Measurement Methodologies for Evaluating Service Quality in Next-Generation Satellite Connectivity

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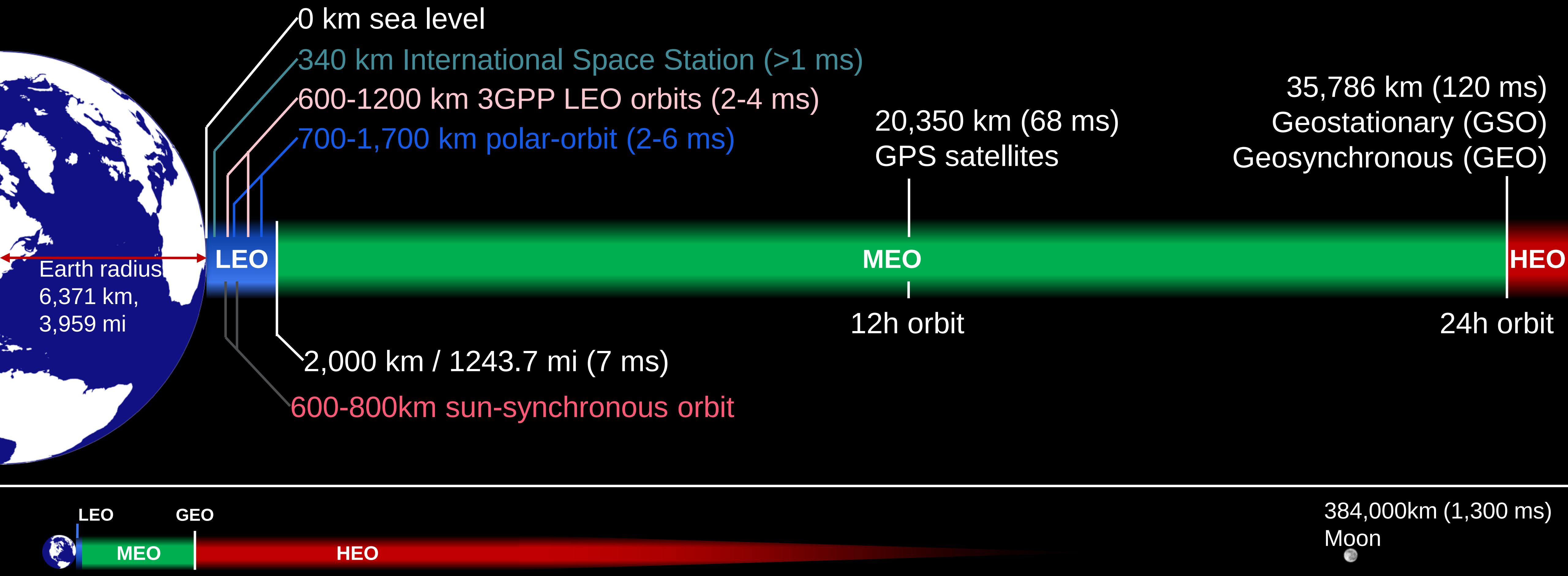
Topics

- Introduction of NTN and its advantages
- Challenges Facing NTN networks
- Unique Challenges of NTN field testing
- Key NTN Measurement Use cases
- Measurements for NTN

Introduction of NTN and its advantages

Satellite Orbits

Orbital altitudes and signal delays

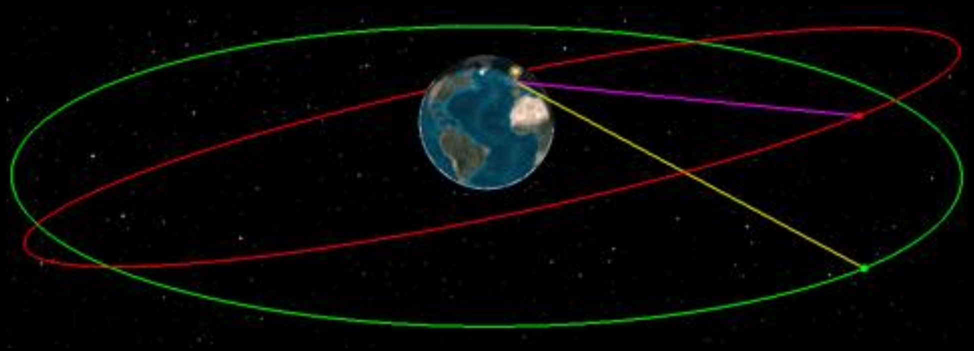


Low Earth Orbit (LEO) and GEO Stationary Orbits (GSO)

The Differences And Characteristics

- GEO stationary satellites with orbital velocity to match Earth daily rotation
- 35786km orbital altitude
- **Large delay** (~550 ms), **Large Path Loss**
- **GSO with inclination** have delay and Doppler variation (~ 1-2 kHz)

- LEO satellites with low altitude orbit
- Velocity causes big Doppler error in frequency (L and S bands ~ +/- 50 kHz)
- 300 ... 2000 km orbital altitude
- **Fast delay variation**
- **Large Doppler** of up to 50 kHz per link

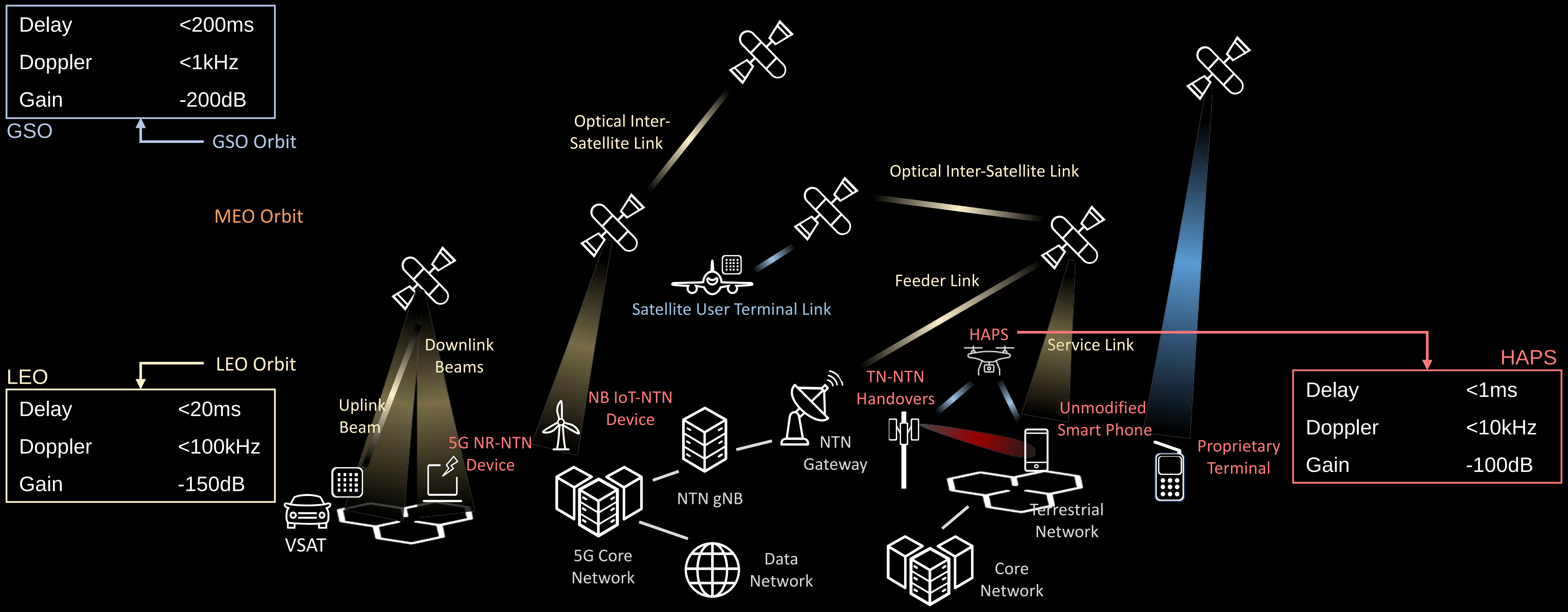


GEO

LEO

5G NTN Network Architecture

Moving Towards Layered 3D Networks by Adding Satellite and HAPS



Key Advantages of NTN networks

- **Extended coverage:** NTNs extend connectivity to remote areas, including rural locations, oceans, and flight paths, which lack traditional cellular service.
- **Improved reliability and resilience:** By providing an alternative to terrestrial networks, NTNs offer crucial service continuity during disasters when ground infrastructure is damaged. They also add redundancy to the overall network architecture.
- **Support for various services:** NTNs can support SMS, voice, broadband data, and emergency calls, making them versatile for a wide range of needs, from basic connectivity to complex IoT applications.
- **Cost-effectiveness for specific use cases:** NTNs can be a low-cost solution for wide-coverage scenarios and can reduce infrastructure costs for some service providers, especially for large-scale IoT deployments.
- **Enabling new use cases:** They enable new applications in industries like aviation, maritime, and logistics by providing uninterrupted tracking and communication for assets, vehicles, and aircraft.
- **Native 5G/6G integration:** Modern NTNs are designed to be compatible with 3GPP standards, allowing for seamless integration with existing and future mobile networks, and support mobility between satellite and ground cells.
- **Scalability:** NTNs can be scaled to serve a vast number of devices, making them ideal for the growing demands of the Internet of Things (IoT).

Specification – 3GPP

Spec No	Details
TR 38.811	Study on New Radio (NR) to support non-terrestrial networks", REL-15 SI FS_NR_nonterr_nw, RAN
TR 22.822	Study on using satellite access in 5G", REL-16 SI FS_5GSAT, SA1
TR 38.821	Study on solutions for NR to support non-terrestrial networks (NTN)", REL-16 SI FS_NR_NTN_solutions, RAN3
TR 23.737	Study on architecture aspects for using satellite access in 5G", SI FS_5GSAT_ARCH, SA2; note: SI started in REL-16 but ended in REL-17
TR 38.863	Non-terrestrial networks (NTN) related RF and co-existence aspects", REL-17 WI NR_NTN_solutions, RAN4
TS 38.101-5	NR; User Equipment (UE) radio transmission and reception; Part 5: Satellite access Radio Frequency (RF) and performance requirements", REL-17 WI NR_NTN_solutions, RAN4
TS 38.108	NR; Satellite Access Node radio transmission and reception", REL-17 WI NR_NTN_solutions, RAN4
TS 38.181	NR; Satellite Access Node conformance testing", REL-17 WI NR_NTN_solutions, RAN4
TS 38.521-5	NR; User Equipment (UE) conformance specification; Radio transmission and reception; Part 5: Satellite access Radio Frequency (RF) and performance", REL-17 WI NR_NTN_solutions_plus_CT-UEConTest, RAN5
TR 38.882	Study on requirements and use cases for network verified UE location for Non-Terrestrial-Networks (NTN) in NR", REL-18 SI FS_NR_NTN_netw_verif_UE_loc, RAN
TR 37.911	Study on self-evaluation towards the IMT-2020 submission of the 3GPP Satellite Radio Interface Technology", REL-18 SI FS_IMT2020_SAT_eval, SA1
TR 22.926	Guidelines for extraterritorial 5G Systems (5GS)" REL-18 SI FS_5GET, SA1
TS 22.261	Service requirements for the 5G system", stage 1 spec from SA1
TS 23.501	System architecture for the 5G System (5GS)", stage 2 spec from SA2, esp. clauses 5.4.10 and 5.4.11
TS 38.300	NR; NR and NG-RAN Overall description; Stage-2", RAN2, esp. clause 16.14
TS 22.261	Service requirements for the 5G system", stage 1 spec from SA1
TS 23.501	System architecture for the 5G System (5GS)", stage 2 spec from SA2, esp. clauses 5.4.10 and 5.4.11
TS 38.300	NR; NR and NG-RAN Overall description; Stage-2", RAN2, esp. clause 16.14

Challenges for NTN networks

Challenges facing NTN

Space Environment

- Equipment is inaccessible once deployed
- Operates in harsh conditions: extreme temperatures & radiation
- Requires consistent power generation & storage

Size, Weight, Power & Cost (SWaP-C)

- Limits on high-frequency RF & computing resources
- Transition from GEO 20-ton satellites to compact LEO & HAPS platforms

Security

- Hardware vulnerable over unfriendly territories
- Requires cyber protections & novel operations

Connecting in Constant Motion

- Satellites, HAPS & even RAN components in motion
- Impacts signal quality, handovers & connection setup

Choice of Payload

- Transparent vs. regenerative payloads affect network design
- Dynamic timing relationships → QoS challenges & dropped connections

Latency

- Ground-to-satellite delay prevents **URLLC use cases** (e.g., telesurgery)

Unique Challenges of NTN testing

NTN Testing - Challenges

Timing, Delay & Doppler

- Vast distances → long signal delays
- Fast-moving LEO satellites → significant Doppler shifts
- Exceeds typical Timing Advance capabilities of standard UEs

Link Budget & Random Access

- Large, variable path loss impacts reliability
- Issues with PRACH retransmissions & RAR delays
- HARQ
- TA

Complex Mobility Scenarios

- Intra-satellite (inter-beam) & inter-satellite handovers
- Handover between NTN and terrestrial networks

Interference

- Risk of interference with terrestrial network bands
- Requires detailed analysis for throughput & performance impact

Core

- Unified 5GC with slice-based selection (S-NSSAI).
- Routing policies sensitive to country-specific regulations & cross-border beams.
- AI Native validation

Key NTN Measurement Use cases

Satellite Lab & Field Use Cases

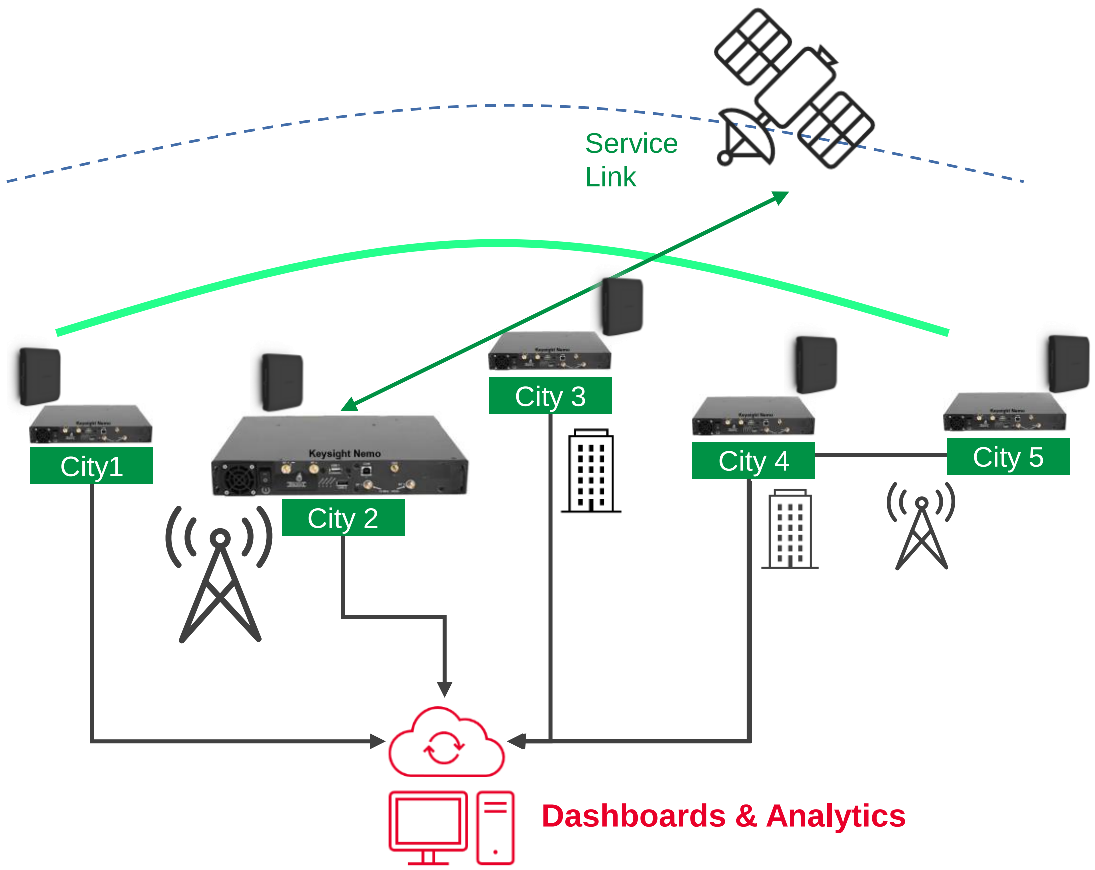
- Satellite Coverage audit & Usable signals
- Performance & QoE testing – SMS (currently tested), Future tests- Data, Voice, Video
- Home Operator – NTN impact on Terrestrial
- Competitive Operator – Interference Claims
- UE and Chipset readiness
- Satellite DTC (Direct to Cell) Schedule Validation– Planned vs Actual schedules

Field Measurements for NTN

High Level NTN measurement Architecture

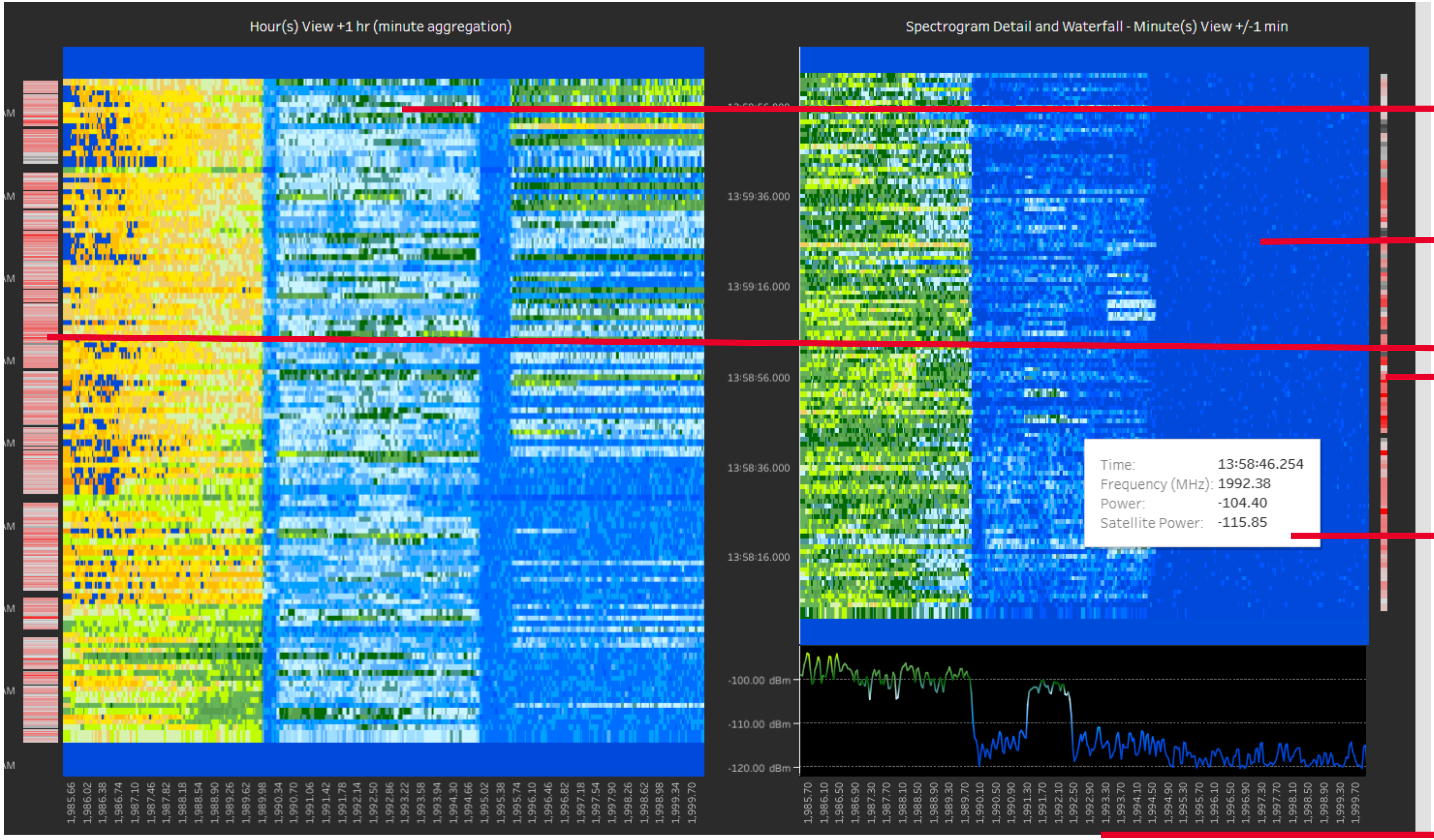
LEO and GEOs

- The NTN measurement architecture provides dashboards and drill-down analysis for various teams to understand the coverage, capacity, interference, and QoE
  - **Post processing tool** with dynamic dashboards for remote monitoring and analytics
  - **Measurement Probes**, IP65-protected autonomous field measurement units for call analysis
  - Field measurement solution with RF scanners



Executive Summary NTN Dashboard

Indication of Satellite Passes and Impact on Satellite Frequency



Hourly view of data

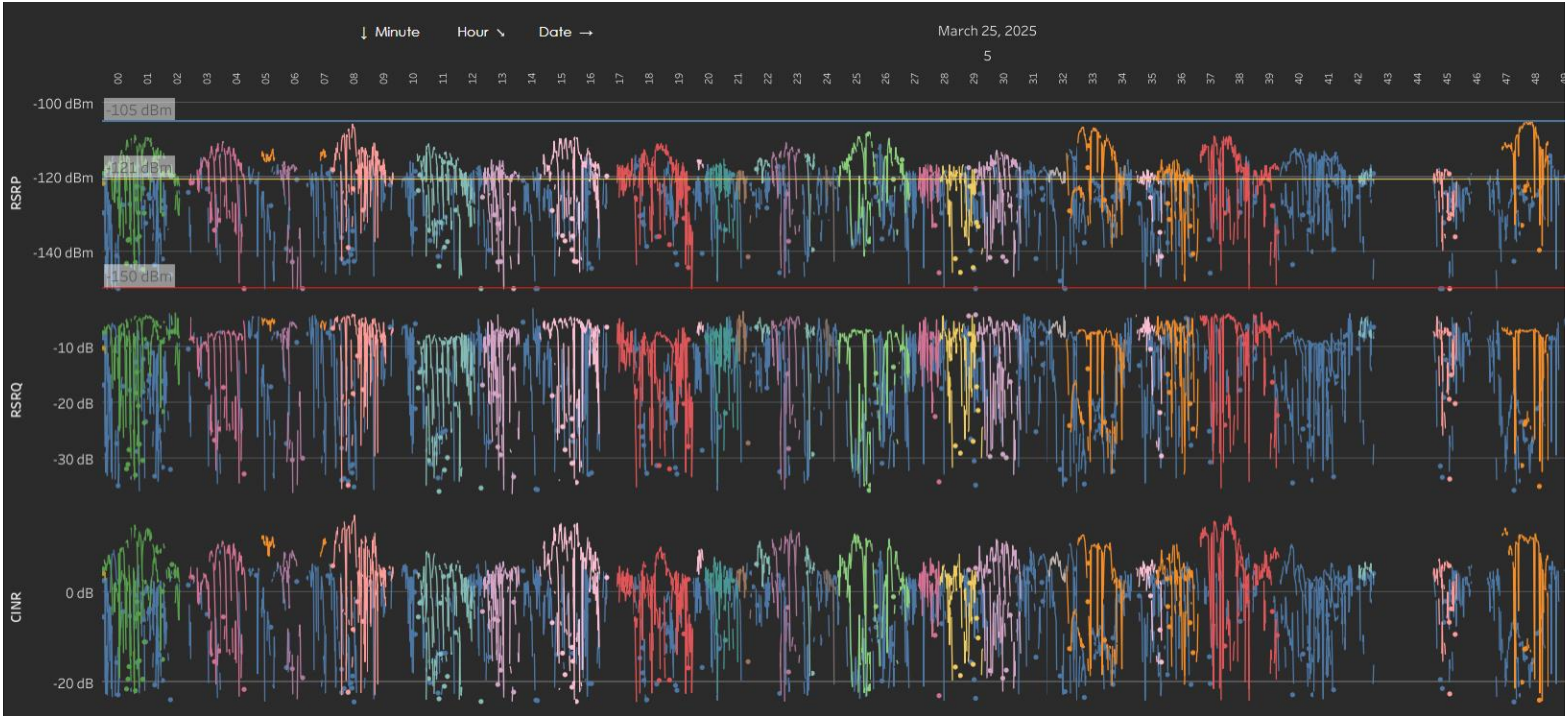
Minute level view granularity

Satellite markers based on UE attach

Rx level from scanner at -104 dB for 1992.38 MHz

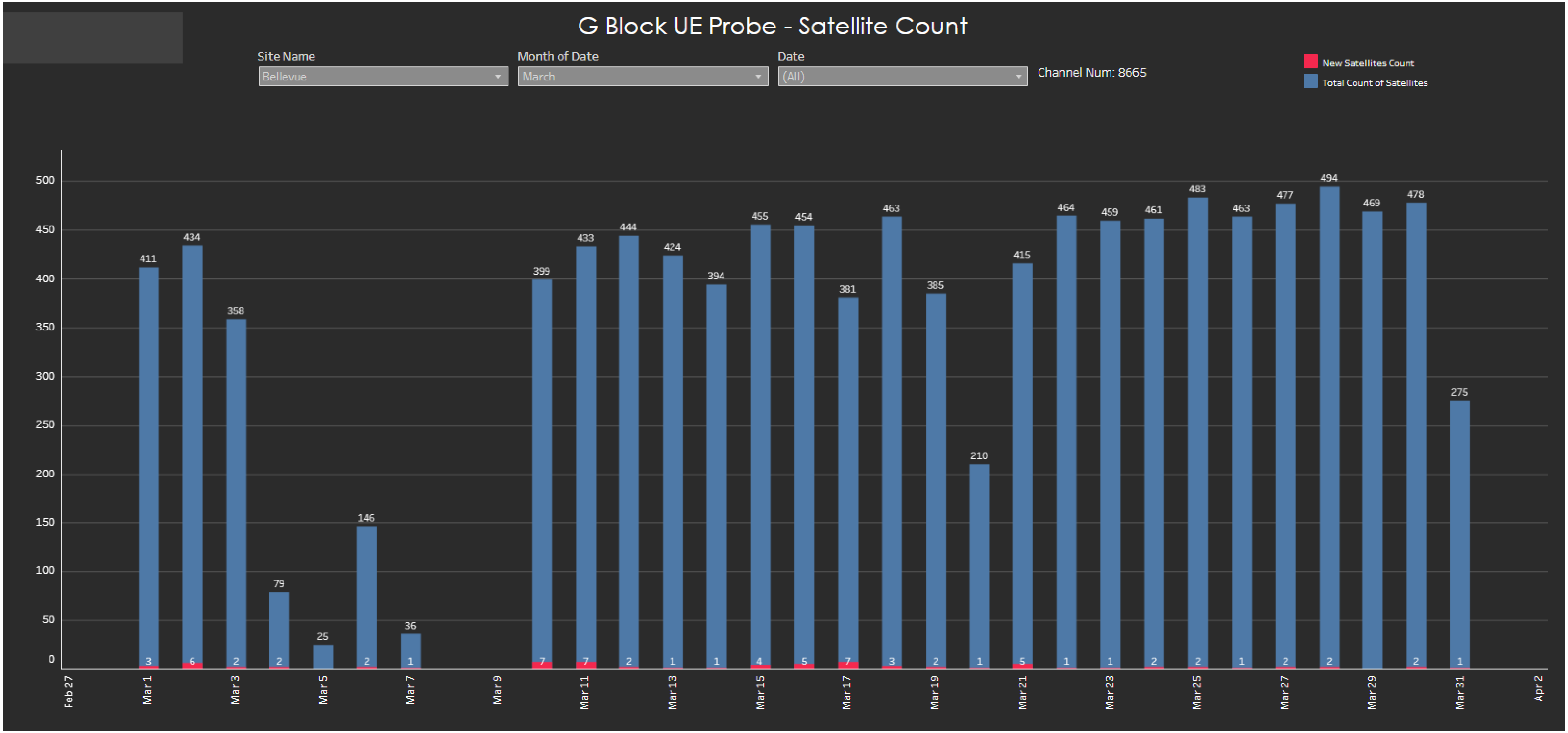
Spectrum sweep of 1992.5 MHz with 15MHz bandwidth configured

Satellite RF Coverage

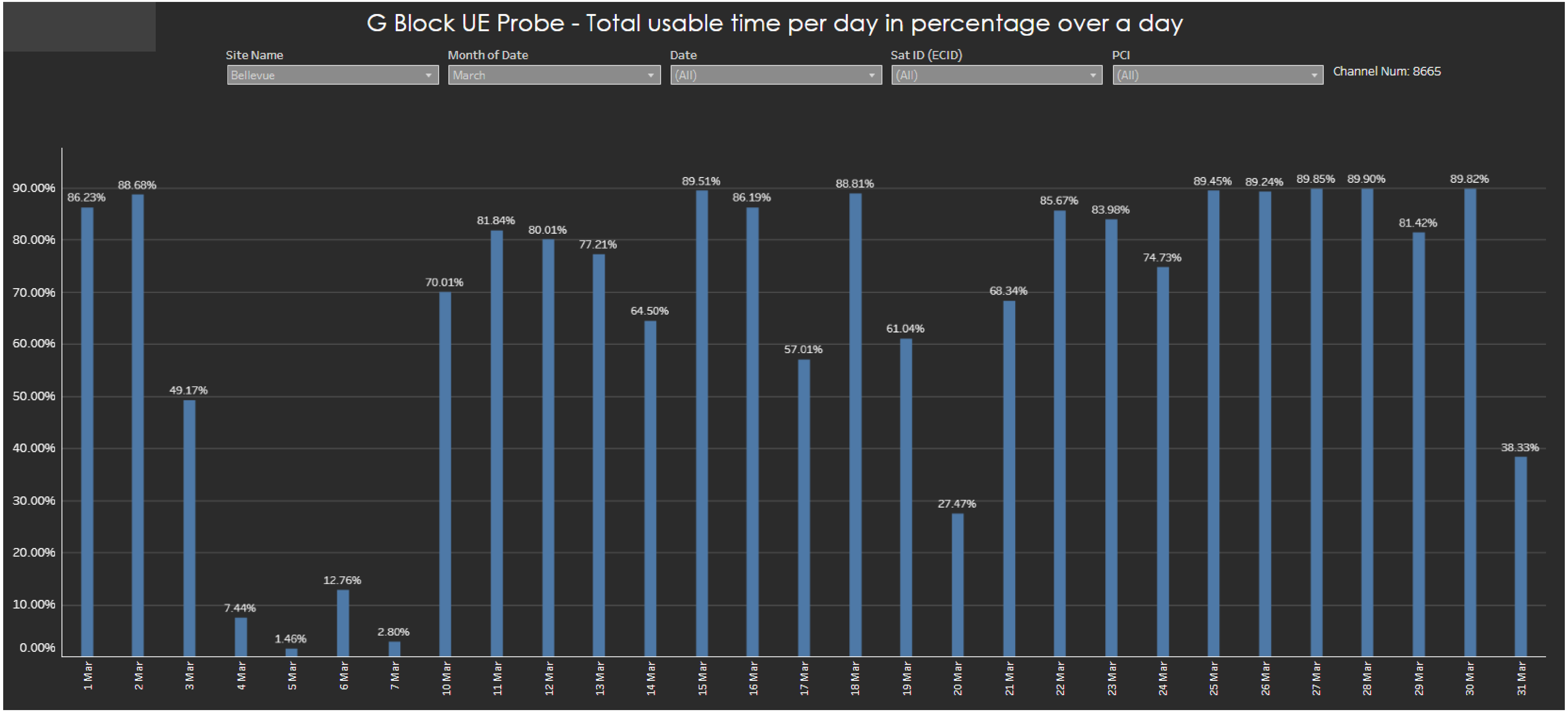


Interference of Satellite Signals on the Terrestrial Network

Daily Satellite Count for March 2025



% Time on Satellite (Satellite Availability)



Performance SMS Testing on Satellites (NTN) vs Terrestrial (TN)

DATE	Type	Total Success Messages	Total Attempt Messages	SMS Send Success Rate	Total Failure Messages	< 5 Sec	< 15 Sec	< 30 Sec	< 1 Min	< 5 Min	< 10 Min	< 15 Min	< 30 Min	< 1 Hr	< 3 Hr	Max delay (s)
11/4/2024	MO NTN	2505	2754	91%	249	76%	94%	99%	100%	100%	100%	100%	100%	100%	100%	58.33
11/5/2024		4020	4352	92%	332	75%	94%	98%	100%	100%	100%	100%	100%	100%	100%	58.62
11/6/2024		3462	3706	93%	244	89%	95%	97%	98%	98%	98%	99%	100%	100%	100%	1993.77
11/7/2024		4087	4359	94%	272	78%	86%	87%	88%	89%	89%	89%	89%	91%	100%	19103.12
11/8/2024		4140	4459	93%	319	75%	94%	98%	99%	99%	99%	100%	100%	100%	100%	627.66
11/9/2024		4517	4835	93%	318	78%	95%	99%	100%	100%	100%	100%	100%	100%	100%	65.56
11/10/2024		4612	4944	93%	332	77%	94%	98%	100%	100%	100%	100%	100%	100%	100%	59.47
11/11/2024		3988	4303	93%	315	77%	93%	97%	99%	100%	100%	100%	100%	100%	100%	238.32
11/12/2024		1155	1242	93%	87	69%	83%	87%	89%	89%	89%	89%	89%	89%	89%	54.03
11/4/2024	MT TN	1355	1355	100%	0	80%	92%	95%	96%	100%	100%	100%	100%	100%	100%	1801.59
11/5/2024		1579	1579	100%	0	84%	92%	95%	96%	100%	100%	100%	100%	100%	100%	611.07
11/6/2024		4746	4746	100%	0	93%	95%	96%	96%	100%	100%	100%	100%	100%	100%	703.92
11/7/2024		4359	4359	100%	0	67%	71%	73%	74%	79%	79%	79%	80%	91%	100%	4262.14
11/8/2024		3424	3424	100%	0	93%	96%	97%	98%	100%	100%	100%	100%	100%	100%	1172.76
11/9/2024		3891	3891	100%	0	82%	91%	91%	92%	94%	94%	96%	97%	99%	100%	3885.90
11/10/2024		3519	3519	100%	0	94%	98%	98%	99%	100%	100%	100%	100%	100%	100%	1139.55
11/11/2024		3605	3605	100%	0	90%	96%	97%	98%	100%	100%	100%	100%	100%	100%	1188.31
11/12/2024		958	958	100%	0	86%	95%	97%	97%	100%	100%	100%	100%	100%	100%	783.79