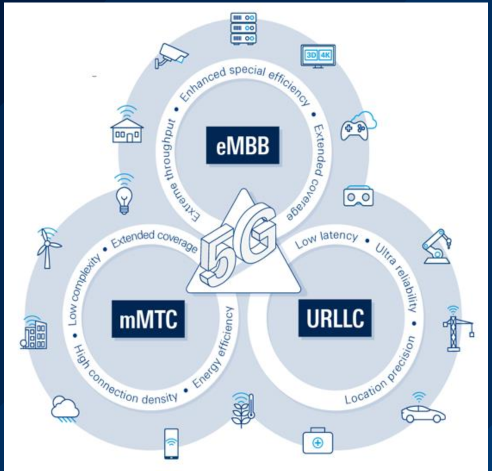
5G NTN TAKES FLIGHT:
5G NON-TERRESTRIAL NETWORKS
T&M TACKLING THE CHALLENGES OF NTN EVOLVING ON THE PATH TO 6G

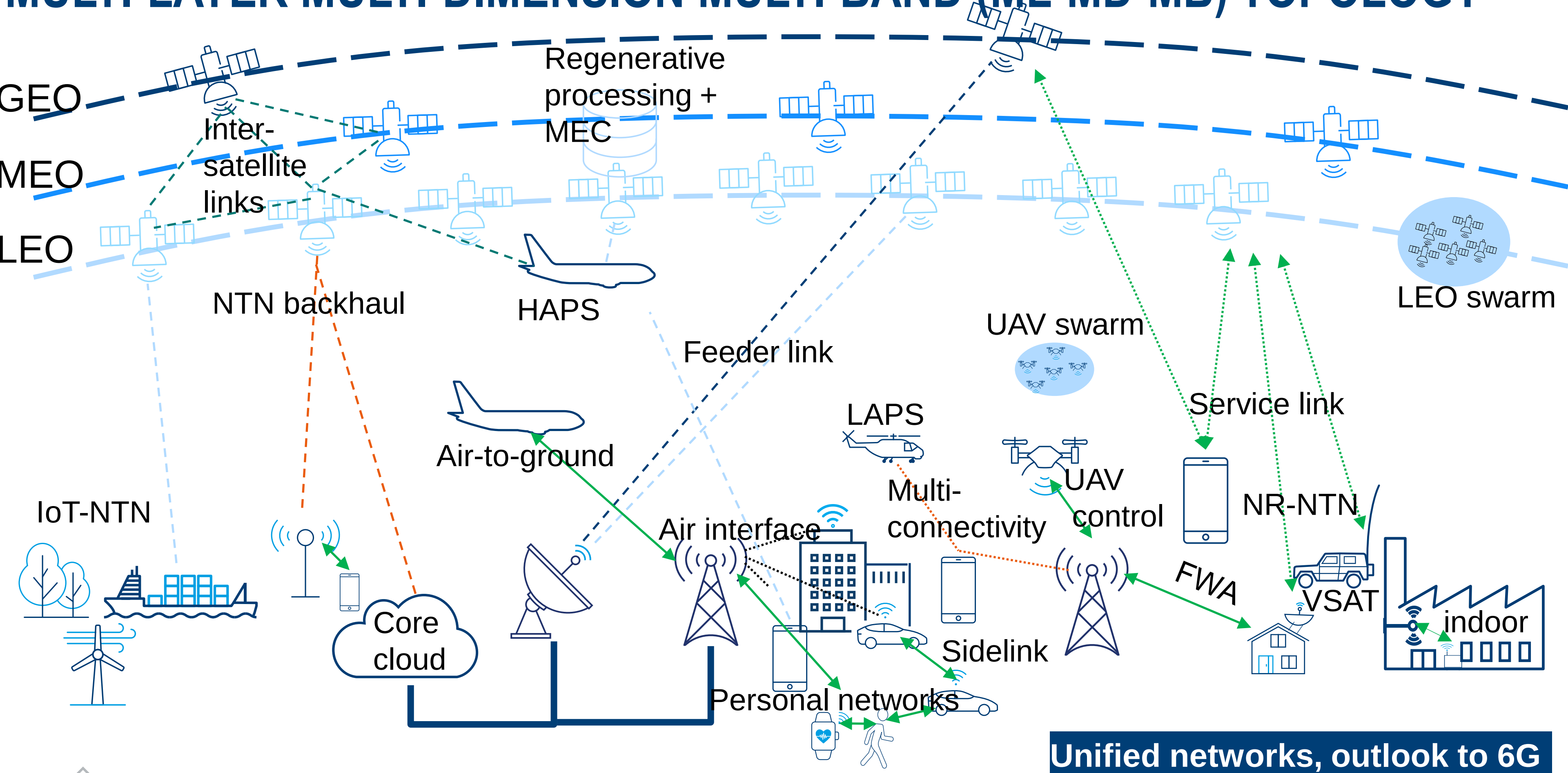


Reiner Stuhlfauth
Technology Manager Wireless

ROHDE&SCHWARZ

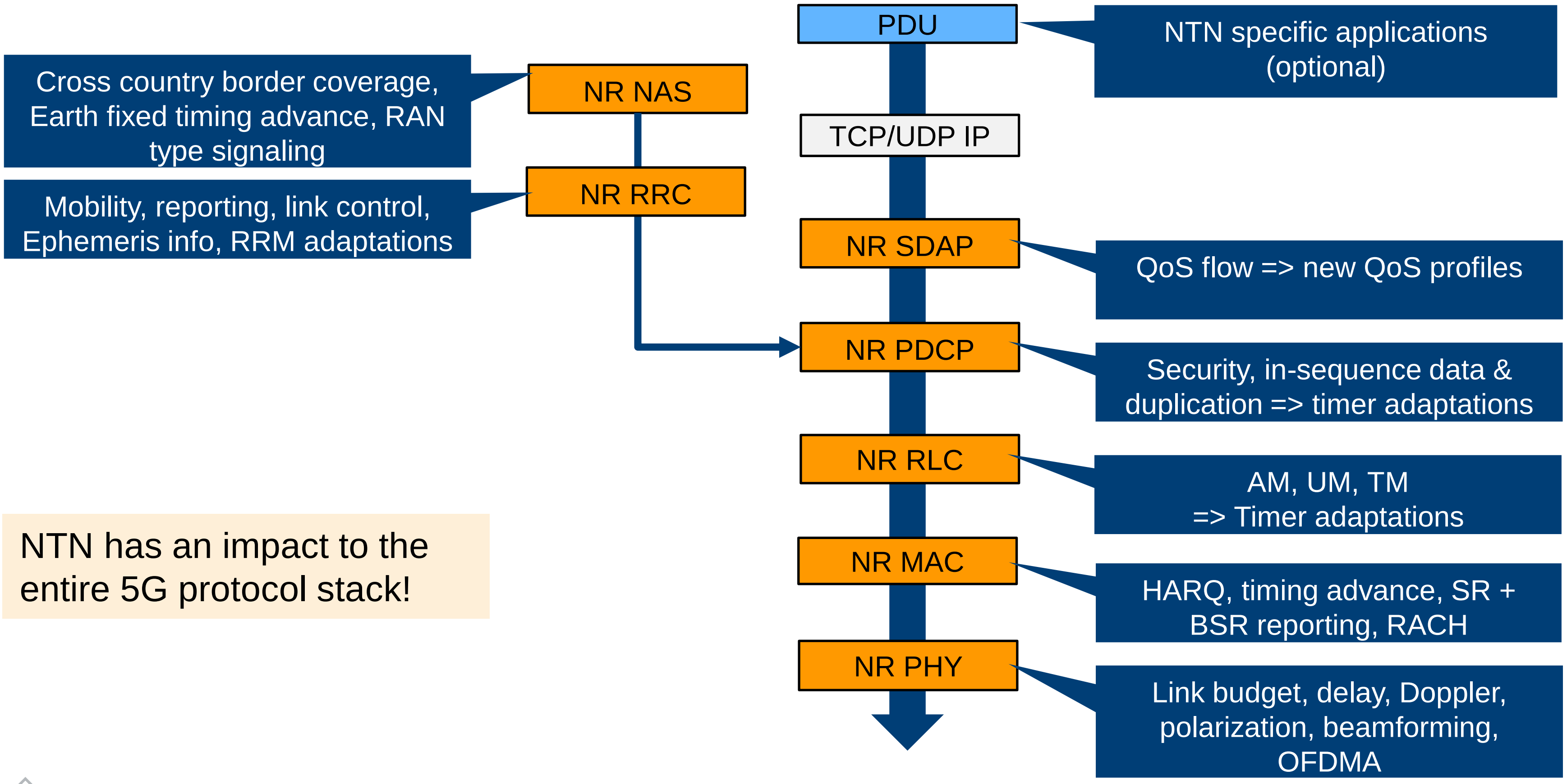
Make ideas real

MULTI-LAYER MULTI-DIMENSION MULTI-BAND (ML-MD-MB) TOPOLOGY



Unified networks, outlook to 6G

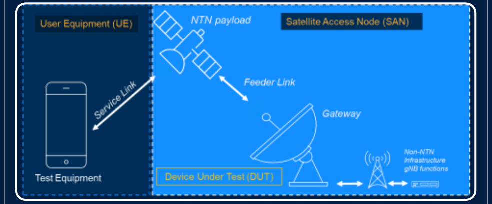
5G-NTN: PROTOCOL STACK

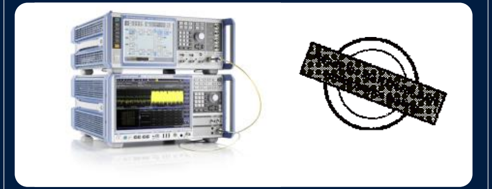


NTN has an impact to the entire 5G protocol stack!

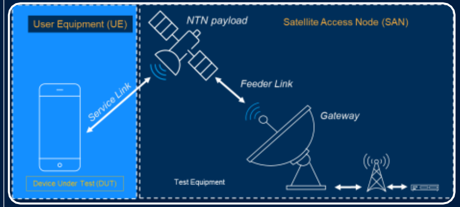
NTN test applications across the entire value chain.

Satellite Access Node (SAN) Testing	User Equipment (UE) Testing	End-to-End System Emulation	Field Testing





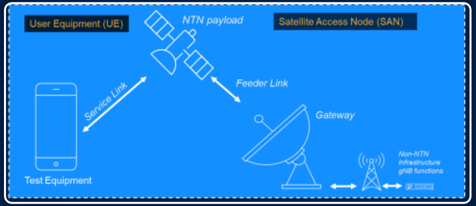
- R&D
- 3GPP Conformance
- Regulatory CE/FCC
- Production



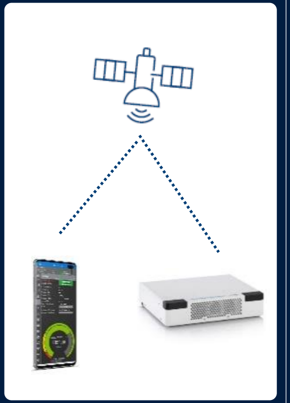
NB IOT-NTN R17

5G NTN-NR

- R&D
- 3GPP Conformance/Netop
- Regulatory CE/FCC
- Production



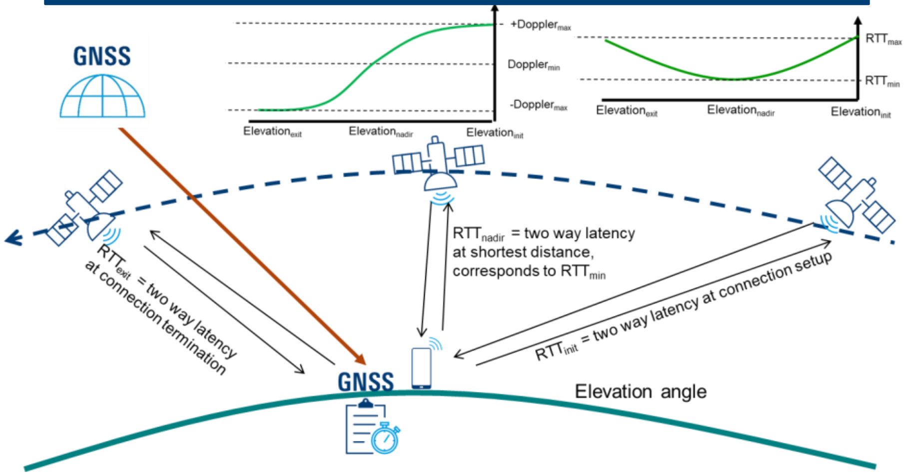
- R&D NTN E2E Demonstrator in S/L/Ka/Ku bands in GEO/LEO



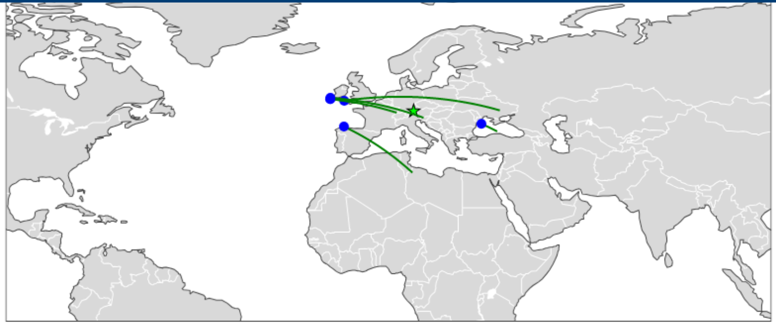
- NTN Field and network testing

NTN: ROUND-TRIP TIME (RTT) ASPECTS AND DOPPLER SHIFT

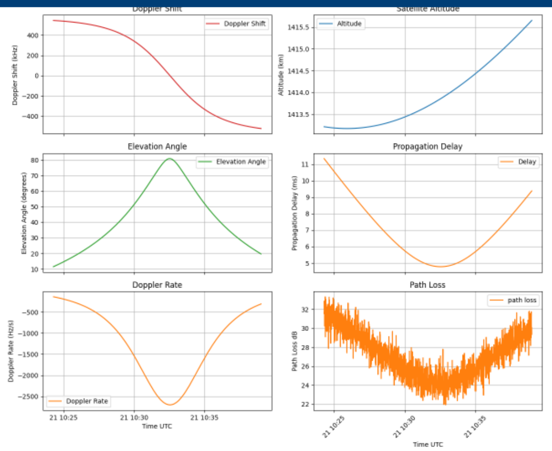
Theoretical background: NTN RF challenges



Visibility check of satellites: Set UE location + check sat visibility



Generate RF signal according to SAN fading profile

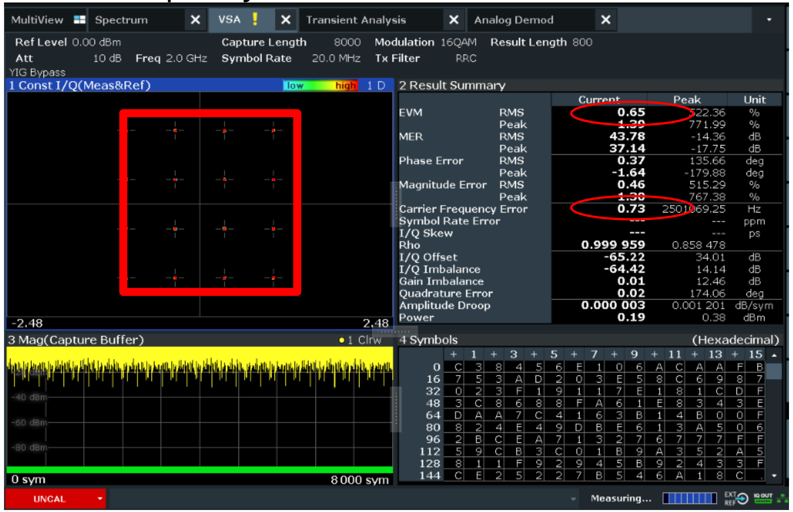


Satellite constellation emulation tool: Configure or load your sat constellation

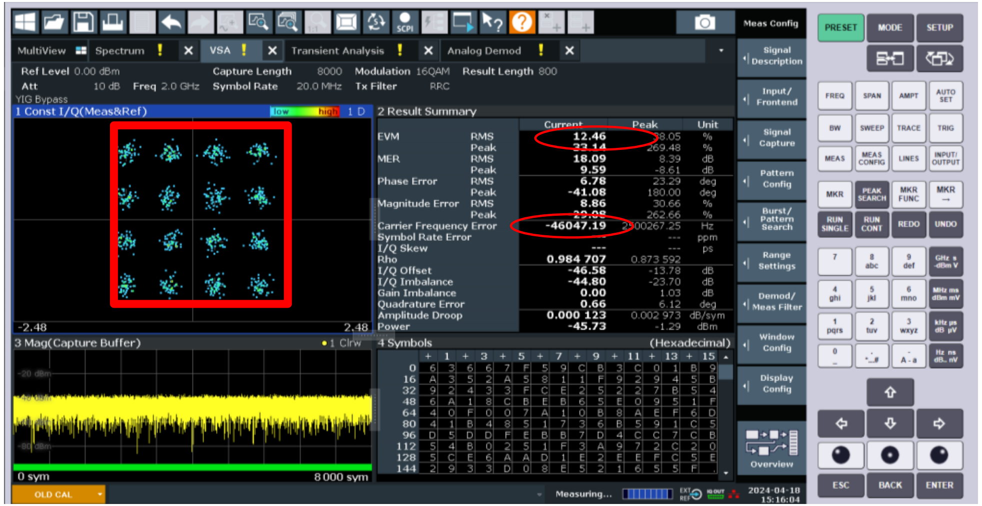
DOPPLER SHIFT APPLIED TO 20MHz - 16QAM SIGNAL

Setup: Mobile radio tester emulates SAN flight path with changing Doppler + fading.
=> Verify DL signal with spectrum analyzer
=> Objective: NR-NTN UE receiver performance test

Parameters without fading / Doppler
-Constellation Diagram (clean)
-EVM: 0.65%
-Carrier Frequency Error: 0.73 Hz



Parameters with fading / Doppler
-Constellation Diagram (noisy)
-EVM: 12.46%
-Carrier Frequency Error: 46 kHz



NTN: LINK BUDGET – UPLINK DIRECTION

Example: TS38.821 scenario SC29: FR1@2GHz, LEO = 1200km altitude. UE to sat @ 0.36MHz bandwidth

$$\mathrm{CNR}\ [\mathrm{dB}] = \mathrm{EIRP}\ [\mathrm{dBW}] + \frac{G}{T}\ [\mathrm{dB/K}] - k\ [\mathrm{dBW/K/Hz}] - PL_{FS}\ [\mathrm{dB}] - PL_{A}\ [\mathrm{dB}] - PL_{SM}\ [\mathrm{dB}] - PL_{SL}\ [dB] - PL_{AD}\ [\mathrm{dB}] - B\ [\mathrm{dBHZ}]$$

$$EIRP[dBm] = P_{TX}[dBm] - L_c[dB] + G_{TX}[dBi]$$

23dBm

$P_{TX}[dBm] = Transmit\ power$

$L_c[dB] = Cable\ loss$

$G_{TX}[dBi] = Transmit\ antenna\ gain$

$$G/T\ [\mathrm{dB}] = G_R\ [\mathrm{dBi}] - N_f\ [\mathrm{dB}] - 10\log_{10}\left(T_0\ [\mathrm{K}] + (T_a\ [\mathrm{K}] - T_0\ [\mathrm{K}])10^{-0.1 N_f\ [\mathrm{dB}]}\right)$$

-4.9 dB/K

$$k = Boltzmann's\ constant = -198.6\frac{dBm}{K \cdot Hz}$$

$$PL_{FS}[dB] = Free\ space\ path\ loss = 164.5\ dB$$

$$PL_A[dB] = Atmospheric\ path\ loss = 0.07\ dB$$

$$PL_{SM}[dB] = Shadowing\ margin = 3\ dB$$

$$PL_{SL}[dB] = Scintillation\ loss = 2.2\ dB$$

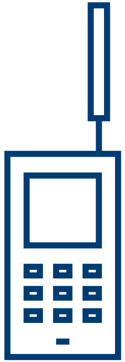
$$PL_{AD}[dB] = Additional\ loss = 0\ dB$$

$$BW[dB \cdot Hz] = Bandwidth\ influence = 55.6dB$$

$$CNR = 23[dBm] - 4.9\left[\frac{dB}{K}\right] + 198.6\left[\frac{dBm}{K \cdot Hz}\right] - 164.5[dB] - 0.07[dB] - 3.0[dB] - 2.2[dB] - 0.0[dB] - 55.6[dB \cdot Hz] = \boxed{-8.6\ dB}$$

5G NTN LINK BUDGET – UL HIGH POWER UE & REALITY

If we want to enhance NTN services, we need to enhance the Uplink!



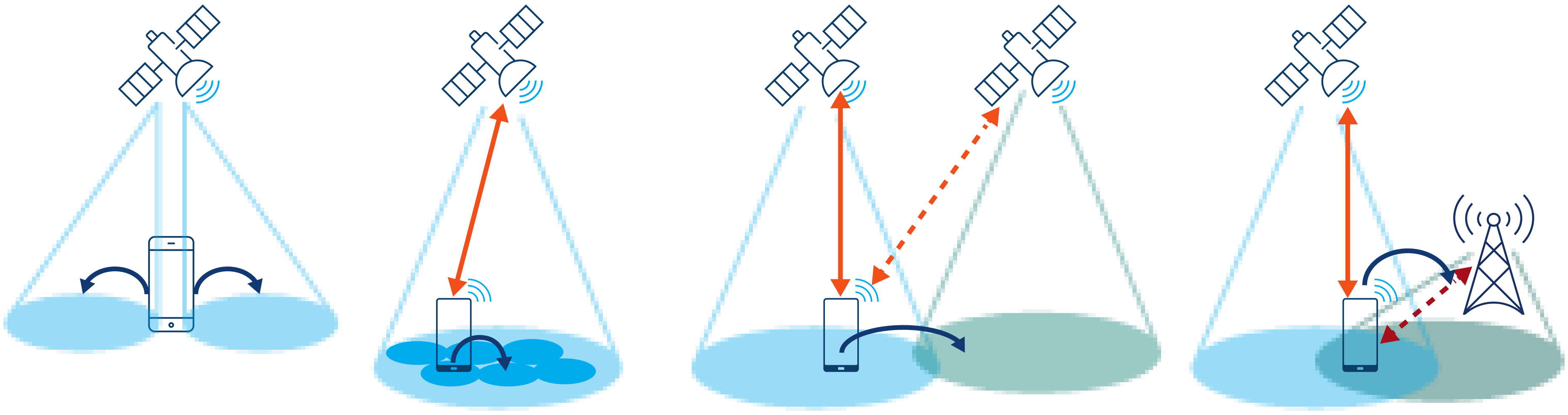
Power class	Applicable to	#TX band / CA	Pout/Tolerance/ ACLR
1	FDD/TDD – no CA	1	31/+2/-3/37
1.5	TDD / CA	2/4/2/3	29/+2/-3/31
2	FDD/TDD/CA	1/2/2/3	26/+2/-3/31
3	FDD/TDD/CA	1/2 (2NRU) / 2	23/+2/-3/ 30 (2 NRU)
5	NRU / no CA	1 / na	20 /+2/-3/27
Increment power	Inter-band CA	2/3	+1.8 dBm power

Terrestrial UE, max power TX test:
~20.xxx dBm

NTN prototype, max power TX test:
~25 dBm

Reality in T&M: There seems to be a „flexible“ understanding of tolerance values between TN and NTN UE types

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

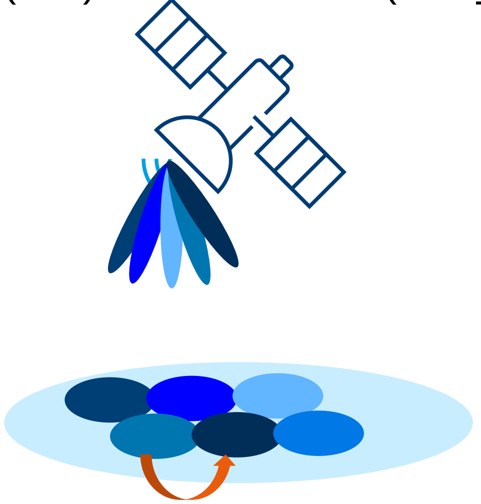
NR-NTN connection

Target or simultaneous dual connectivity NR-NTN connection

Target or simultaneous dual connectivity terrestrial connection

5G NTN MOBILITY SCENARIOS – NTN SIGNALING EXAMPLE

Assumption: A satellite uses multiple beams in parallel. Each beam is identified via physical cell ID (PCI) and SSB index (SSB_ID)

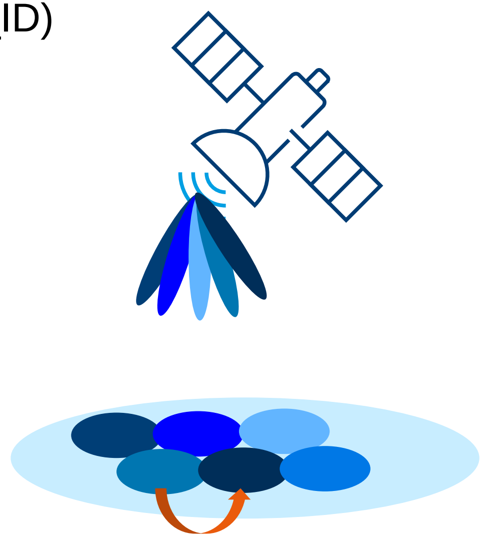


Scenario 1:

Each beam is different SSB_ID

All beams have same PCI

=> Mobility of UE is via beam change procedure



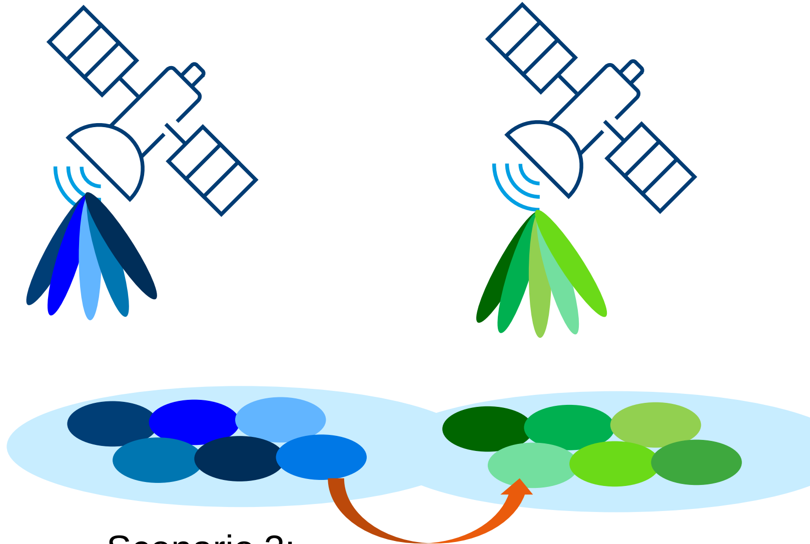
Scenario 2:

Each beam is different SSB_ID

Each beam is different PCI

⇒ Inter-cell change handover

⇒ Sat sends SIB19 neigbour info with frequency & PCI



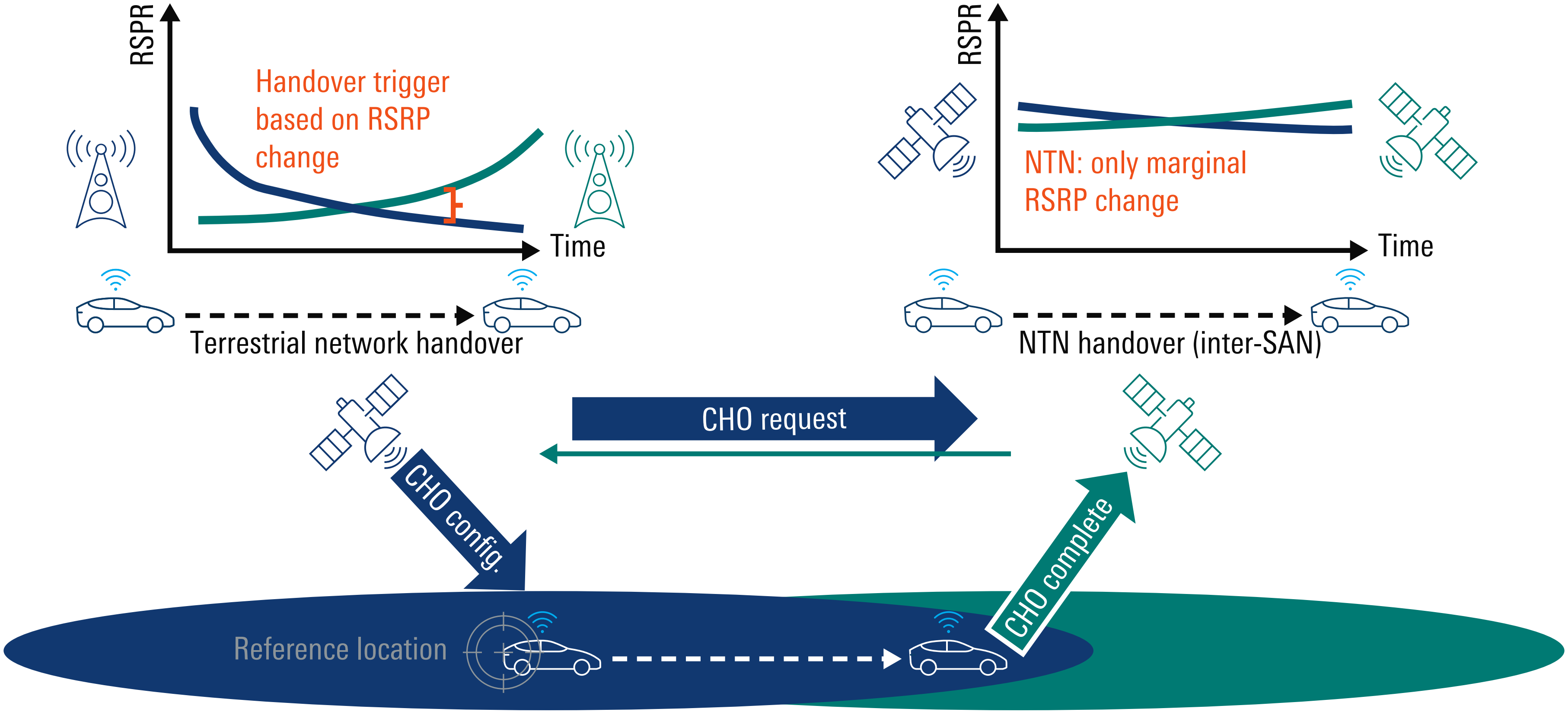
Scenario 3:

Handover to another satellite

⇒ Inter-cell change handover

⇒ Sat sends SIB19 neigbour info with frequency & PCI & satellite ephemeris info (NTN_config)

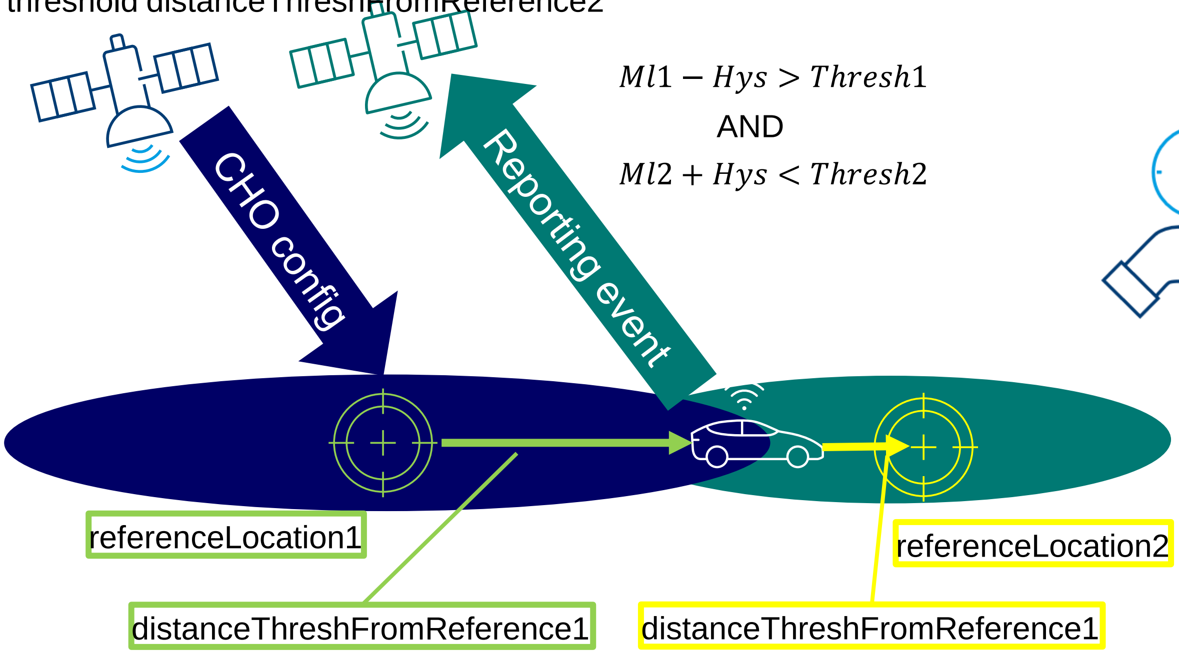
5G NTN HANDOVER EXAMPLE (CHO)



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

5G NTN CONDITIONAL HANDOVER

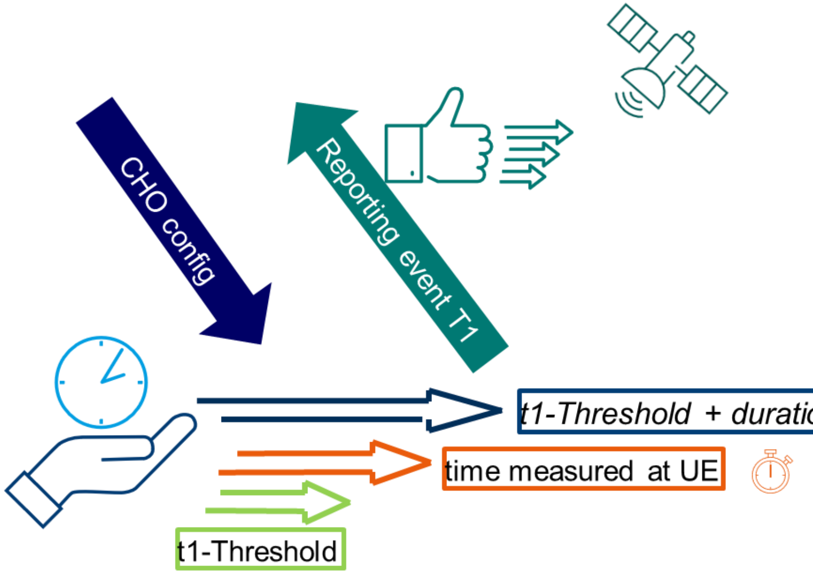
CondEvent D1: Distance between UE and a reference location referenceLocation1 becomes larger than configured threshold distanceThreshFromReference1 and distance between UE and a reference location referenceLocation2 of conditional reconfiguration candidate becomes shorter than configured threshold distanceThreshFromReference2



$$Ml1 - Hys > Thresh1$$

AND

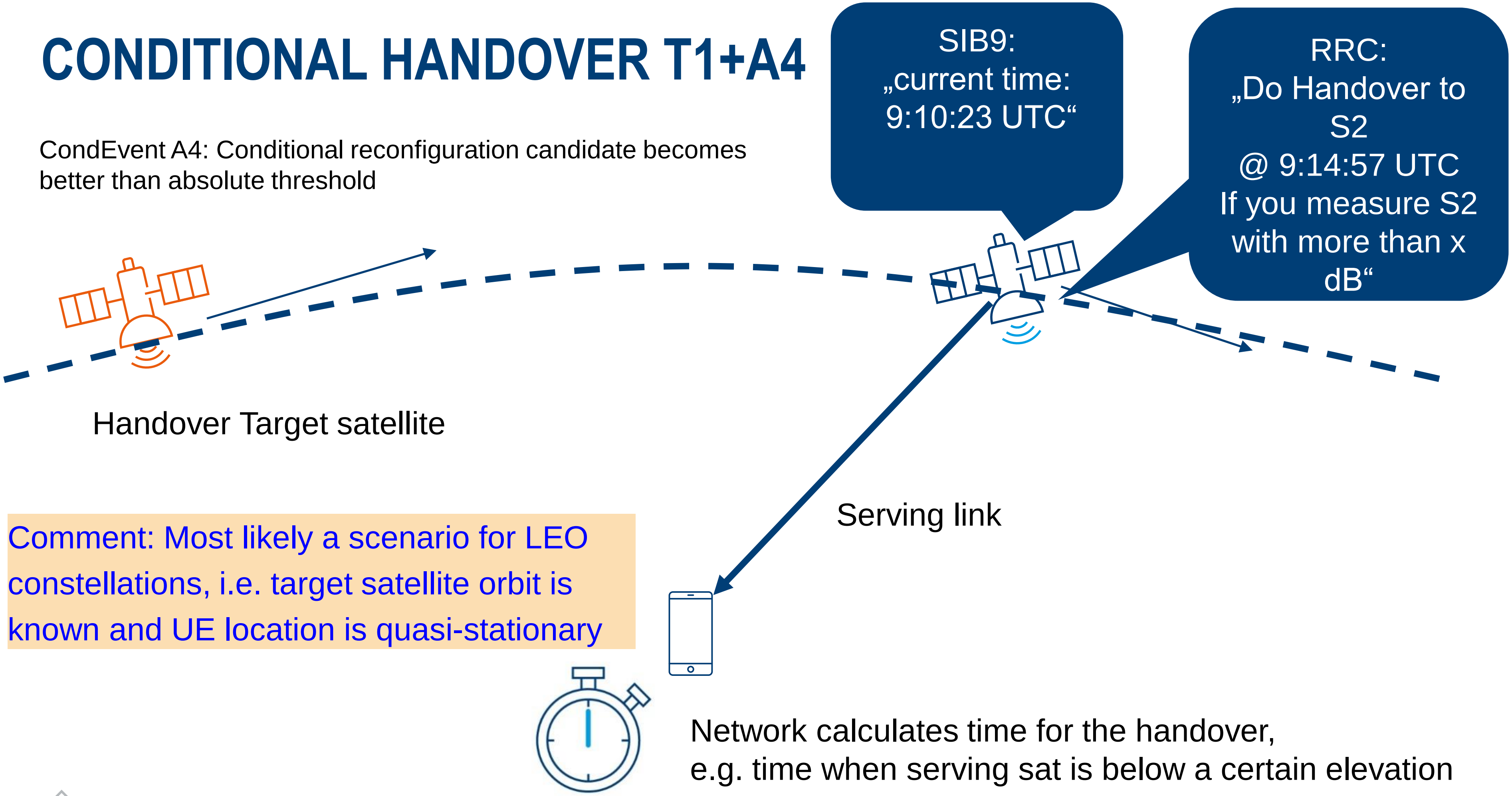
$$Ml2 + Hys < Thresh2$$



CondEvent T1: Time measured at UE becomes more than configured threshold t1-Threshold but is less than t1-Threshold + duration

CONDITIONAL HANDOVER T1+A4

CondEvent A4: Conditional reconfiguration candidate becomes better than absolute threshold



Comment: Most likely a scenario for LEO constellations, i.e. target satellite orbit is known and UE location is quasi-stationary

Network calculates time for the handover,
e.g. time when serving sat is below a certain elevation

CONDITIONAL HANDOVER D1+A4

For earth fixed beams
Each cell has a center point and a radius
UE must be moving to trigger condition

RRC: If you are 100m closer to the cell center point of S2 than center point S1, and S2 has a minimum receiver power of x dB, do handover

SIB19:
Cell center
48N, 12E

SIB19:
Cell center
48N, 11E

Comment: Most likely a scenario for GEO/LEO satellites with Eart fixed beams, i.e. handover is needed because of UE mobility, similar to terrestrial handover

Onboard Fading & Channel Emulation

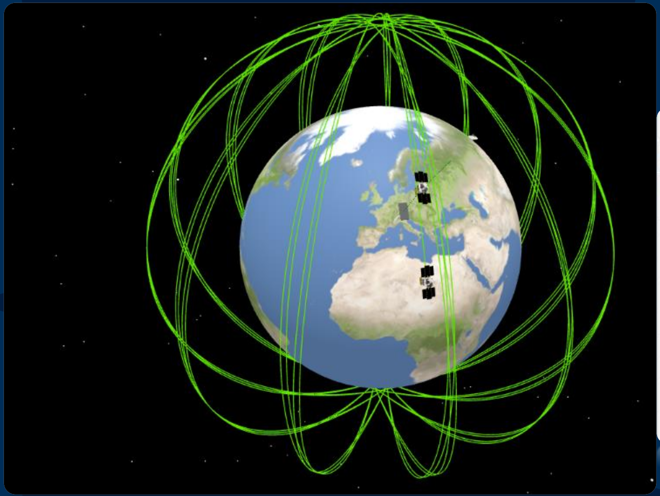
Protocol Testing

RF Measurements

Application Testing

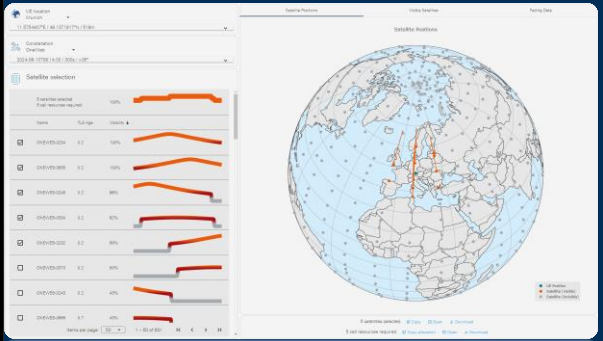
Mobility Testing

User defined bands

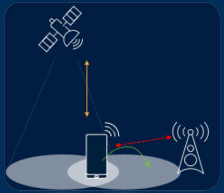


Satellite Constellation Tool

Load, configure, visualize and deploy satellites.



Mobility/Handover



NTN ↔TN handover

Cell selection

Inter beam handover

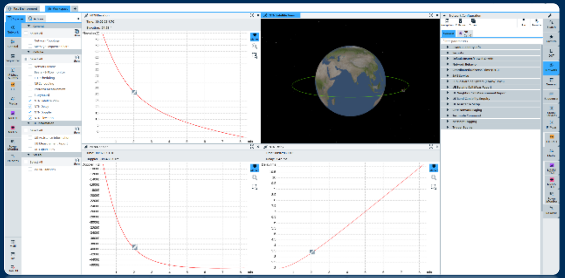
Inter-satellite handover

Auto-Handover

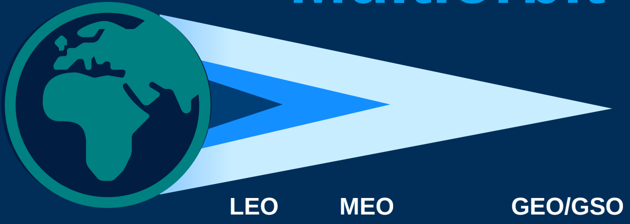
Long time tesing, simulator selects automatic handover satellite candidates

All-in-one WebGUI

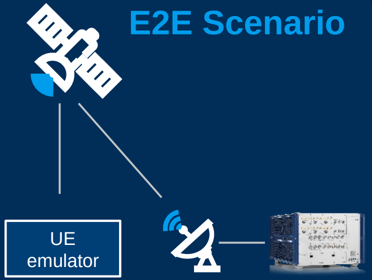
Experience seamless control and visualization



Multiorbit



E2E Scenario



Multiband

S-Band

L-Band

Ku-Band

Ka-Band

5G NTN RF CHALLENGES DUE TO VARIOUS BANDS & UE TYPES

High throughput
High capacity
Large Antenna (>= 8x8 Array)
directive
Complex and higher price

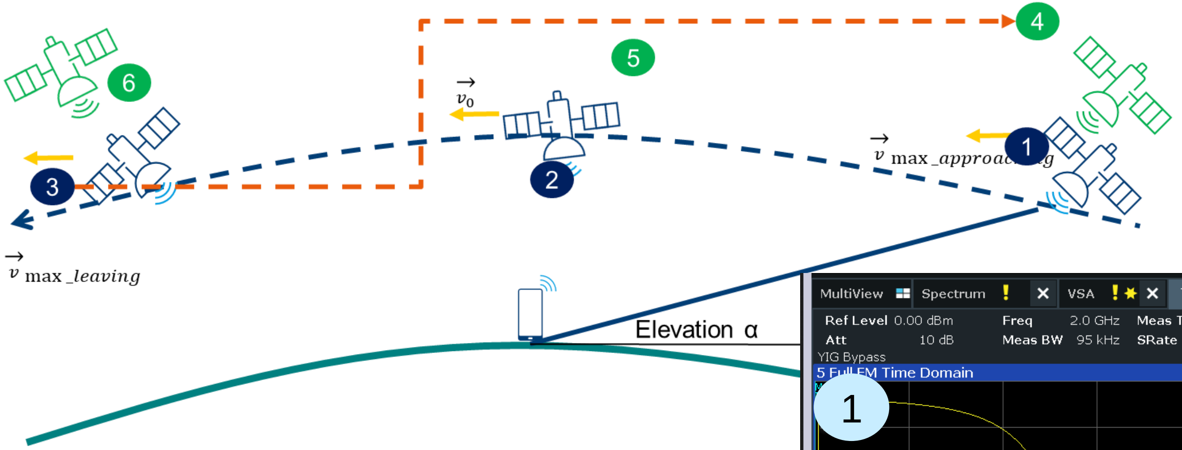
Ka-Band
N510, N511, N512

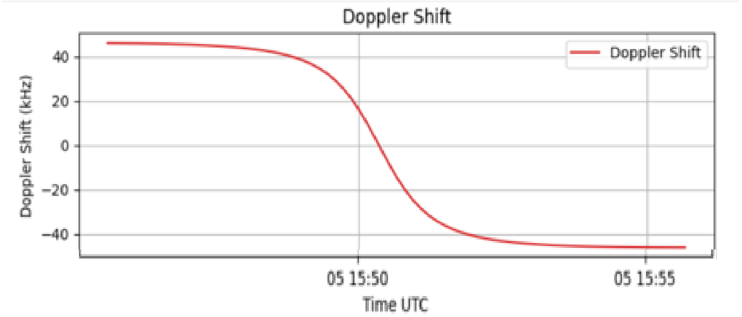
Ku-Band
~10 – 15GHz

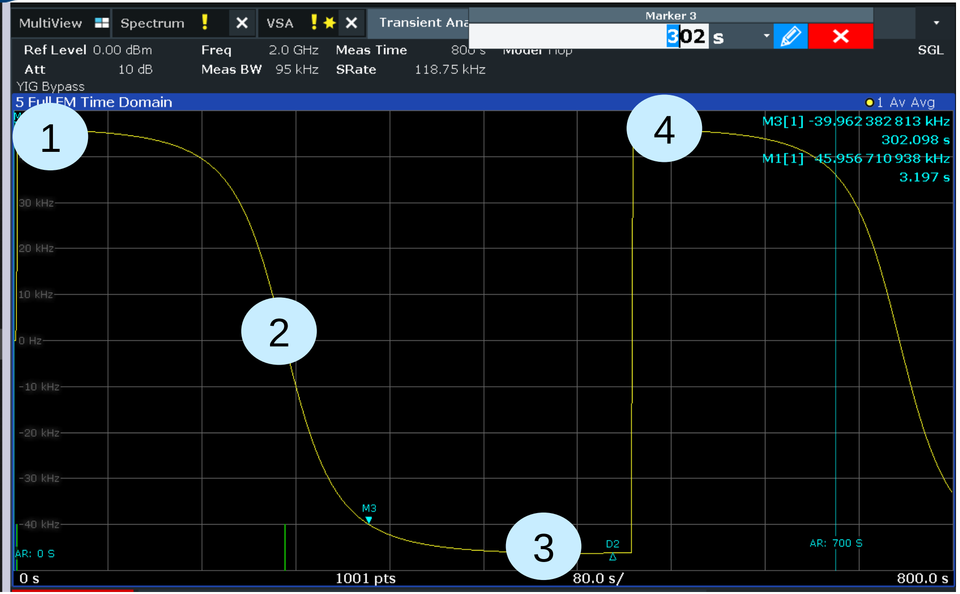
L- and S-Band
N255, N256

- Low-medium throughput
- Small antenna, omni
- Inexpensive
- „unmodified“ phone HW
- emergency call & IoT

DOPPLER SHIFT SCENARIO DURING HANDOVER

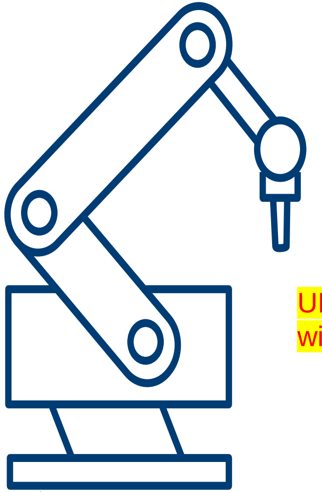


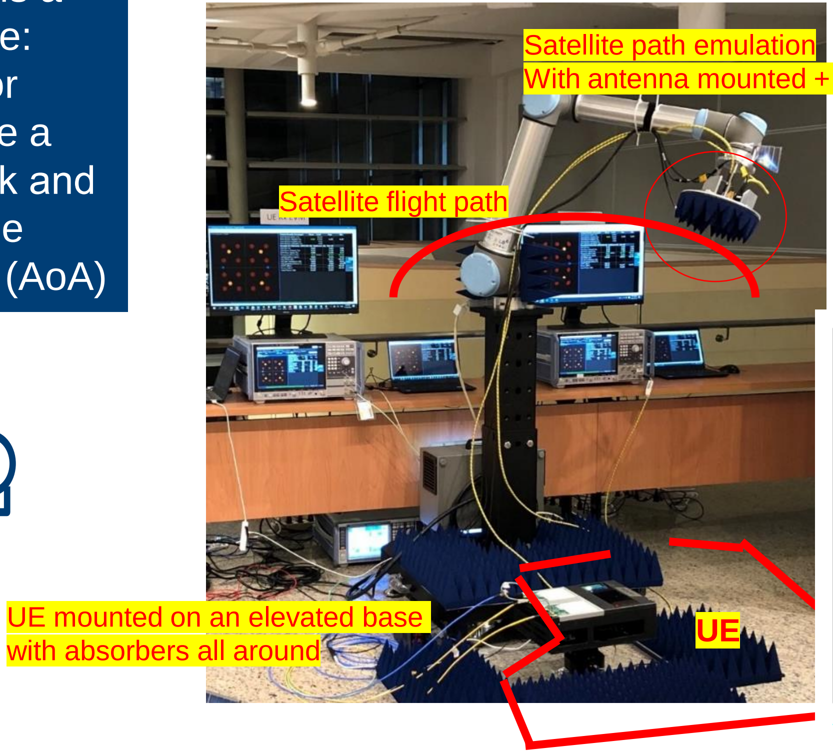




NTN TESTING OUTLOOK: OTA TEST SETUP IDEA

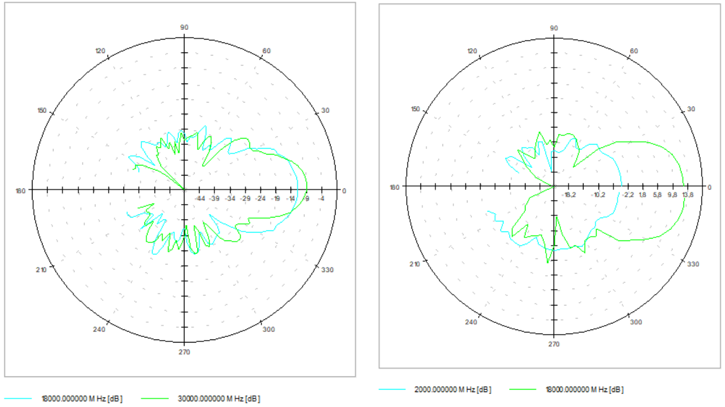
NTN UE testing is a paradigm change: System simulator needs to emulate a „moving“ network and varying + multiple angle of arrivals (AoA)



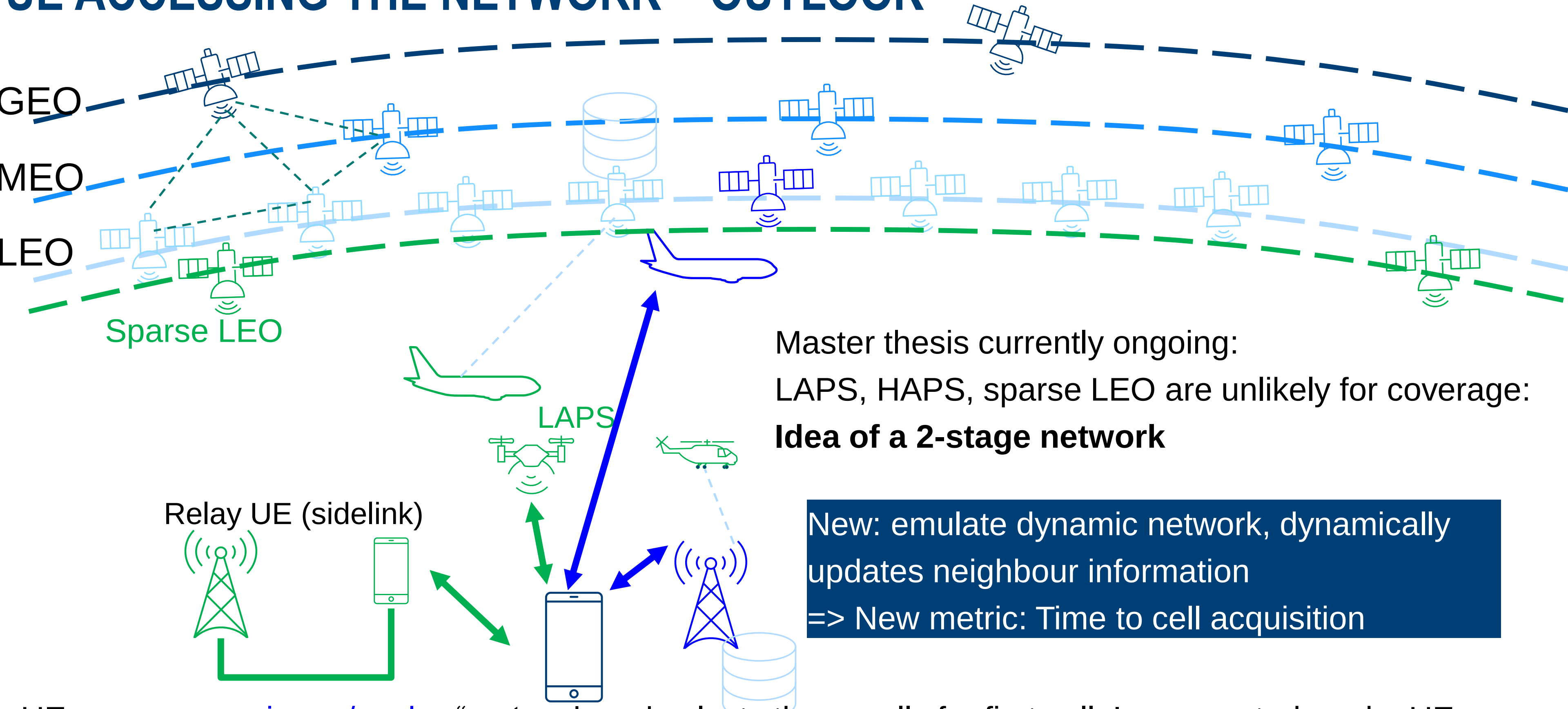


0.65 GHz to 50 GHz

TC-TA50CPR



UE ACCESSING THE NETWORK – OUTLOOK



Master thesis currently ongoing:

LAPS, HAPS, sparse LEO are unlikely for coverage:

Idea of a 2-stage network

New: emulate dynamic network, dynamically updates neighbour information

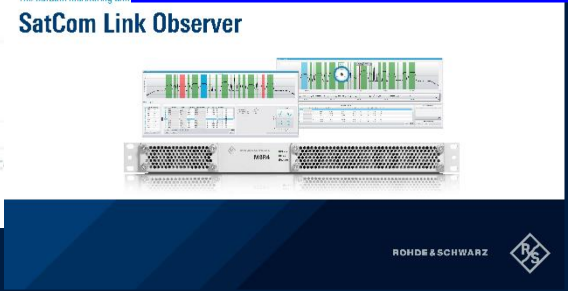
=> New metric: Time to cell acquisition

UE camps on „primary/anchor“ network and selects those cells for first call. In connected mode, UE may handover to „secondary/dynamic“ network

Example: Coverage measurement of NTN LTE signal

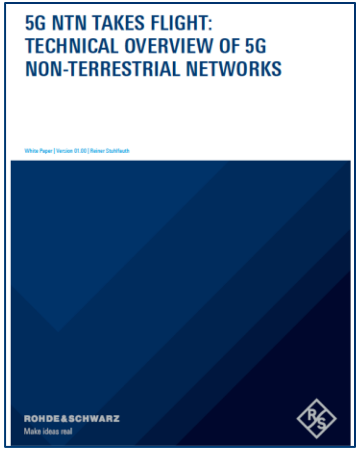
► Scanner measurements of a LEO satellite network transmitting a standard LTE signal

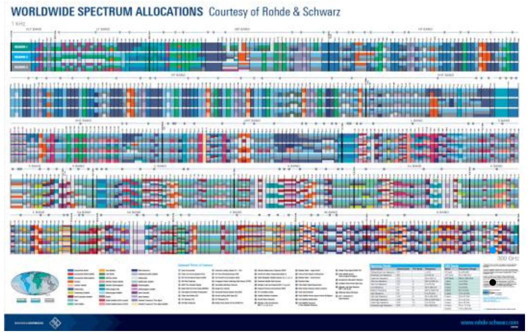
NTN = combination of satellite link monitoring & mobile network testing



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)

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

THANK YOU

Future networks: Fiber to the space (FTTS)