Testing NR NTN over legacy GEO and MEO transparent payload satellites

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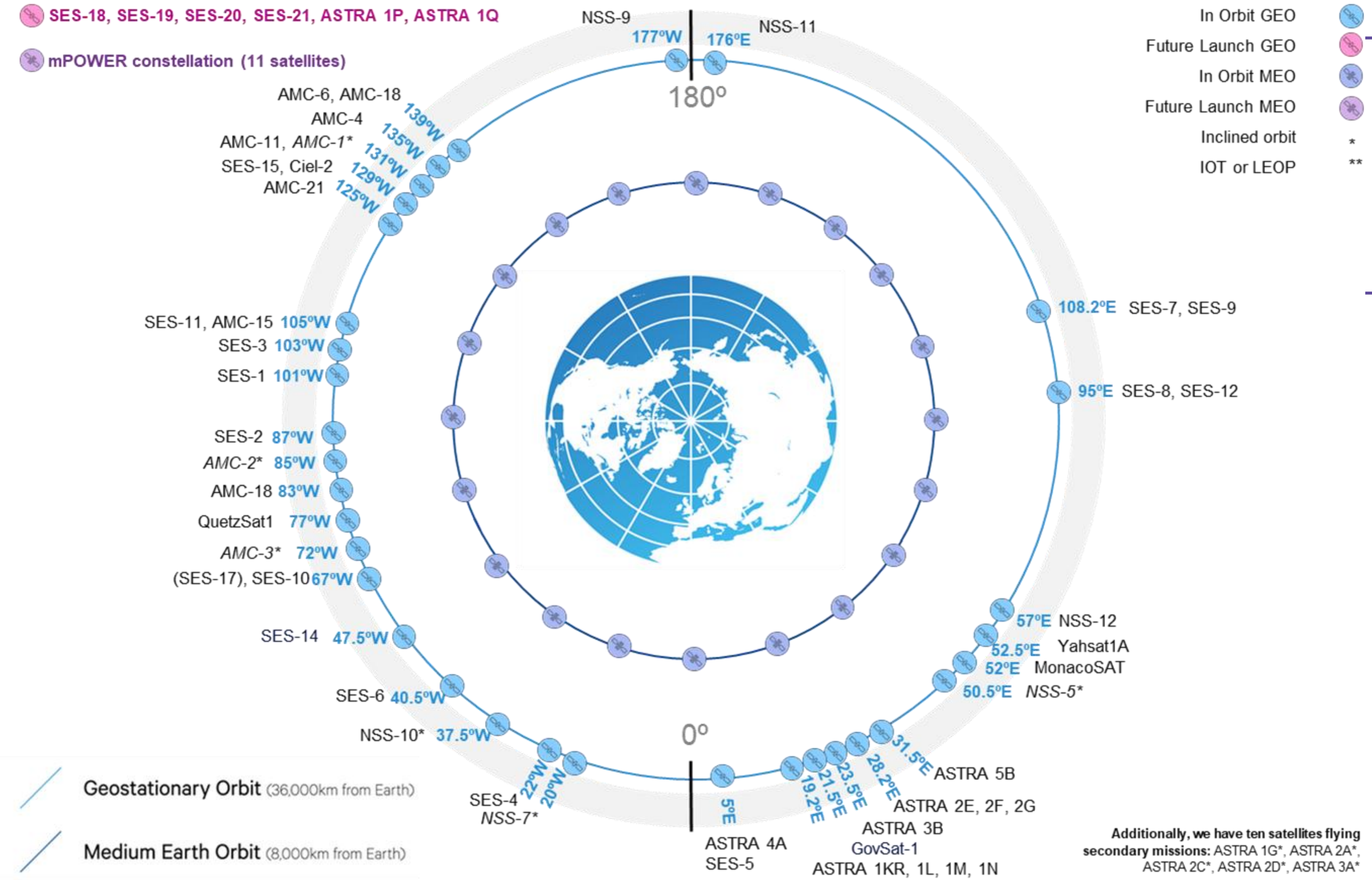
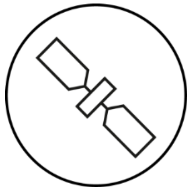
SES Fleet overview



Additionally, we have ten satellites flying secondary missions: ASTRA 1G*, ASTRA 2A*, ASTRA 2C*, ASTRA 2D*, ASTRA 3A*

The combination of GEO wide/HTS beams and MEO high throughput and low latency spot beams give SES a competitive advantage and a unique selling point

Together, GEO/MEO satellites cover 99% of the world population



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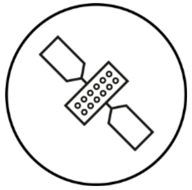
GEO (SES Legacy)



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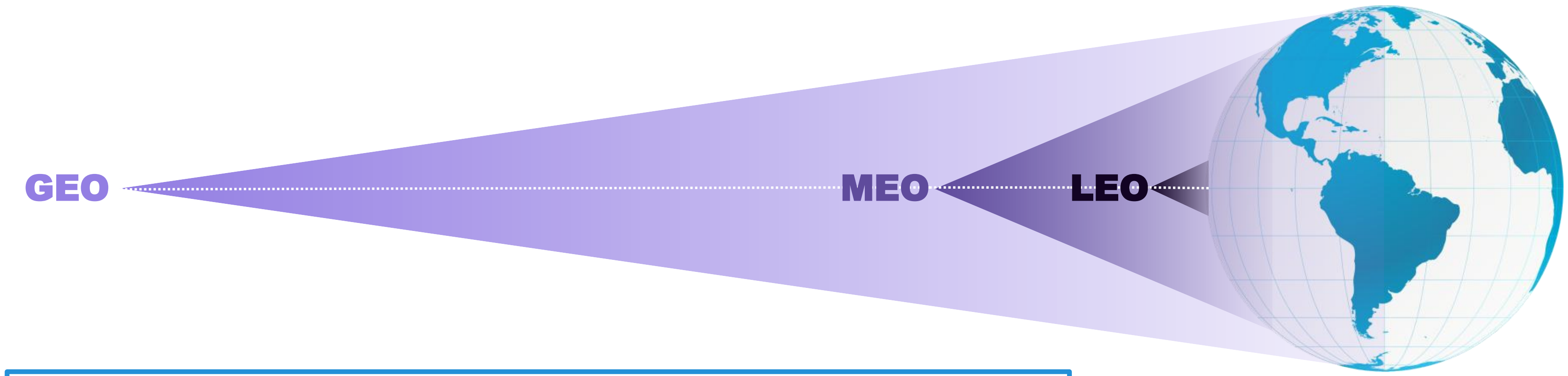
MEO (mPower and O3B classic)

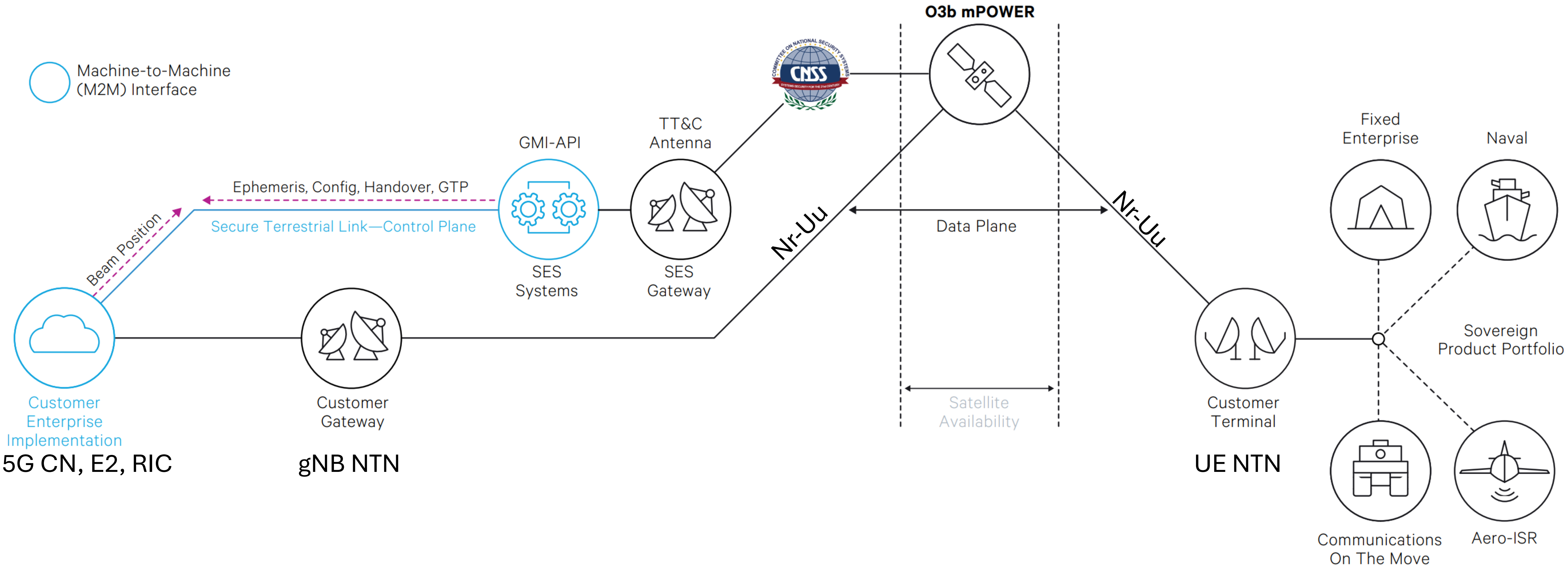
Orbits



GEO – 36,000km	MEO – 8,000km	LEO – 1,000km
High latency (~700 msec)	Low latency (~150 msec)	Very low latency (~50 msec)*
Very large Earth view	Large Earth view	Small Earth view
Continental gateways	Regional gateways	Many local gateways needed or OISL
Stationary antennas	6-hour tracking	20-minute fast tracking

** Gateway distance dependent*

Sovereign Services Architecture



Gateway Ephemeris Formats

CNSS OEM

- Best-knowledge of the orbit
- Clear validity date
- Simple orbit propagator (interpolation)
- Not compact

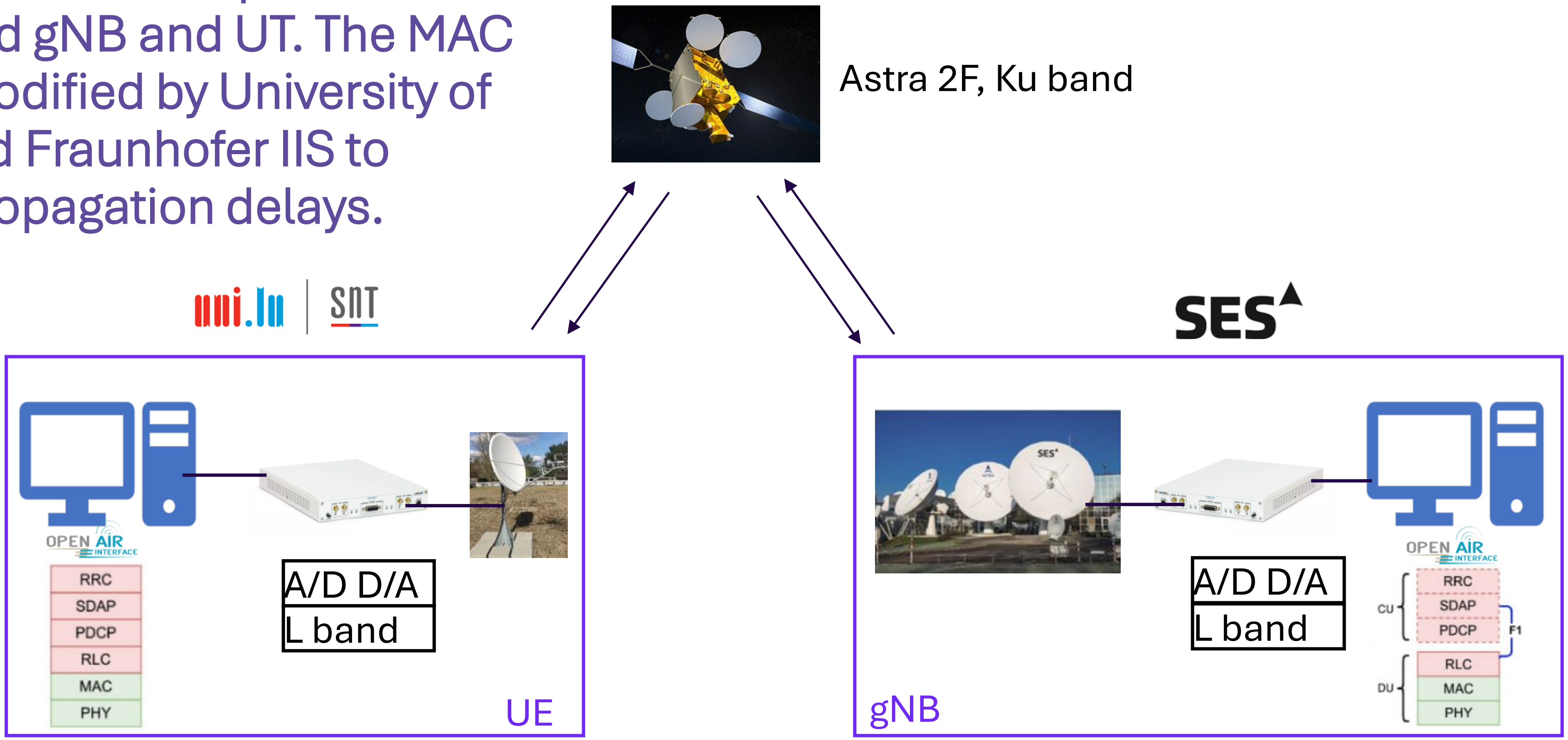
TLE

- Compact format
- Widespread
- Orbit propagator (SGP4)
- Inherited fitting error

Corresponds to ECEF and NIMA IT 8350.2 as per 3GPP TS 38.331

NTN for GEO Test

Was done in 2023 with the pre-release 17 software-defined gNB and UT. The MAC software was modified by University of Luxembourg and Fraunhofer IIS to support large propagation delays.

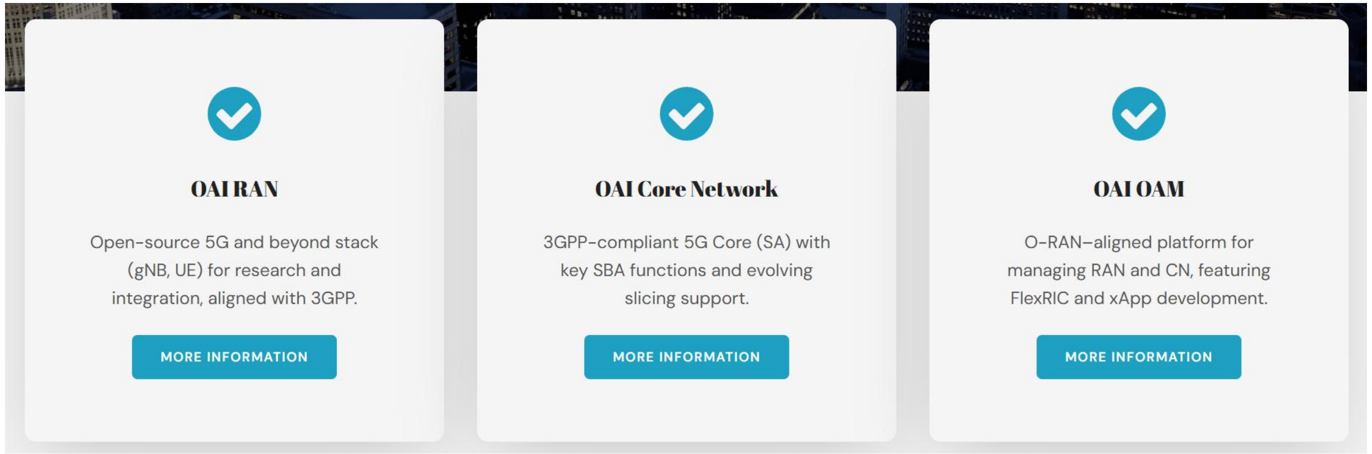


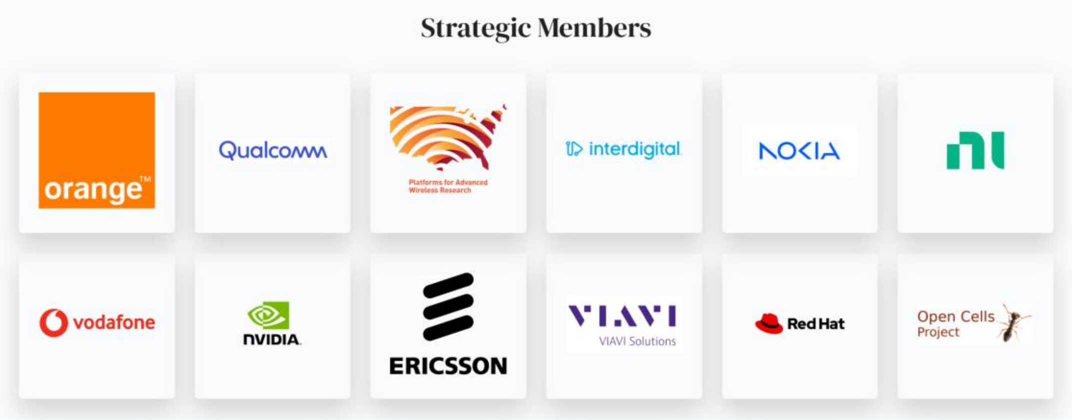
Openairinterface5G

As of Jan 2026

- gNB MAC NTN
  - ❑ Support downlinkHARQ-FeedbackDisabled-r17
  - ❑ Support for 32 PDSCH and PUSCH HARQ processes per UE
  - ❑ Consider ntn-Config-r17.cellSpecificKoffset-r17 in scheduling
  - ❑ Function-based interface for ntn-Config-r17 updates

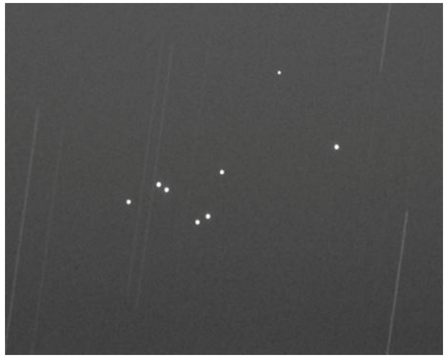
- UE RRC according to 38.331 Rel.17
  - ❑ Reception of ntn-Config-r17 from SIB19 or reconfigurationWithSync
  - ❑ Handling of ntn-UlSyncValidityDuration-r17 in SIB1
- UE MAC
  - ❑ Support downlinkHARQ-FeedbackDisabled-r17
  - ❑ Support for 32 PDSCH and PUSCH HARQ processes
  - ❑ Consider ntn-Config-r17.cellSpecificKoffset-r17 in scheduling
- UE PHY
  - ❑ TA adjustment based on ntn-Config-r17 information
  - ❑ Different TA adjustment algorithms between SIB19 receptions:
  - ❑ Autonomous TA adjustment based on DL time tracking
  - ❑ Standard compliant epoch time-based TA adjustment including orbital propagation
  - ❑ DL Doppler compensation based on ntn-Config-r17 information
  - ❑ UL Doppler pre-compensation based on ntn-Config-r17 information and residual DL FO estimation

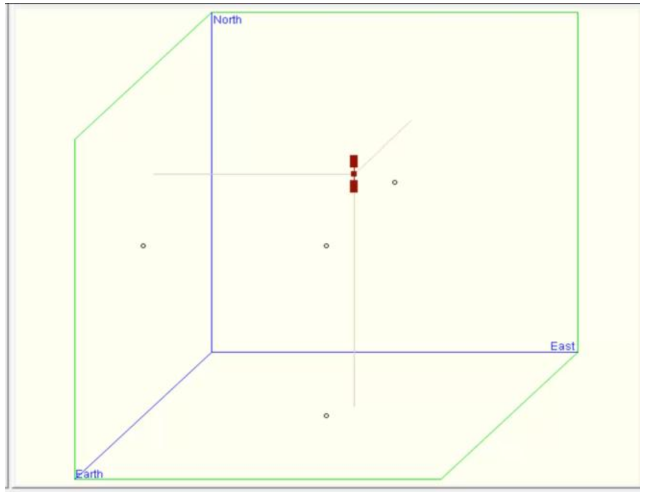


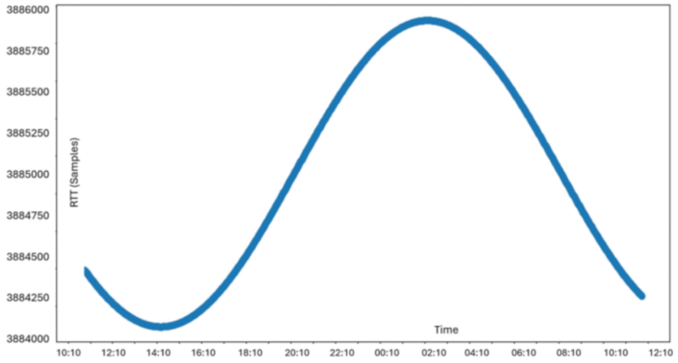


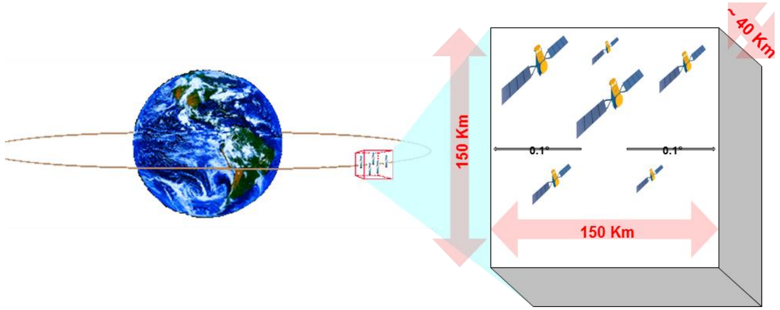
GEO Satellite Movement

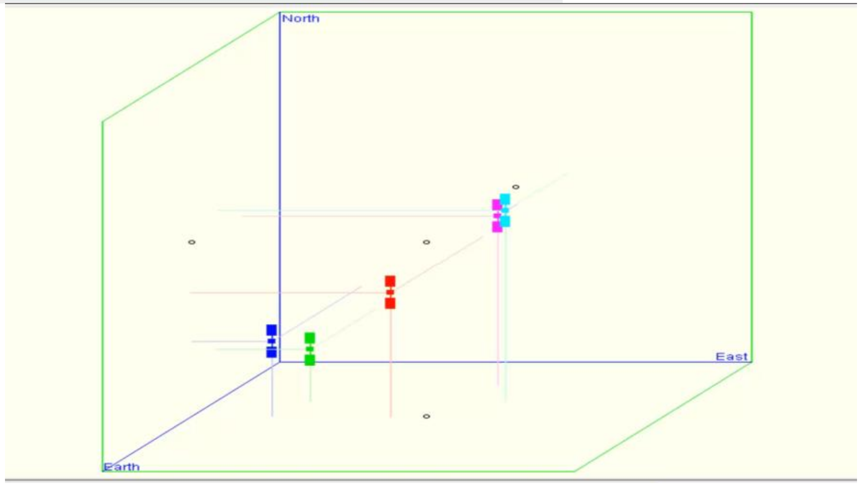
Station-keeping maneuvers allow us to maintain the satellite (or many co-located satellites!) in the Stationkeeping box (up to 4 maneuvers per day)











Timing Advance in NTN for GEO

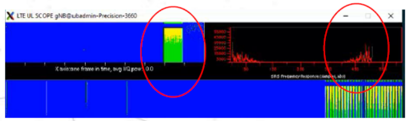
S. Kumar, J. Krivochiza et al.,
"5G-NR Over Transparent Payload GEO Satellites: A Hands-On Approach Using OpenAirInterface5G-NTN," in
IEEE Open Journal of the Communications Society, vol. 6, pp. 5969-5987, 2025, doi: 10.1109/OJCOMS.2025.3586871.
URL: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=11073184&isnumber=10829557

OTA Timing Advance Experiment

Calculating common TA from the geometry

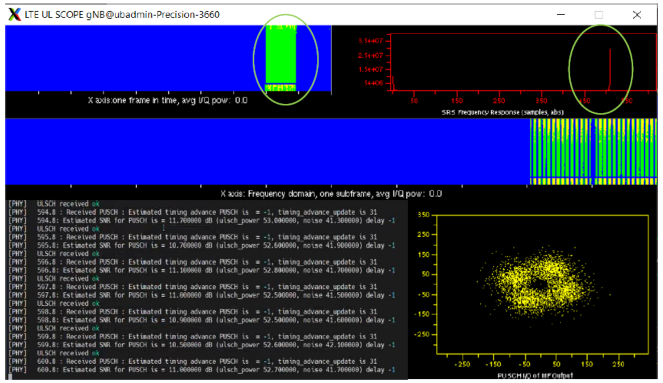
SLANT D.		t
JFK	37997.08 km	0.126744616 s
SES	37997.58 km	0.126746284 s
	total	0.2534909
	2x total	0.506982 s
c	299792458 m/s	
Rate	7.68E+06 Sps	3893620.22 samples

W/o hand tuning

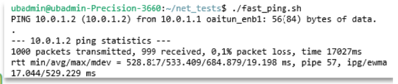


- Missing correct time slot
- No correlation peak

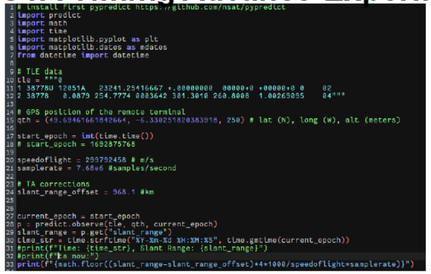
Hand tuning



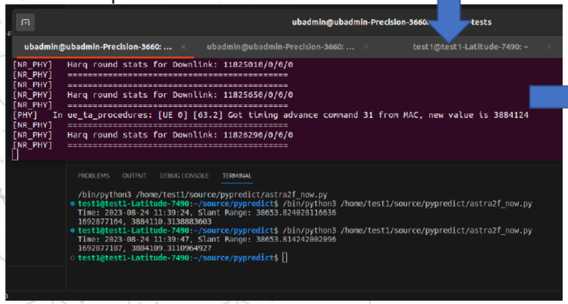
- Correct time slot
- Strong correlation peak
- Recovered constellation
- Ok Decoded pilots



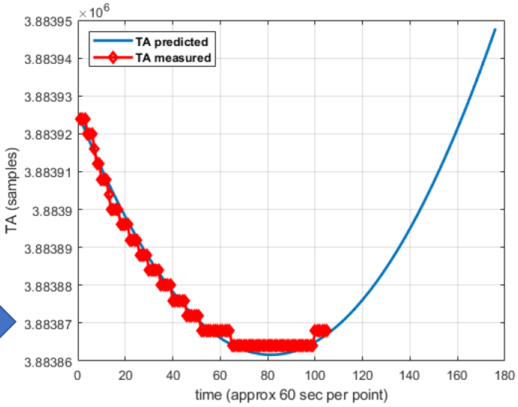
OTA Timing Advance Experiment



TLE based prediction of common TA



Common TA fitting (±60 samples for OAI)



TA measured and predicted are fitted

NTN for GEO Conclusions

- The NTN gNB has to broadcast updated ephemeris in GEO case (E2 interface for example).
  - ❑ TLE format is ok, but needs to be calibrated every time
  - ❑ The antenna doesn’t need TLE for tracking in GEO, so potentially we can use directly ECEF format

- While in our tests we tried to push performance.
  - ❑ In FWD link, for a **10dB SNR** link, **using 5 MHz carrier**, 10/10 slots scheduled and max 40 iterations for LDPC we got **~7.5 Mbps** with a **SE ~1.5 bps/Hz at IP**
  - ❑ MCS 16 of Table 1-1 was used, modcod SE is ~2.6 bit/symbols
  - ❑ Removing L1 overhead (for 5MHz) we have SE ~ 1.98 bps/Hz
  - ❑ From 1.98 bps/Hz to 1.5 bps/Hz it remains ~30% overhead. This comes from L2, L3 OH and control channels + (maybe) scheduling inefficiencies due to the 5 MHz carrier

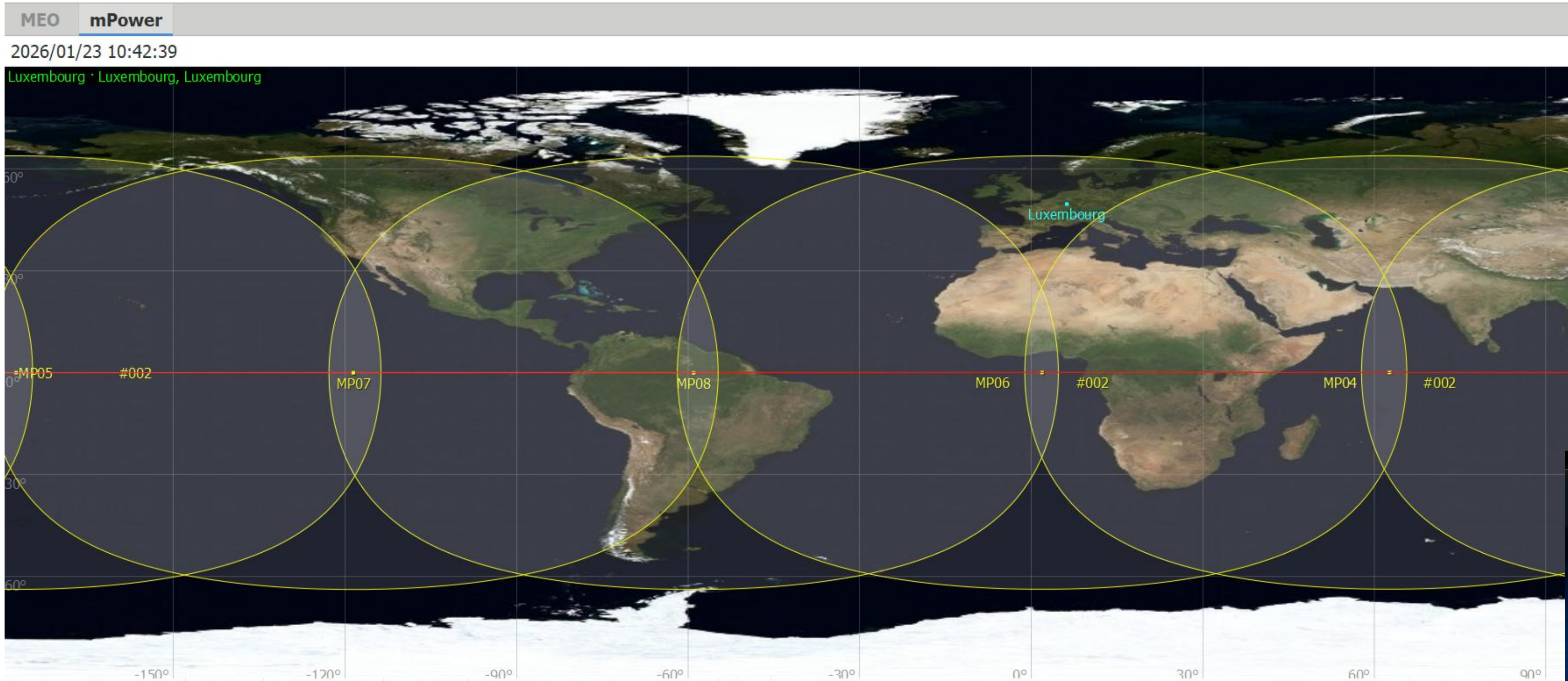
NTN for GEO vs MEO

- SNR in GEO is quite stable while in MEO SNR changes over the pass
  - In addition, GEO is Ku while MEO is Ka
- No handover procedure in GEO while HO happens in MEO
- Doppler/CFO and timing offsets are very stable in GEO while in MEO we have Doppler and timing offset variation over time
- Total CFO (doppler + frequency offset) might be different on a spacecraft-by-spacecraft basis
- Terminal/GW antenna mis-pointing/tracking can be another cause of SNR jitter (this is what happens with mechanical tracking antennas)
- We expect that the margins needed for 5G are larger in MEO than GEO!

- In MEO maneuvers are very rare – less than 2 times per year.

mPower Constellation

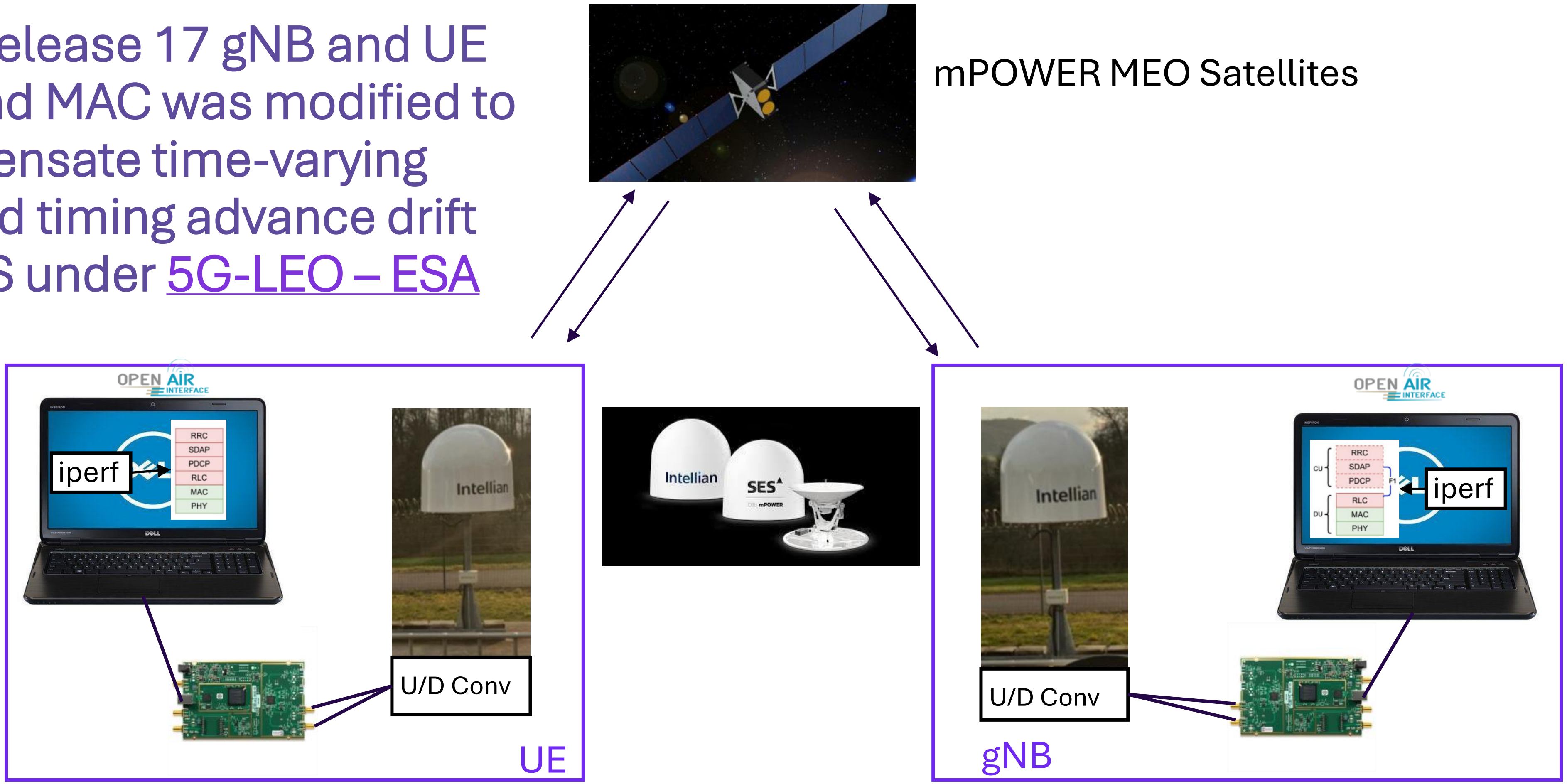
Satellite visibility (not the actual beam coverage)



Satellite		Az	El	Dir	Range	Next Event	Alt	Orbit
MP06	**#002**	**185.64°**	**15.07°**	↑	**11388**	**LOS: 2026/01/23 11:34:08**	**8058**	
MP04	#002	116.67°	-5.04°	↓	13525	AOS: 2026/01/23 14:59:02	8064	
MP08		250.66°	-10.04°	↑	14104	AOS: 2026/01/23 11:00:48	8055	
MP01	#002	70.01°	-36.73°	↓	17331	AOS: 2026/01/23 14:00:08	8070	
MP07		297.89°	-41.08°	↑	17814	AOS: 2026/01/23 12:00:16	8063	
MP05	#002	4.85°	-54.90°	↓	19200	AOS: 2026/01/23 12:59:08	8068	

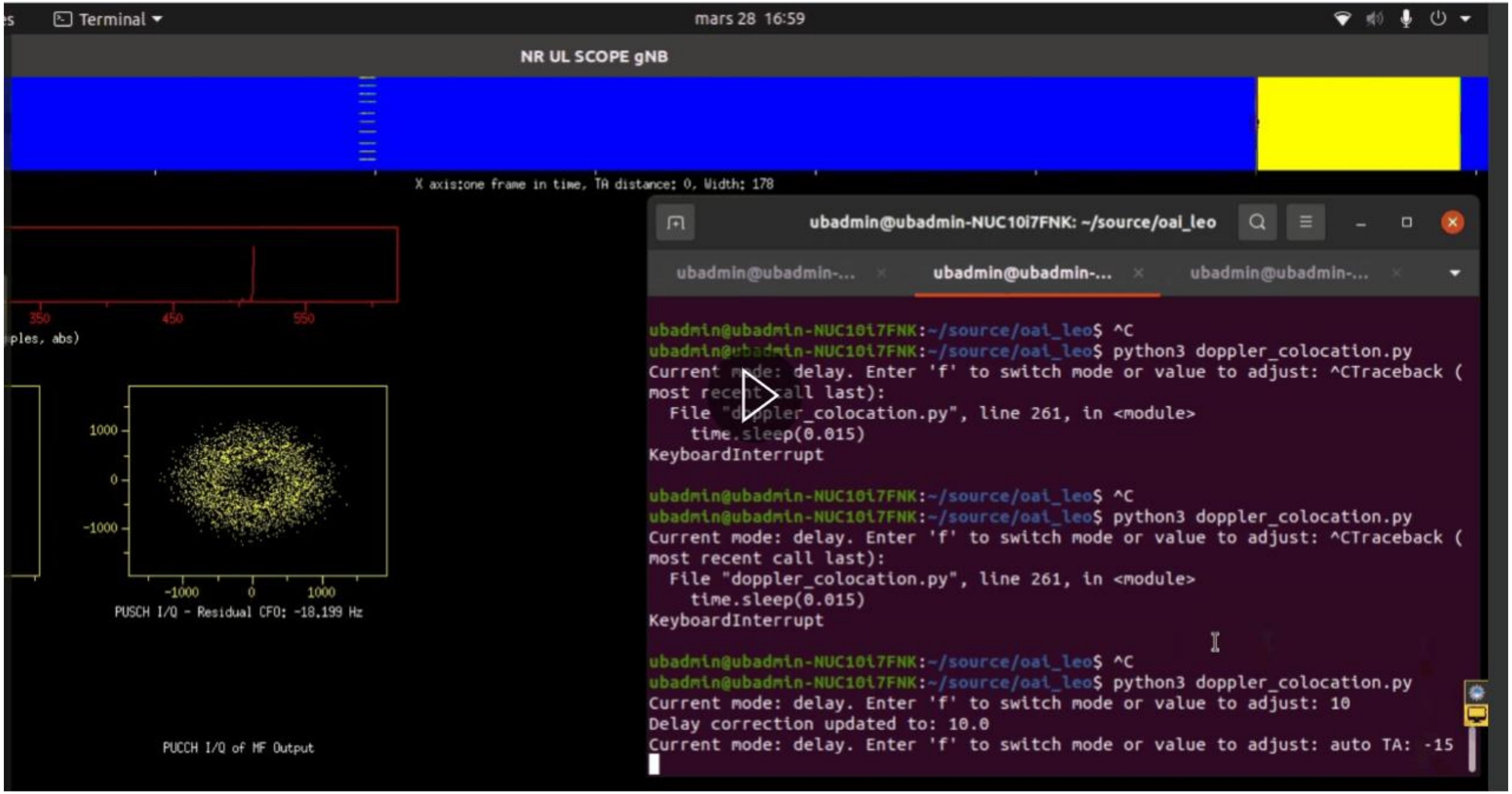
NTN for MEO Test

Was done with release 17 gNB and UE (SIB-19). PHY and MAC was modified to track and compensate time-varying Doppler shift and timing advance drift by Fraunhofer IIS under 5G-LEO – ESA CSC.



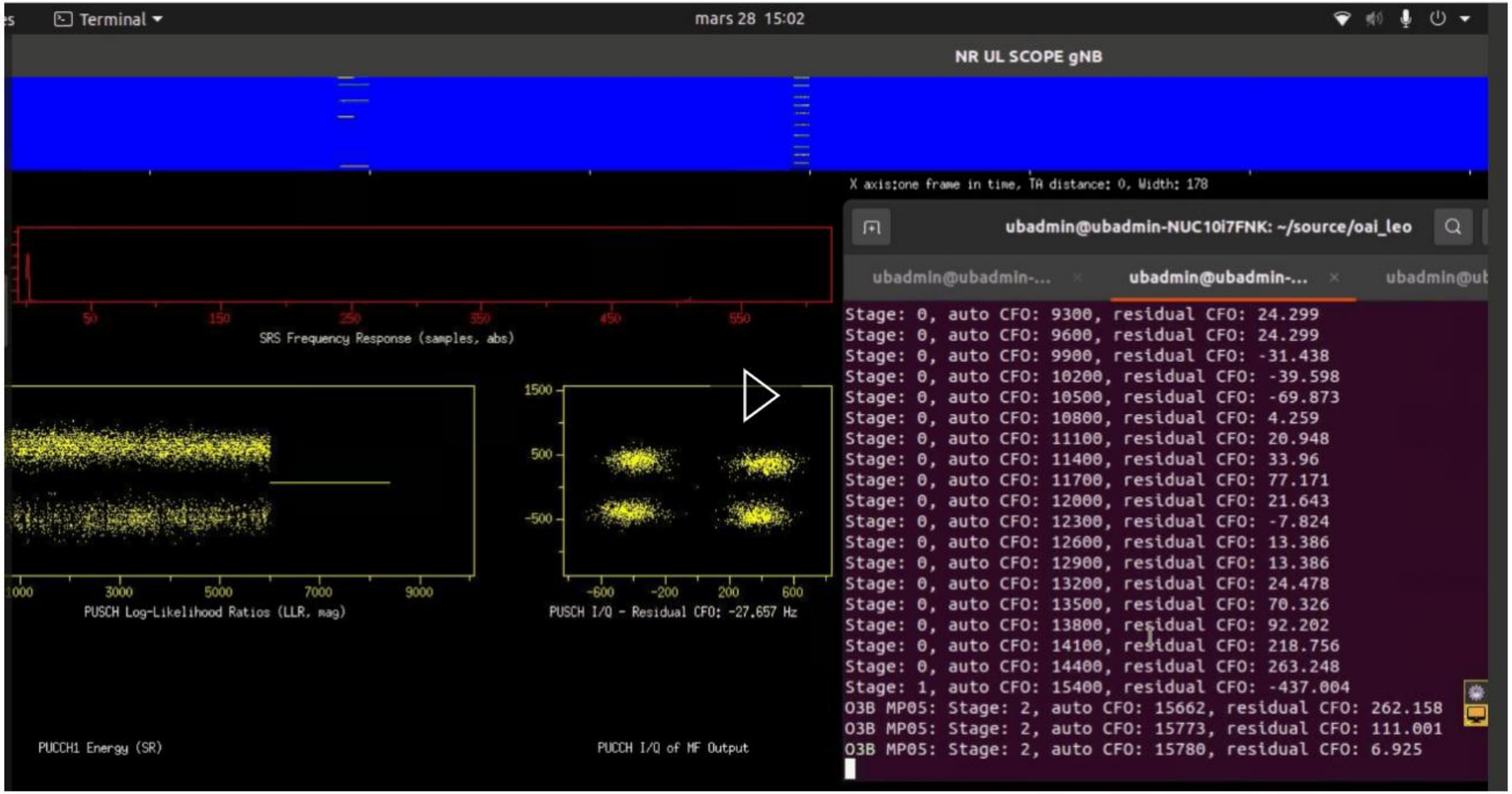
NTN for MEO Uplink Timing Advance Offset

NTN gNB compensates Timing Advance error due to ephemeris and UE position error



NTN for MEO Uplink Central Frequency Offset

NTN gNB-side compensates residual ~15 kHz of fixed CFO due to HW components

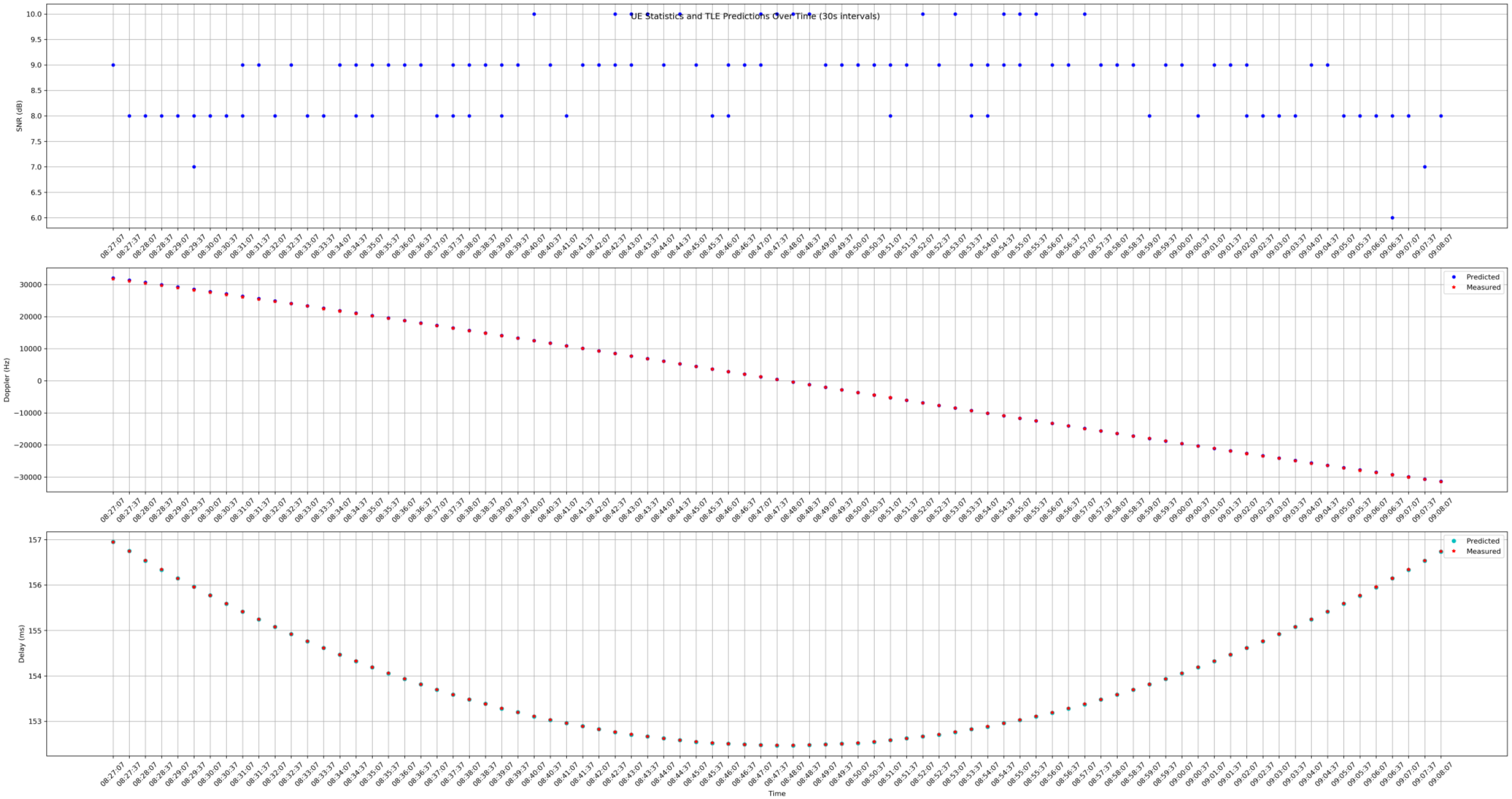


NTN for MEO Channel Tracking

Single satellite pass

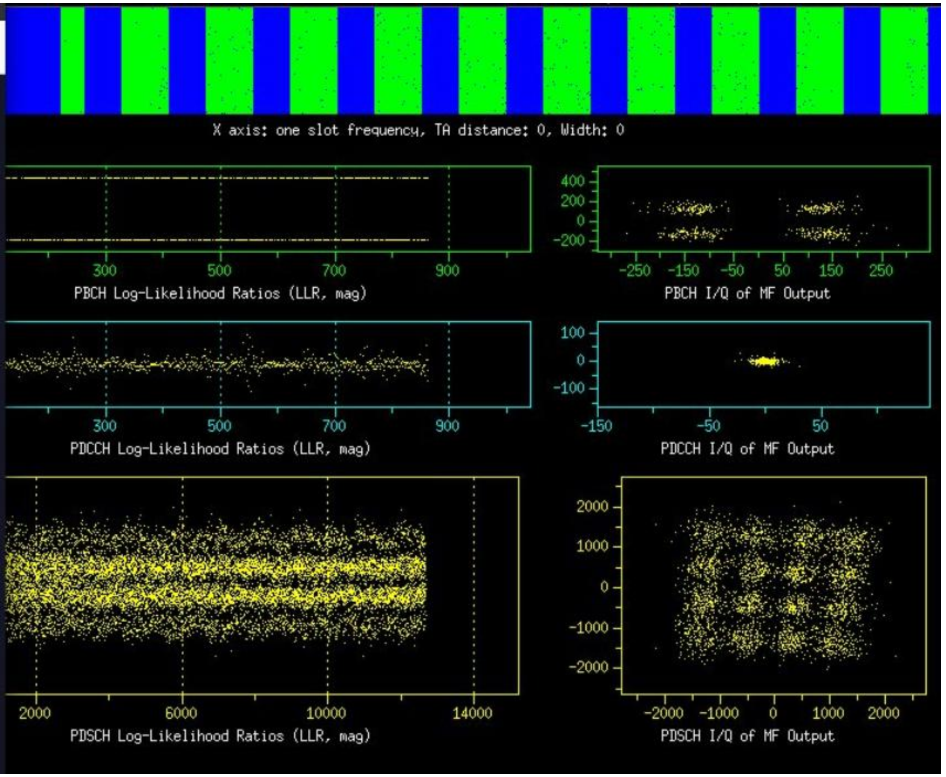
SNR: it jitters due to:
-Antenna instabilities
-Weather (rain)
-Estimator accuracy

Doppler/Delay: accurate prediction if TLE are updated on time and the gNB is calibrated for each satellite (std: 2.4kHz, 0.17ms)



NTN for MEO Downlink Performance

10 MHz BW, 30kHz scs, MCS 16



NTN for MEO Conclusions

- Margins needed are much larger than the Ku GEO case
  - Main cause: SNR jitter by ~3dB (even much more in some cases)
    - possible cause:
      - antenna jittering every now and then,
      - weather (rain),
      - tracking algorithms to be improved (higher NR subcarrier spacing is better)
- L2 ARQ RLC AM when HARQ is disabled (in MEO and GEO)
  - It correct errors up to ~5% of BLER
  - The correction introduces latency jitter with max values 1 or 2 time the RTT (in addition to the RTT)
- Satellite Doppler+CFO and delay predictions accuracy (Satellite position and UT position) is very important
  - For TA, this is especially true while going to larger subcarrier spacing (we tested 15 and 30 kHz)
  - gNB can be calibrated for each satellite to facilitate UE handling handovers
  - TLE is OK for NGSO satellite tracking antennas without updates for days or even months

Thank you