONS



Platform	Altitude	Orbit	Beam footprint
GEO	35786 km	Position fixed in elevation/azimuth to a given Earth point	200 – 3500 km
LEO	500-2000 km	Circular arount the Earth. Not stationary to a given Earth point	100 – 1000 km



Steerable beams: Fixed with respect to Earth‘s surface

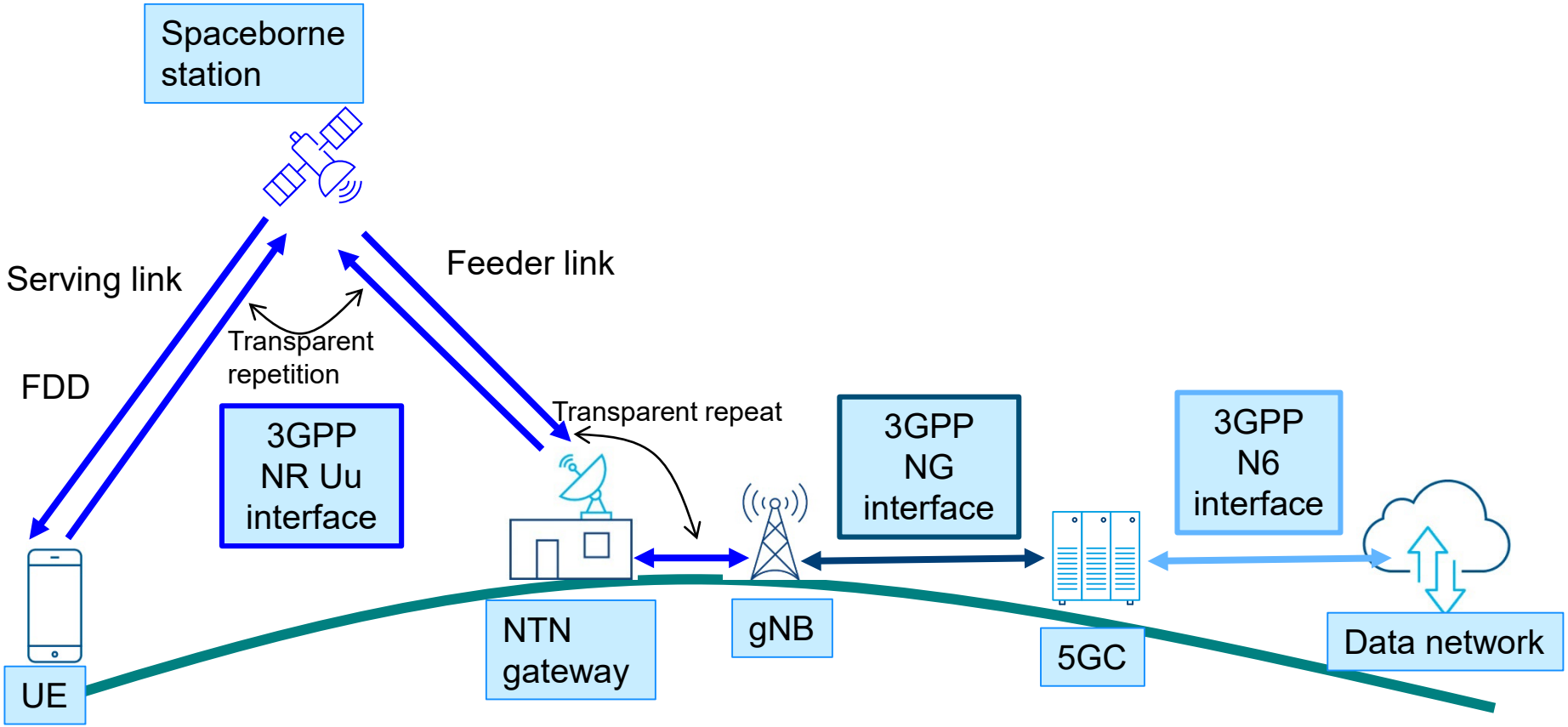


Fixed beams: Moving with respect to Earth‘s surface

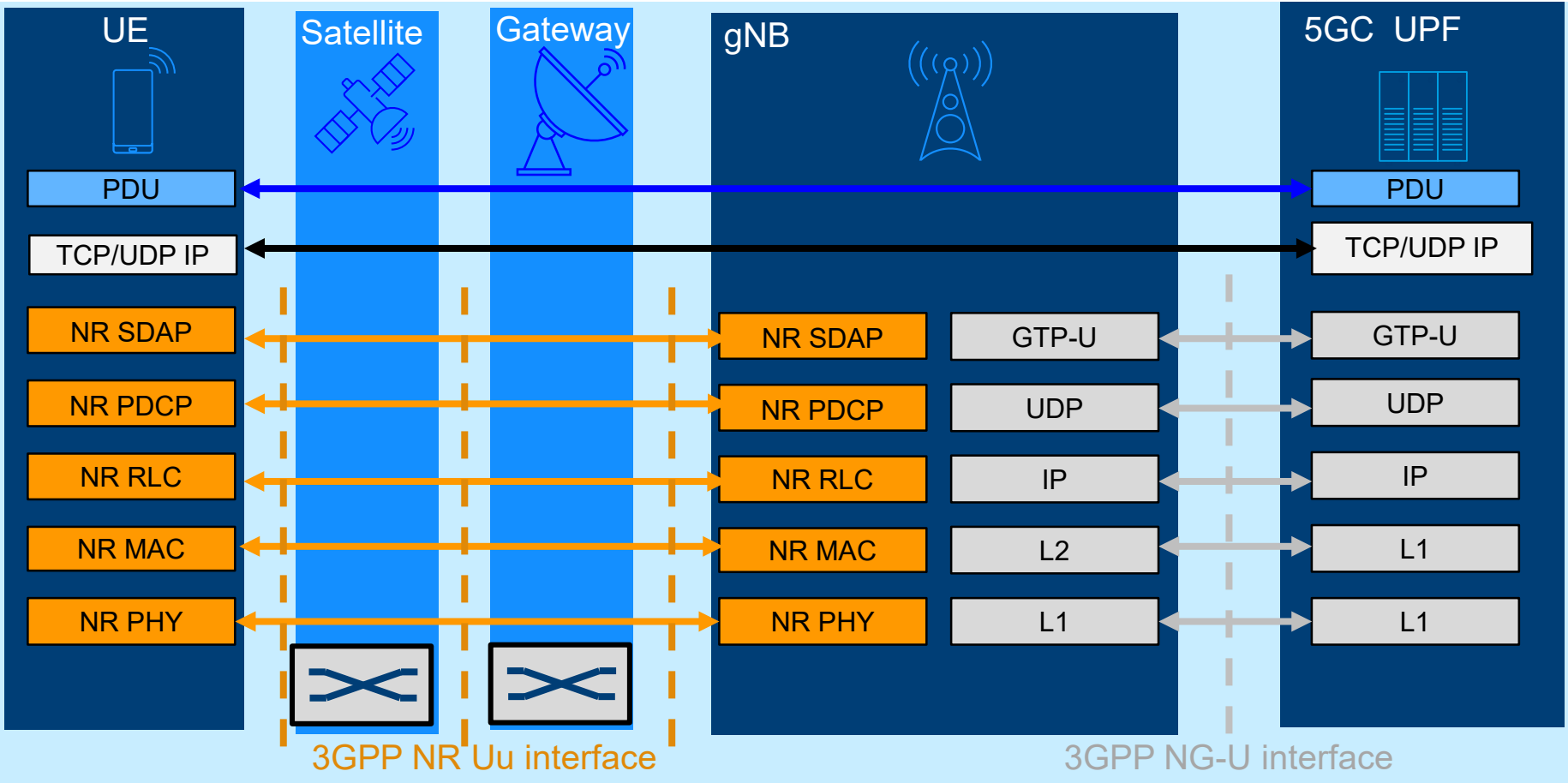
Non-terrestrial networks (NTN)

ARCHITECTURE

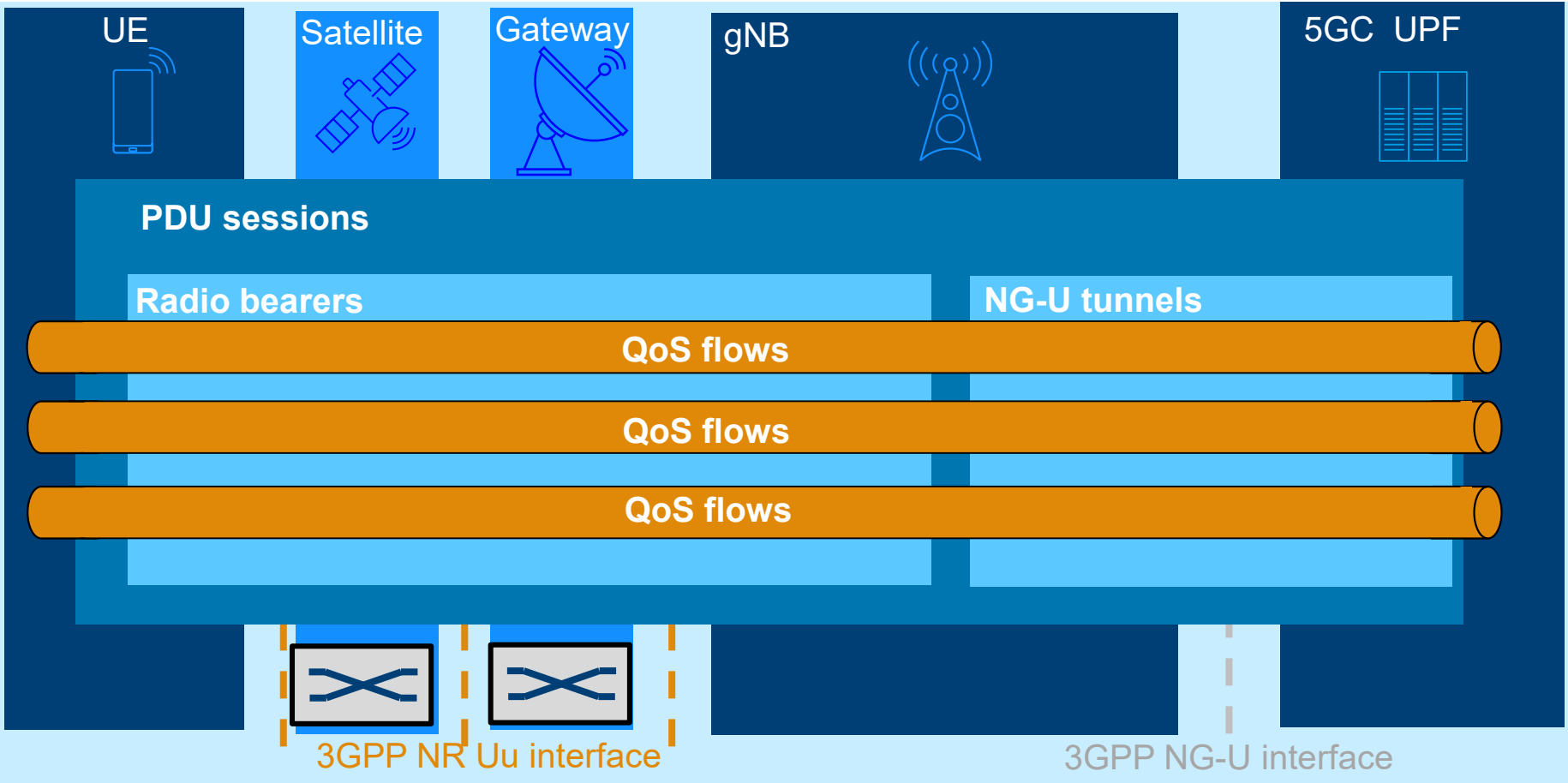
NTN: TRANSPARENT PAYLOAD ARCHITECTURE



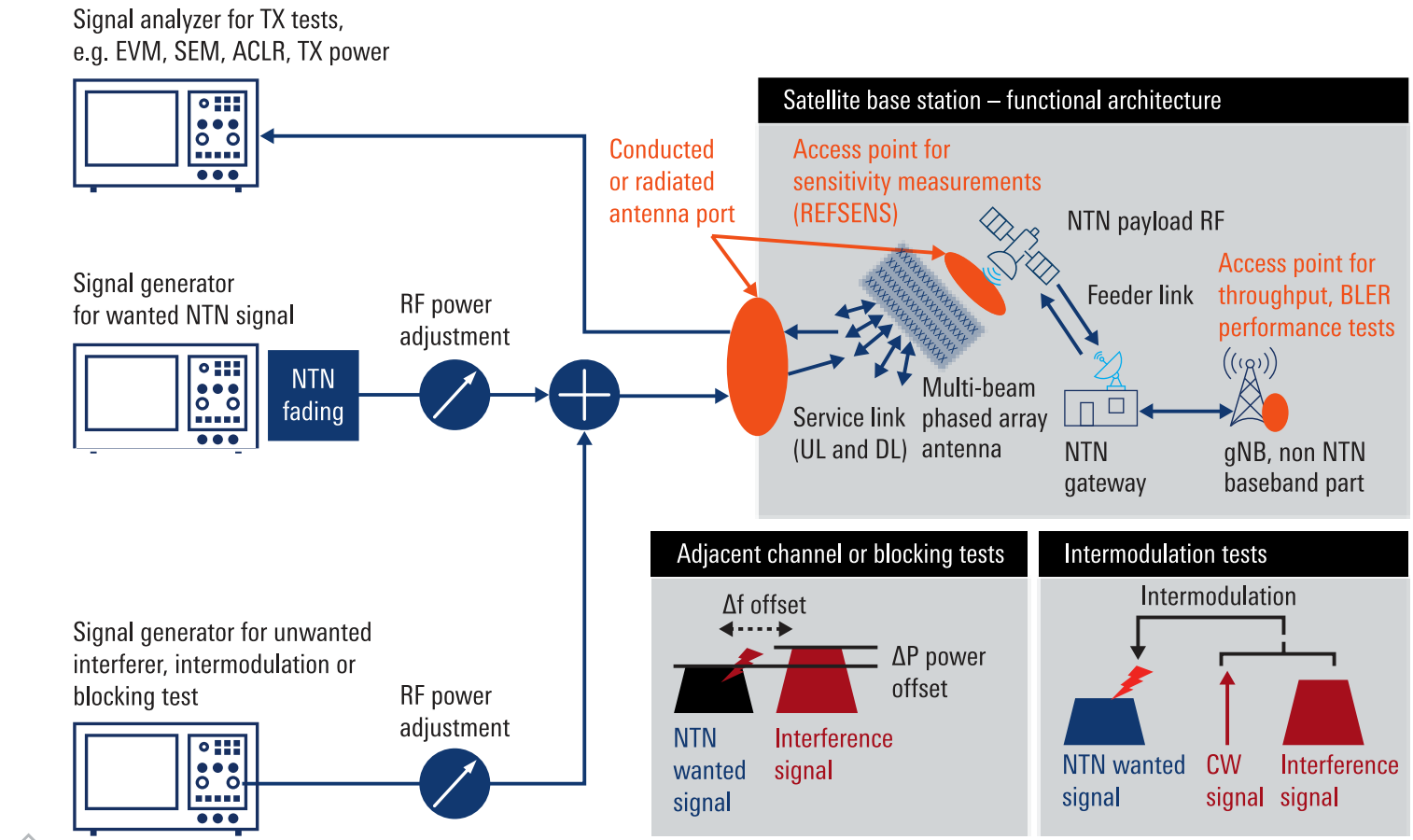
NTN: TRANSPARENT PAYLOAD - PROTOCOL STACK, U-PLANE



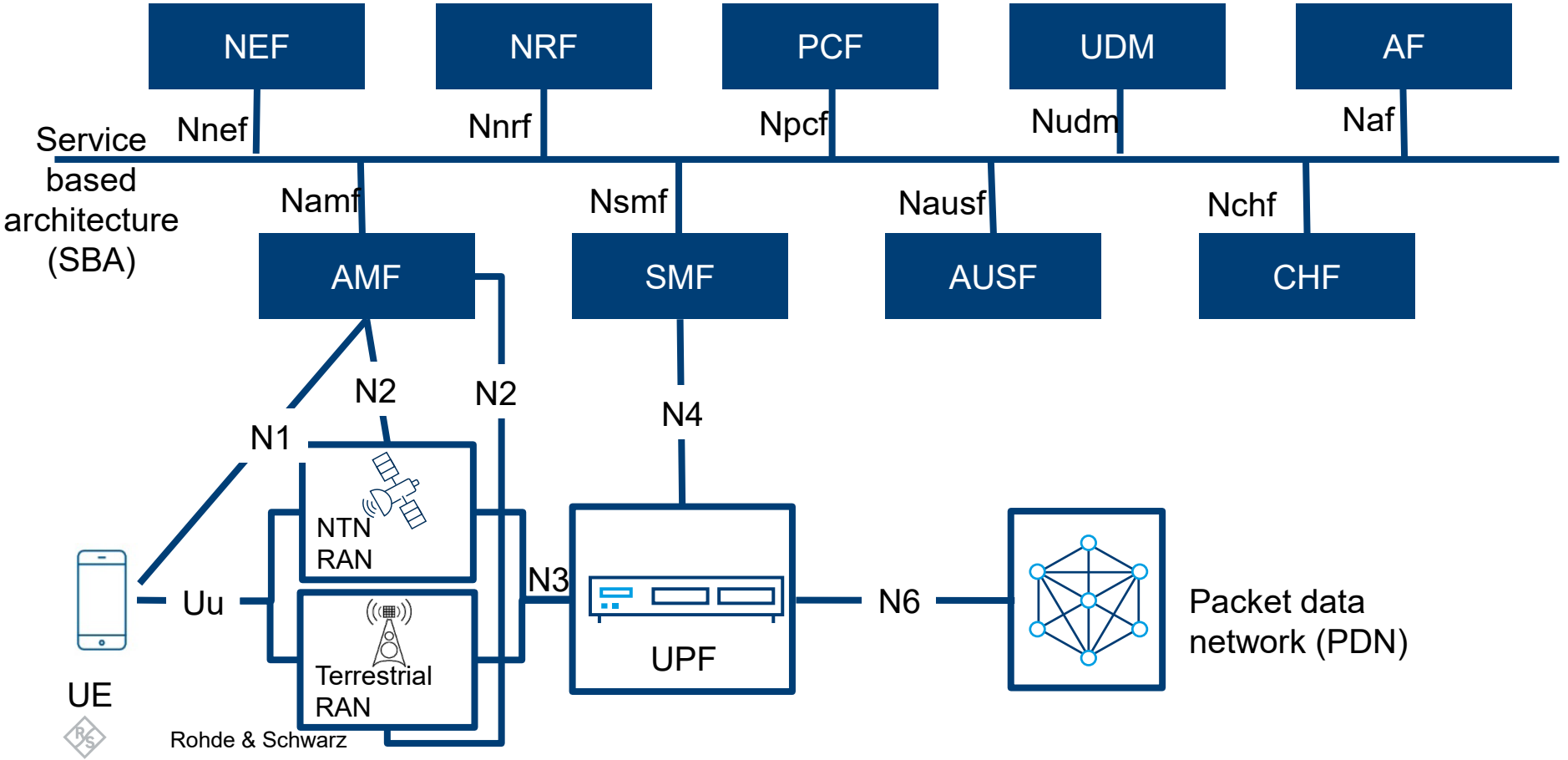
NTN: TRANSPARENT PAYLOAD - BEARER & QoS FLOWS



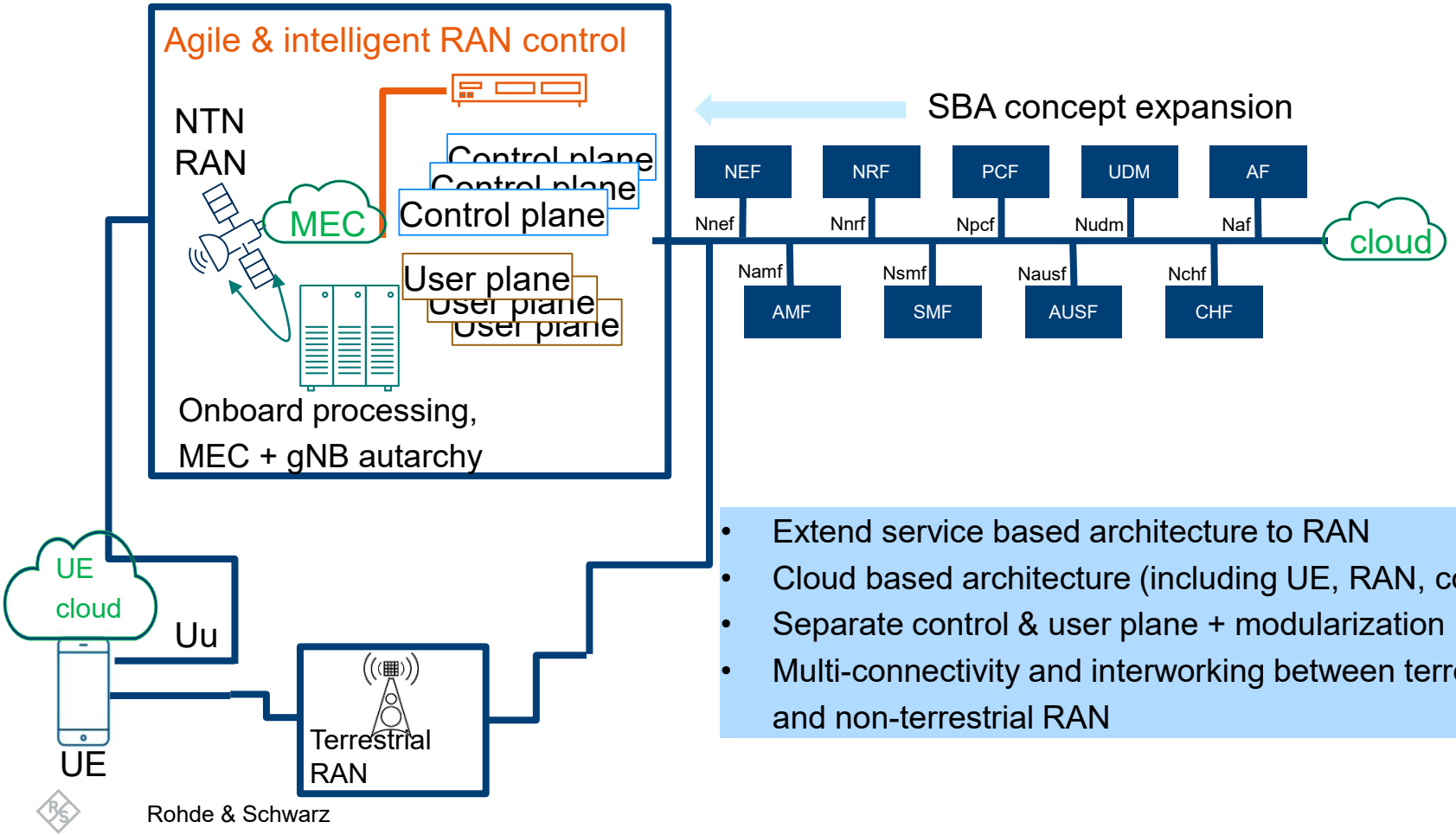
NTN: TRANSPARENT ARCHITECTURE TESTING ASPECTS



5G SYSTEM ARCHITECTURE SUPPORTING NTN

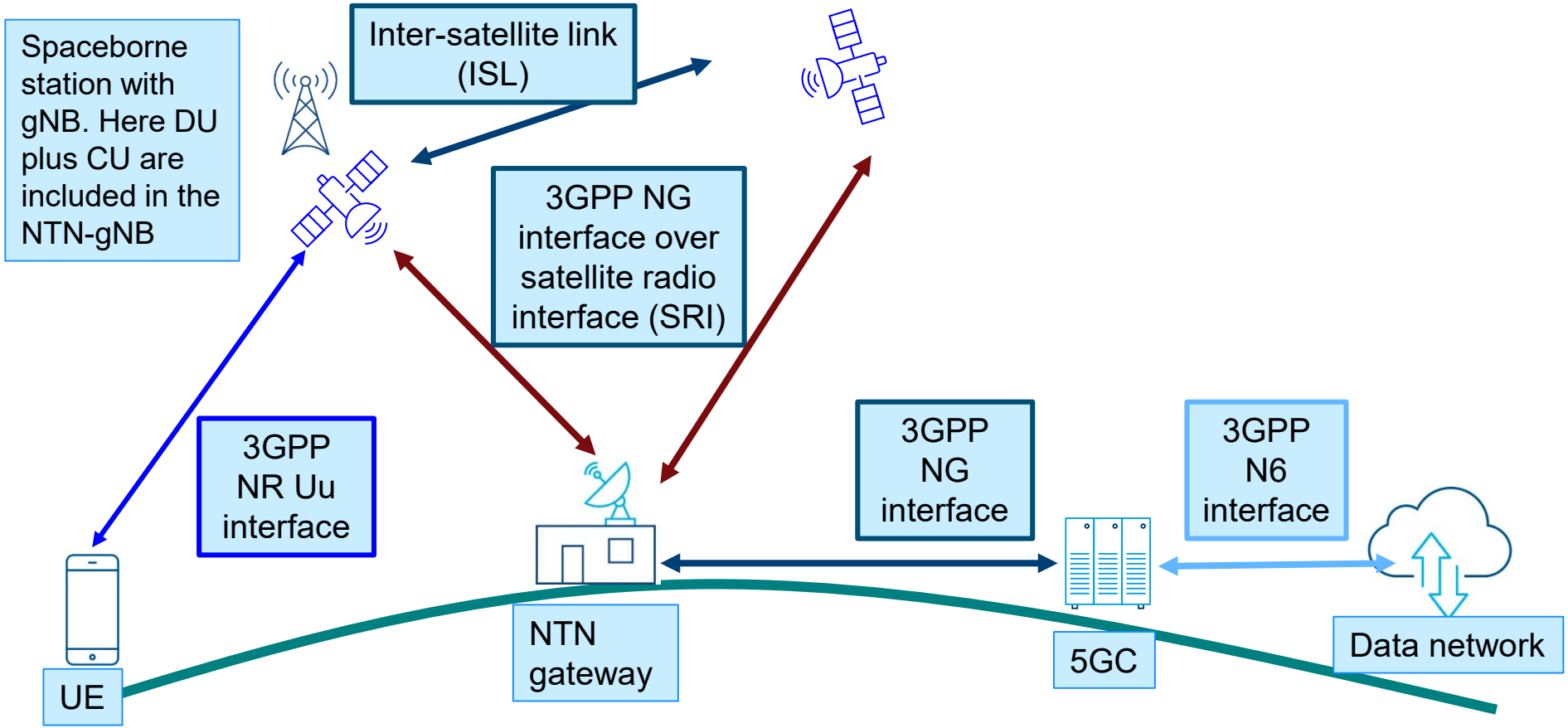


5G NTN ARCHITECTURE TOWARDS 6G

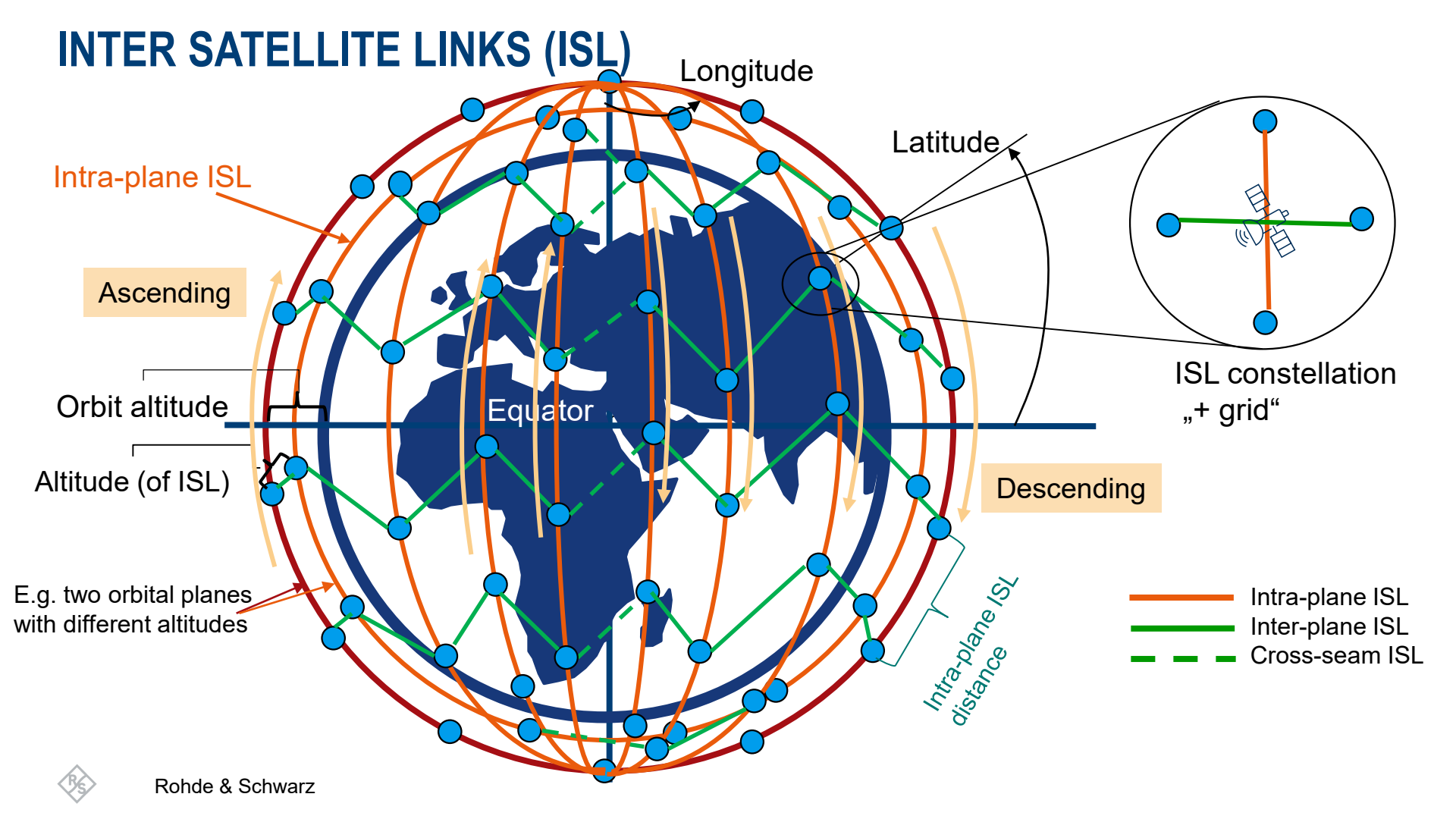


- Extend service based architecture to RAN
- Cloud based architecture (including UE, RAN, core, …)
- Separate control & user plane + modularization
- Multi-connectivity and interworking between terrestrial and non-terrestrial RAN

NTN: REGENERATIVE PAYLOAD ARCHITECTURE



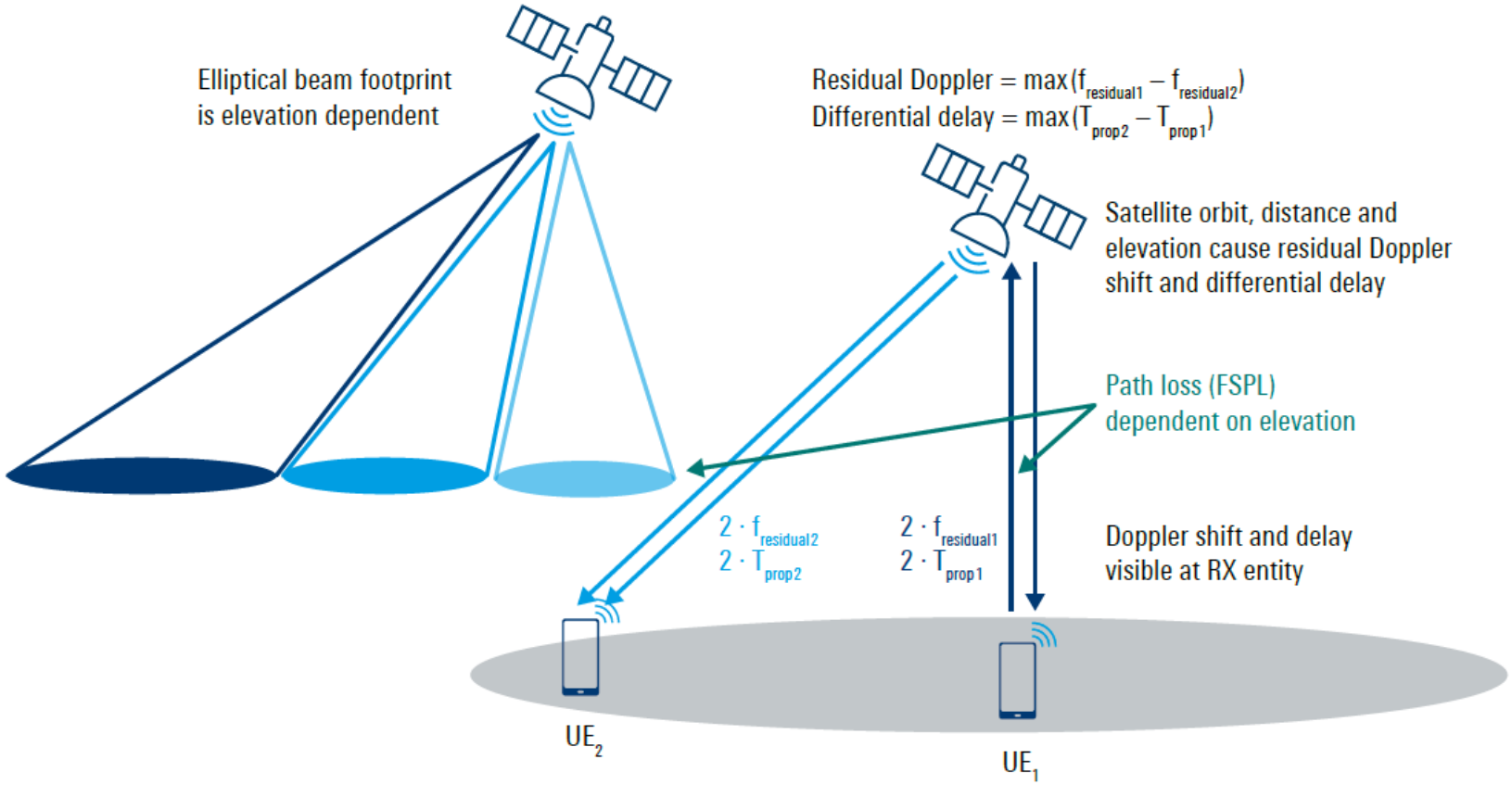
INTER SATELLITE LINKS (ISL)



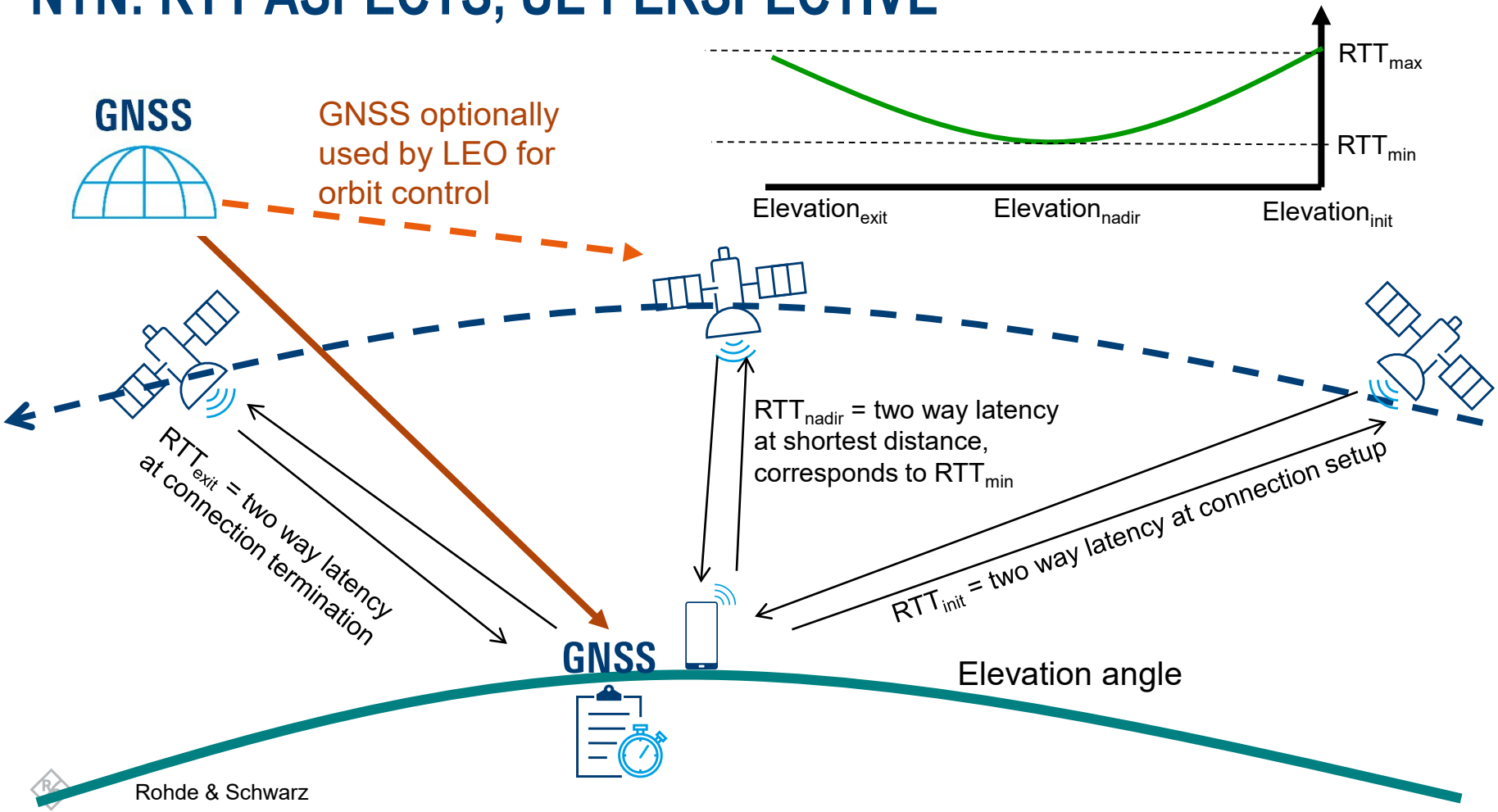
Non-terrestrial networks (NTN)

5G NTN RF ASPECTS AND SOME CHALLENGES

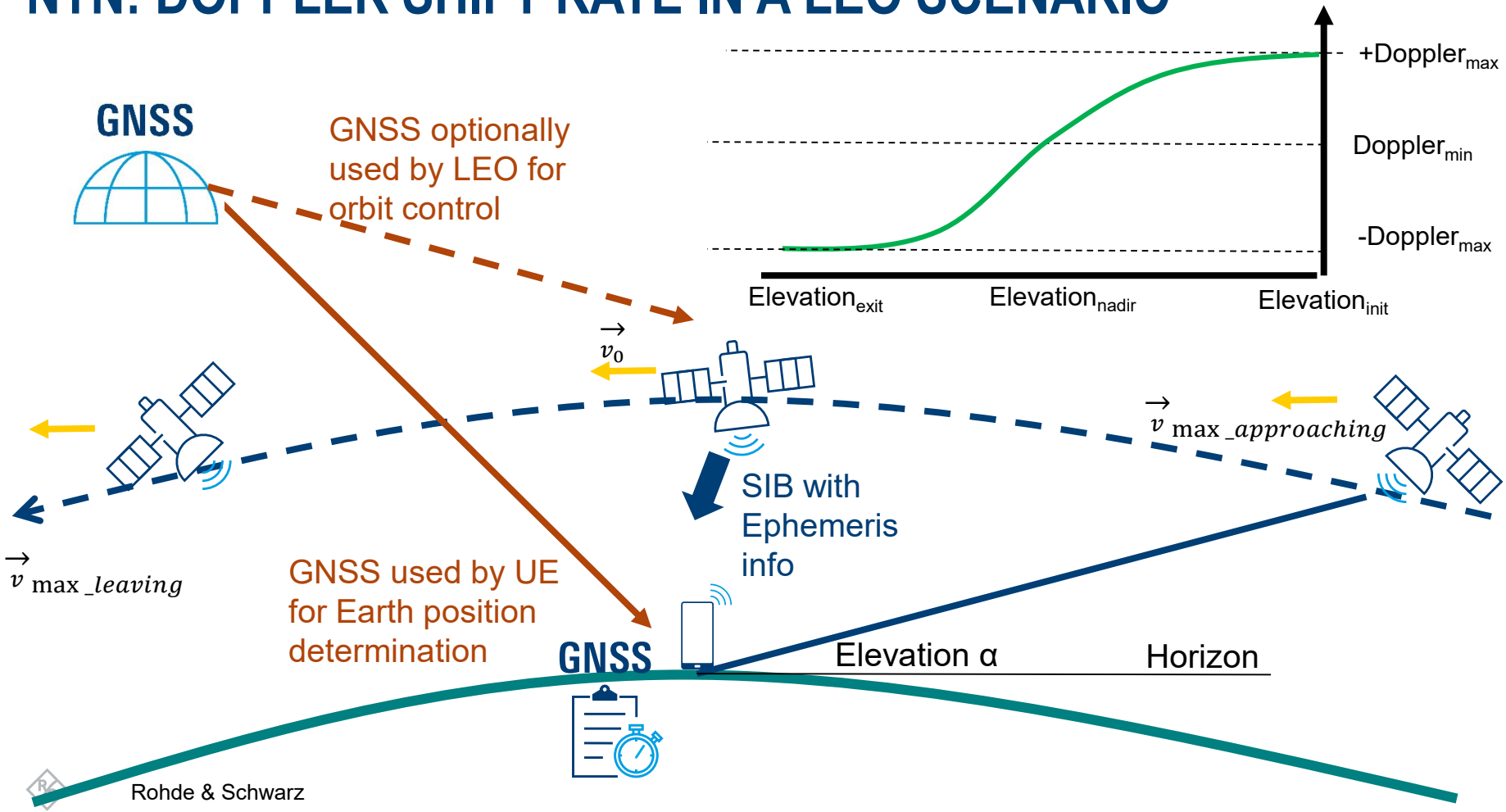
NTN: RTT ASPECTS – PERSPECTIVE SATELLITE



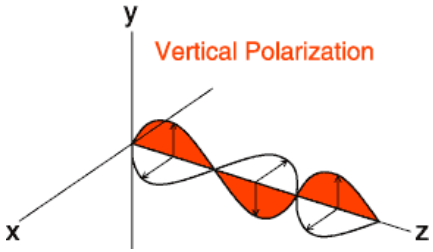
NTN: RTT ASPECTS, UE PERSPECTIVE

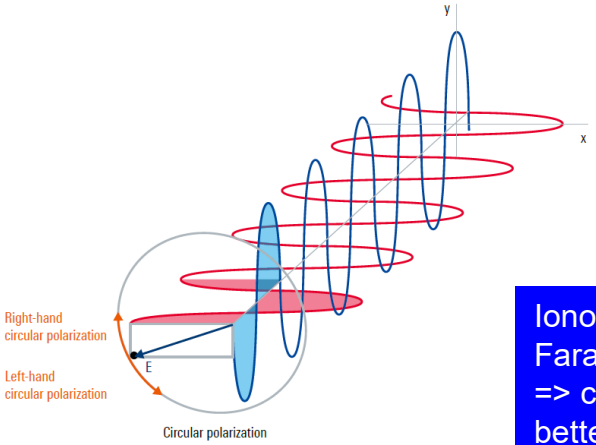


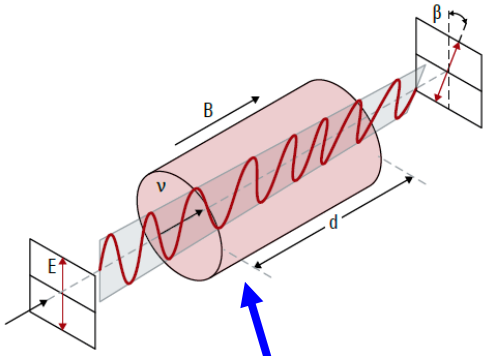
NTN: DOPPLER SHIFT RATE IN A LEO SCENARIO



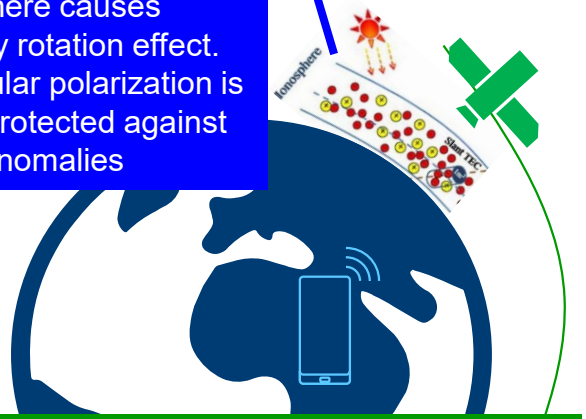
REMINDER: ANTENNA POLARIZATION

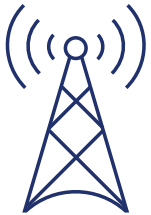






Ionosphere causes Faraday rotation effect.
=> circular polarization is better protected against those anomalies

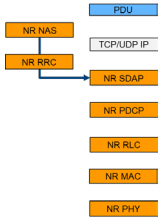




Terrestrial communications often use vertical polarization.
Geometry of antennas is quasi-static

Geometric differences if satellite moves with respect to the fixed Earth-bound station => linear polarization may lose alignment

NTN: UE TESTING ASPECTS



Protocol testing of NTN-UE:

- **Tbd, but assumptions are**: NTN scenarios, call setup/release, protocol parameter testing, RRC signaling, NAS signaling, E2E testing, etc.

GNSS

Emulation of terrestrial position

Signal analyzer for spurious emissions

Mobile radio tester for NTN connection

Signal generator for unwanted interferer, intermodulation or blocking test

NTN fading

Fading and delay

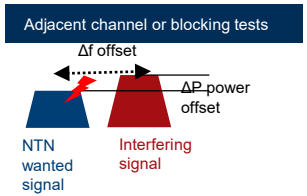
RF power adjustment

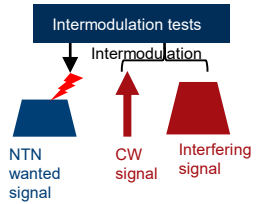
Setup:

Conducted or OTA

RF testing of NTN-UE:

- **TX side**: TX power, power dynamics, frequency error, EVM, occupied bandwidth, ACLR, SEM, spurious emissions, etc.
- **RX side**: RX sensitivity, max input level, blocking & intermodulation, etc.

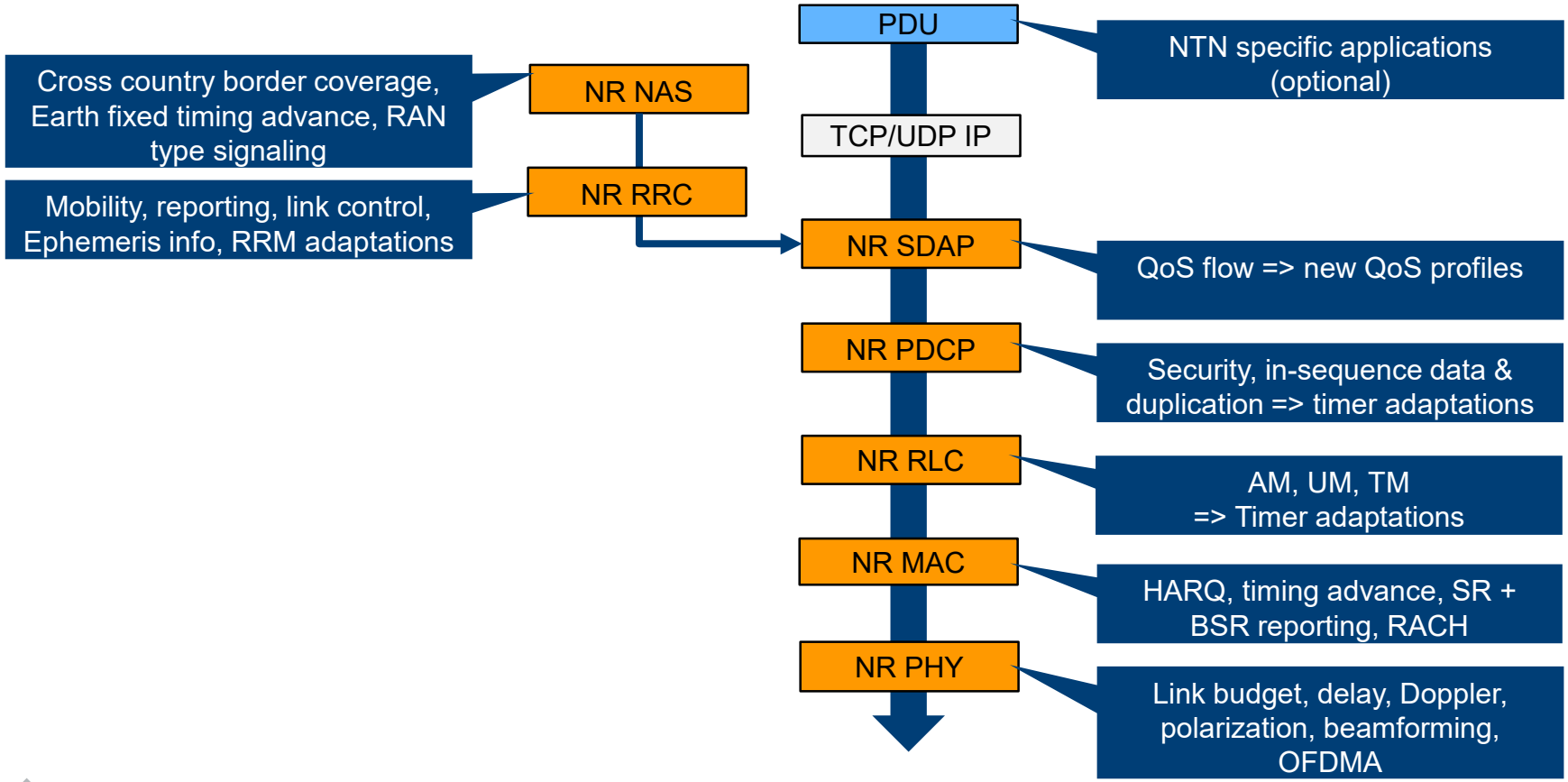




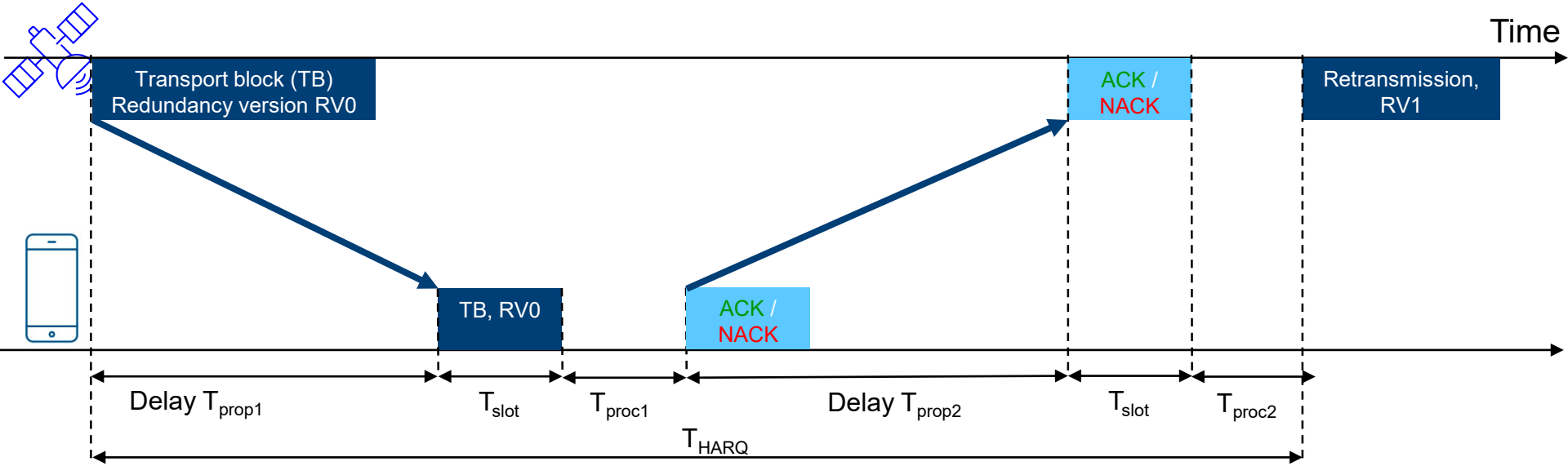
Non-terrestrial networks (NTN)

5G NTN PROTOCOL ASPECTS AND PROCEDURES

5G-NTN: PROTOCOL STACK



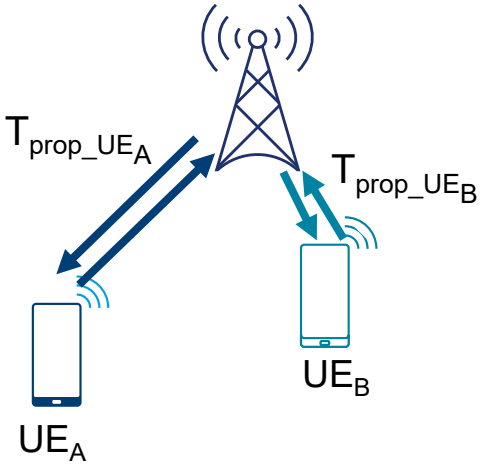
NTN: ROUND-TRIP-TIME ASPECTS AND HARQ



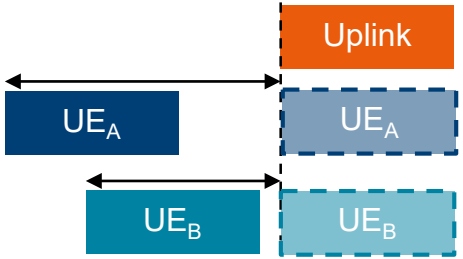
Constellation	T_{HARQ} max	#HARQ processes	UE side feasibility
Terrestrial	16 ms	16	Rel. 15
LEO	50 ms	50 theoretical 3GPP agrees to 32	HARQ extension
GEO	600 ms	600	For future study

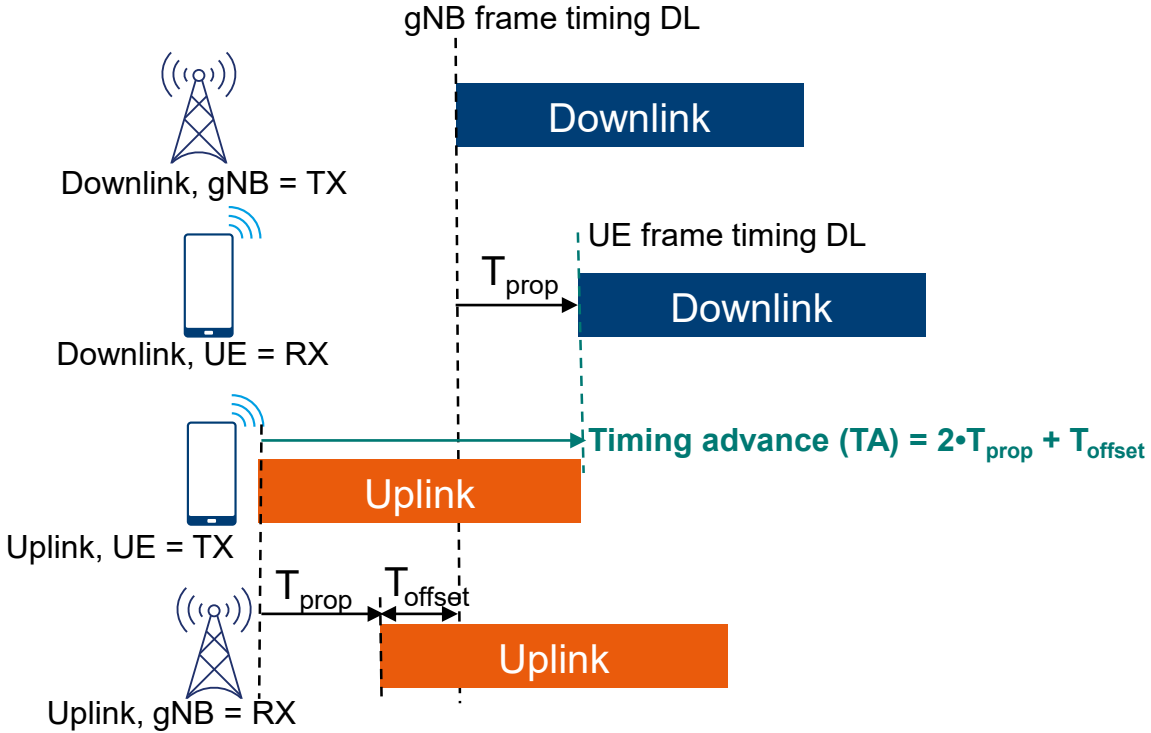
Assumption: 15 kHz SCS and 1 ms slot duration (TR 38.811)

NON TERRESTRIAL NETWORK TIMING ADVANCE



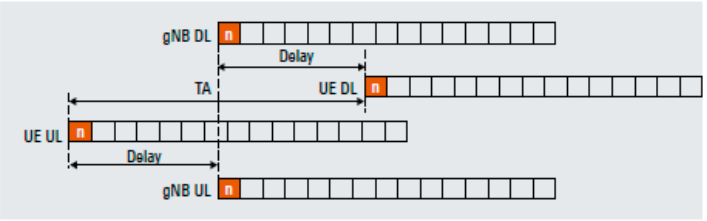
Timing advance aligns UL signals at gNB



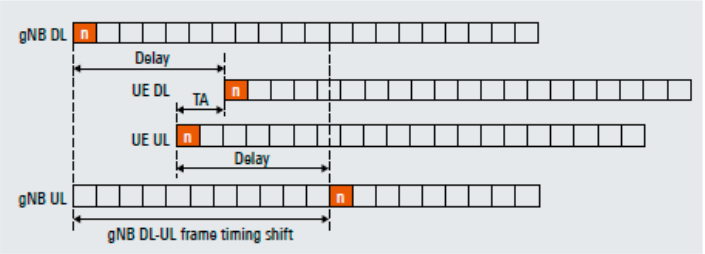


Timing advance with perspective UE and gNB.
T_{offset} can indicate an optional time difference between UL and DL frames at the gNB

NON TERRESTRIAL NETWORK CHALLENGES



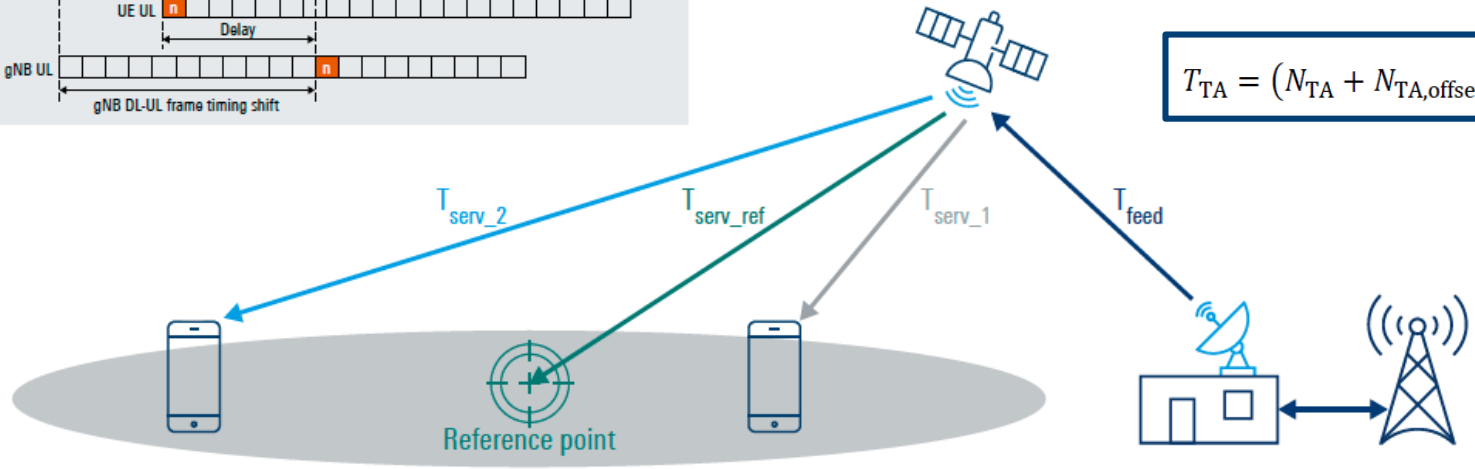
Idea to adjust large timing advance values:
⇒ large TX – RX offset in the UE



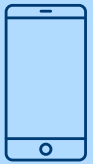
Idea to adjust shorter timing advance values:
⇒ large TX – RX offset in the gNB
⇒ possible SFN shift in gNB for UL/DL

Timing advance depends on UE and cell specific values + TA control

$$T_{\mathrm{TA}} = \left(N_{\mathrm{TA}} + N_{\mathrm{TA,offset}} + N_{\mathrm{TA,adj}}^{\mathrm{common}} + N_{\mathrm{TA,adj}}^{\mathrm{UE}}\right) T_{\mathrm{c}}$$



NON TERRESTRIAL NETWORK CHALLENGES



5G NR time offset signaled, e.g. timer K2

DCI

PUSCH

UE processing time

Timing advance will move PUSCH to an earlier transmission

5G NR terrestrial case: normal timing advance ranges

$$\left\lfloor n \frac{2^{\mu_{PUSCH}}}{2^{\mu_{PDCCH}}} \right\rfloor + K2$$

Timer K2

Timer K_offset

DCI

PUSCH

PUSCH

UE processing time

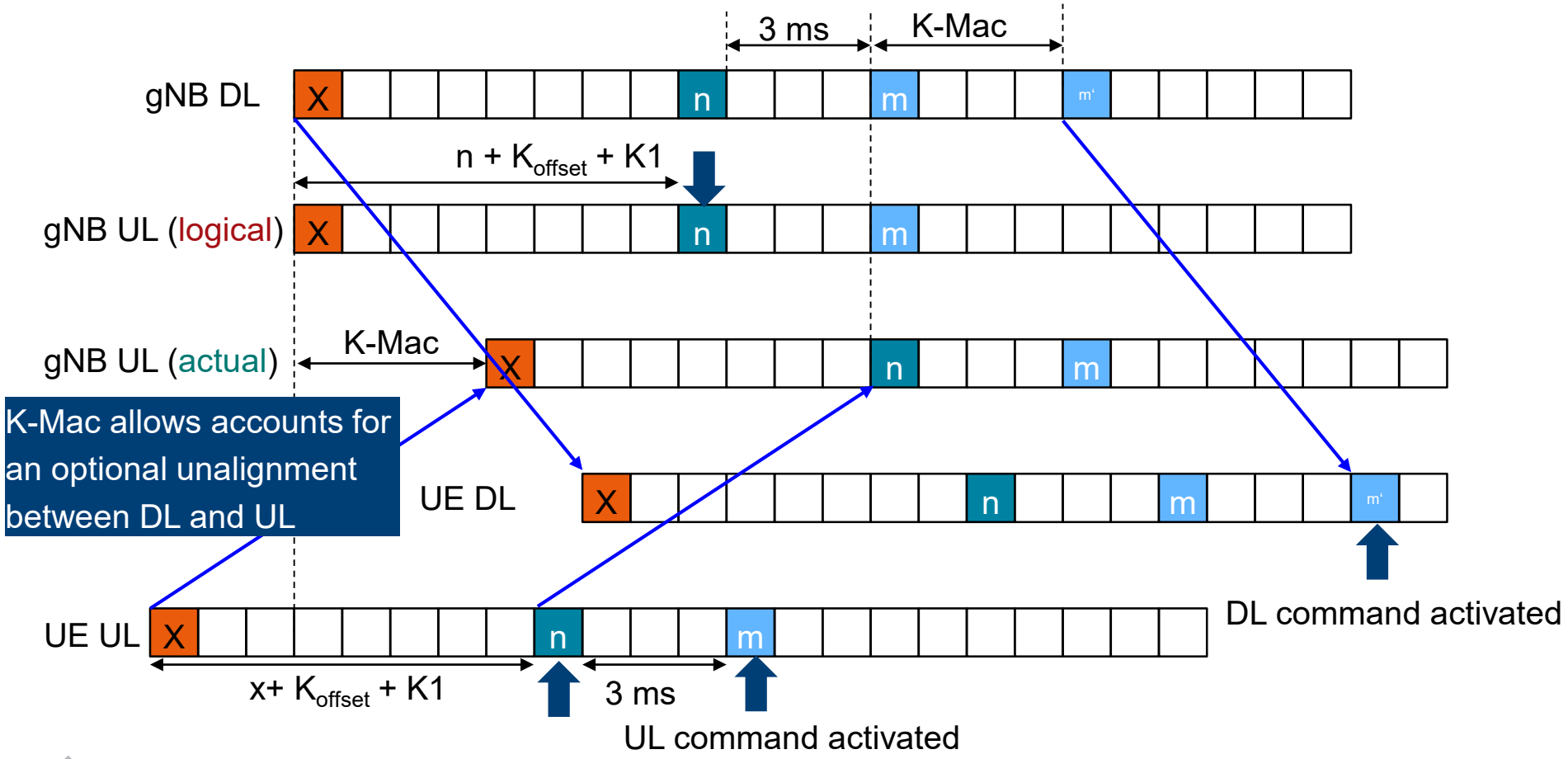
5G NTN case: large timing advance ranges

K_offset

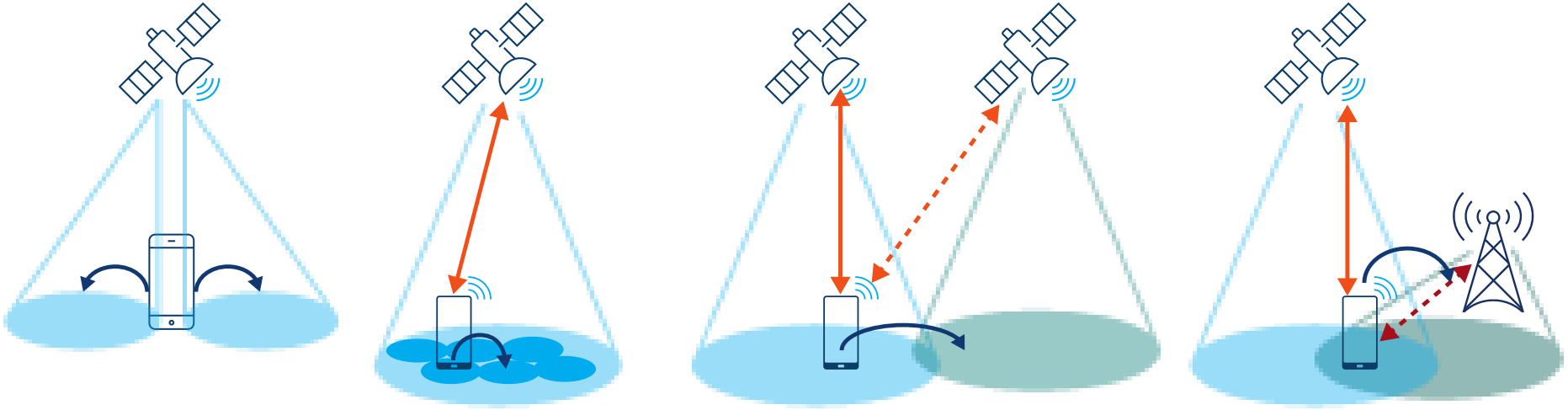
$$\left\lfloor n \frac{2^{\mu_{PUSCH}}}{2^{\mu_{PDCCH}}} \right\rfloor + K2 + K\_offset \frac{2^{\mu_{PUSCH}}}{2^{\mu_{K_{offset}}}}$$

Introduce a cell-specific K_offset (SIB broadcast). UE specific component possible (MAC CE)

NON TERRESTRIAL NETWORK PARAMETER K-Mac



5G NTN MOBILITY SCENARIOS - EXAMPLES



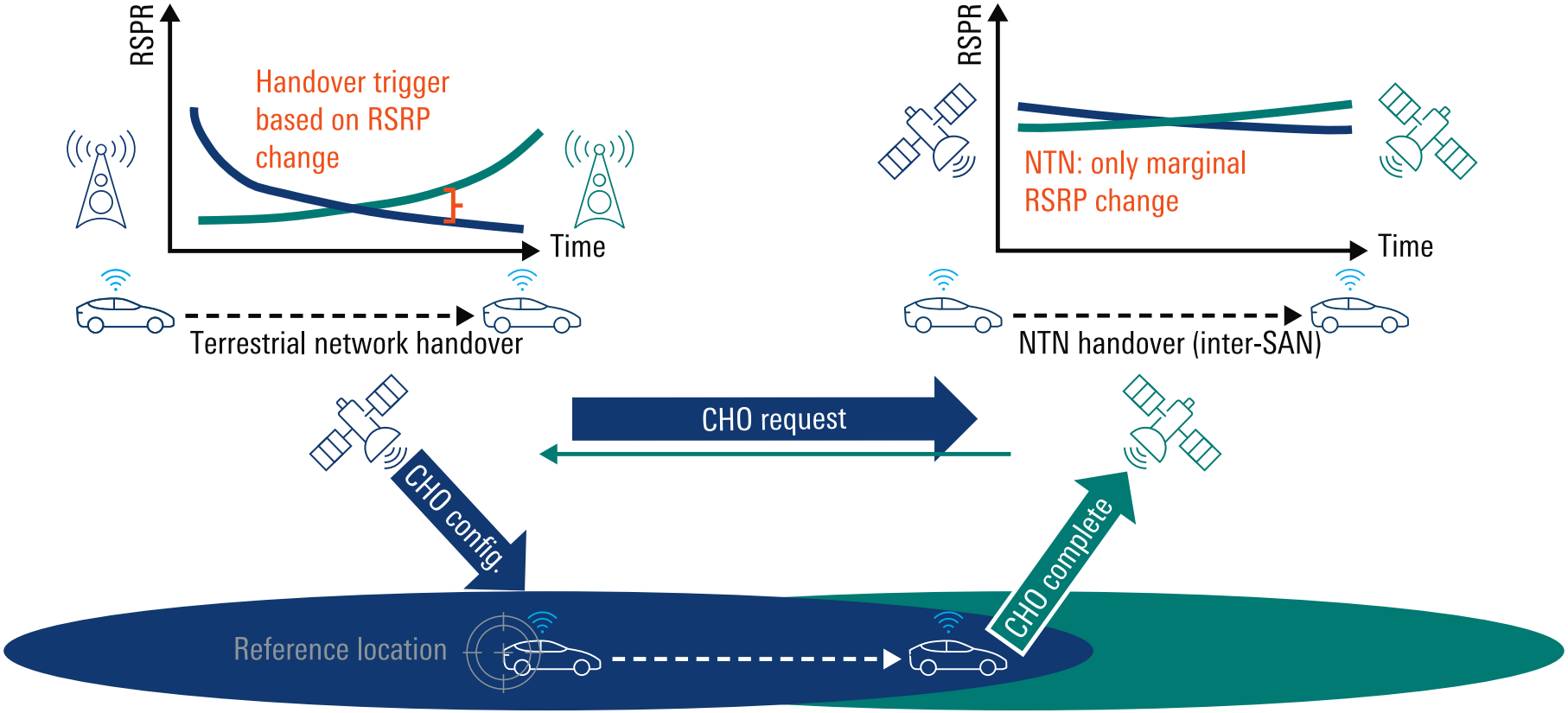
Cell selection/ cell reselection	Intra-satellite/ inter-beam handover	Inter-satellite handover/ inter-satellite dual connectivity (DC)	NTN – terrestrial handover/DC

NR-NTN connection

Target or simultaneous dual connectivity NR-NTN connection

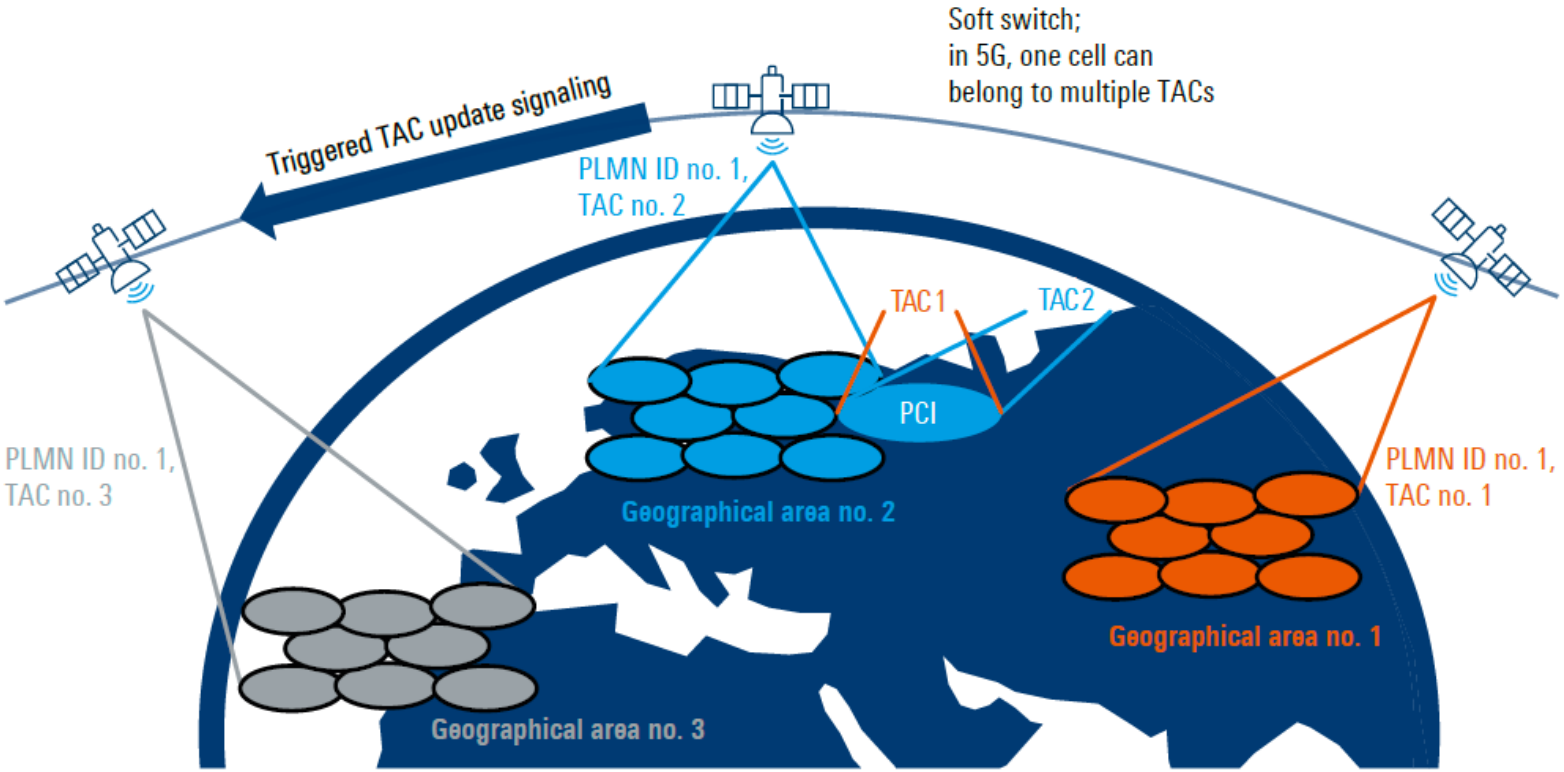
Target or simultaneous dual connectivity terrestrial connection

5G NTN HANDOVER EXAMPLE (CHO)



Conditional handover (CHO): network configures UE with triggering condition; e.g. distance between UE and reference location

NTN: TRACKING AREA ASPECTS

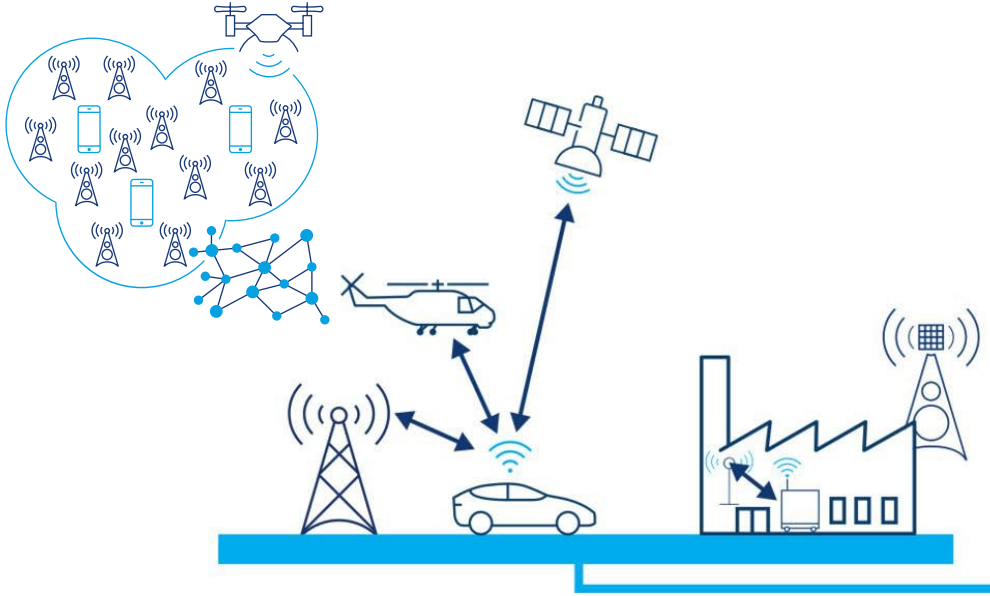


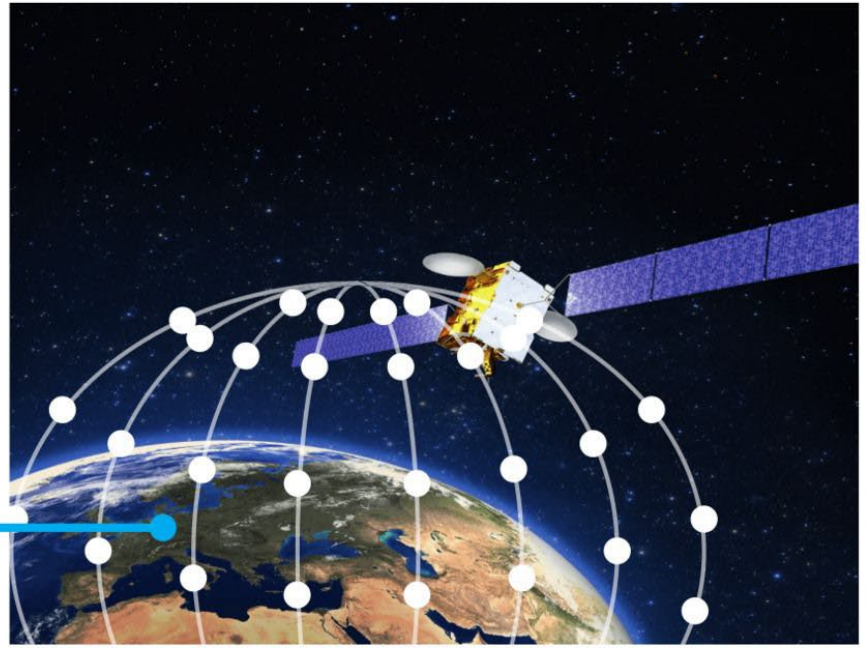
5G NTN supports Earth-fixed tracking area codes (TAC) and multi-TAC signaling

Non-terrestrial networks (NTN)

OUTLOOK

5G NTN – ON THE PATH TO 6G





Beyond cellular – 3D unified networks

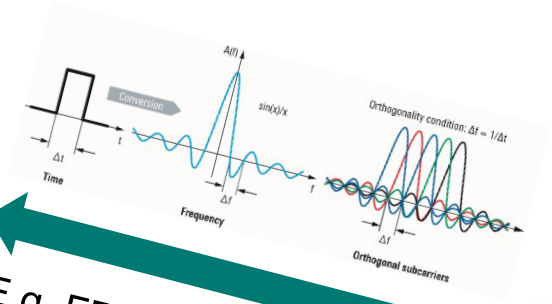
- Dynamic, self-configuring
- Resilient and intelligent
- Autonomous and infrastructure agnostic

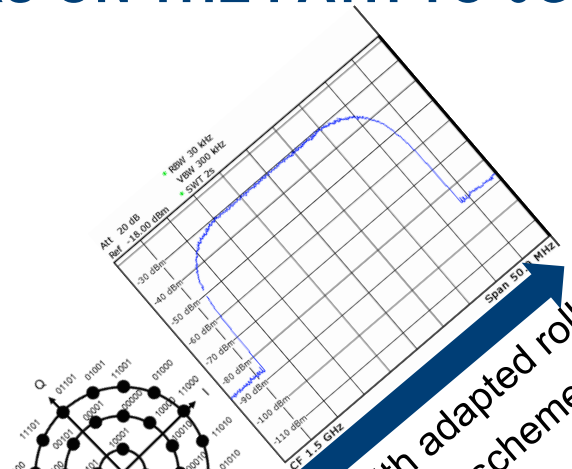
5G NTN – OUTLOOK: 6G

- Beyond cellular: network nodes are dynamic: birth-death scenarios, moving relative to each other
- Autarchic network architecture, resilient networks: node can provide services without core NW
- Unified networks, “network of the networks“ → multiple RATs offered, best QoS RAT selected
- AI for multiple scenarios: flight control, traffic steering, inter-cell coordination, autonomous decisions
- Joint communications and multi-link support, e.g. macro diversity and enhanced MIMO
- NOMA waveforms and interference cancellation methods
- Holographic radio control
- Free space optical (FSO) links, non-RF communication

NON-TERRESTRIAL NETWORKS ON THE PATH TO 6G

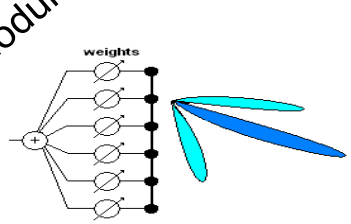
Multi-RAT and spectrum sharing „network of networks“





E.g. DVB-S2 with adapted roll-off and modulation scheme

E.g. FR1 for terrestrial propagation, applying OFDMA



Time

Frequency

E.g. mmWave using single carrier, wide bandwidth and beamforming

6G RESEARCH AREAS

THz communication

Joint communication & sensing

Artificial Intelligence and Machine Learning

Reconfigurable Intelligent Surfaces

Photonics, Visible Light Communication

Multiple access, new waveforms, channel coding

Ultra-massive MIMO

New network topologies, distributed computing

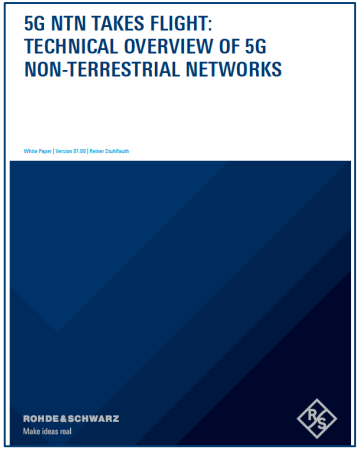
Full-duplex communication

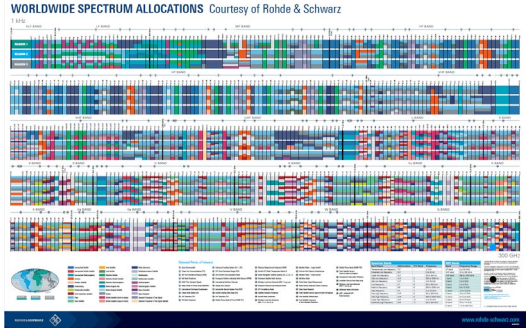
Security & Trustworthiness

A high-level overview on all these research areas is provided in one of our #THINKSIX video. Don't miss it!

ADDITIONAL RESOURCES

5G technology book oline version (>1000 pages on 5G technology): www.rohde-schwarz.com/5G-ebook





[Worldwide Spectrum Allocation Poster (2020)
Free "Demystifying 5G NR" poster | Rohde & Schwarz (rohde-schwarz.com)](Worldwide Spectrum Allocation Poster (2020)
Free "Demystifying 5G NR" poster | Rohde & Schwarz (rohde-schwarz.com))

Whitepaper
https://www.rohde-schwarz.com/solutions/test-and-measurement/aerospace-defense/satellite-test/white-paper-5g-ntn-takes-flight-technical-overview-of-5g-non-terrestrial-networks_255919.html