Using LEO PNT to Synchronize Indoor 5G RAN

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ITSF – November 8, 2022

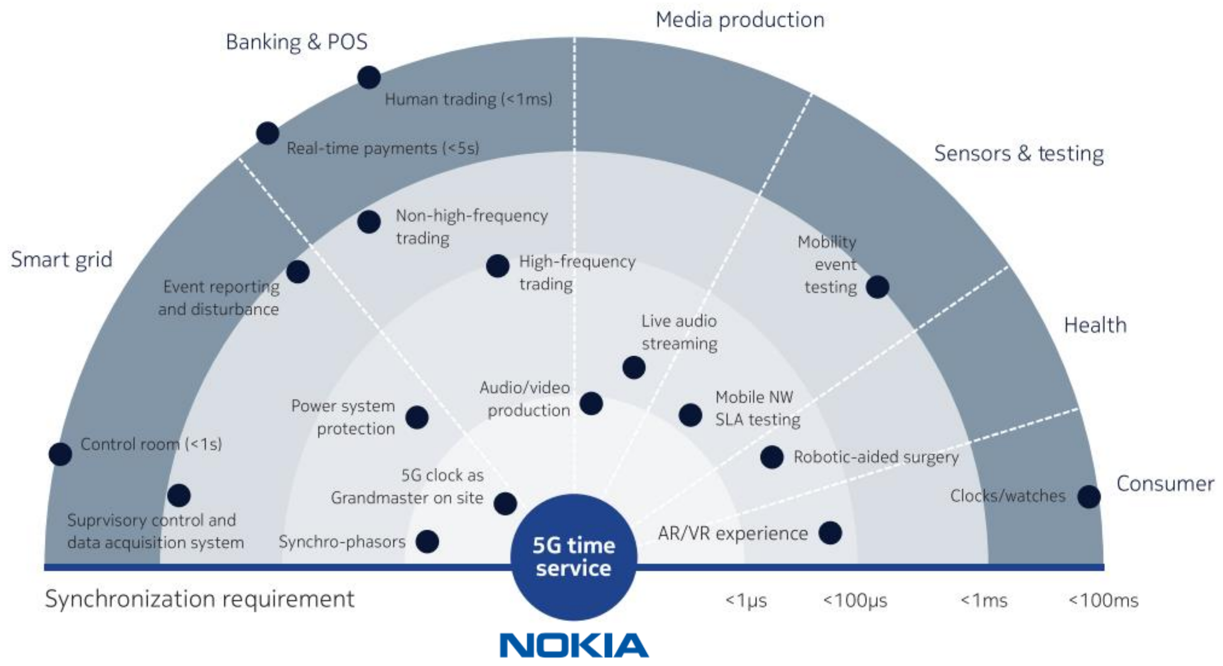
5G is Moving Wireless Communications Indoors

To provide high-speed services directly to users, 5G is moving wireless communication access points (eNBs) from outdoor high power Radio Access Networks (RAN) on towers and buildings to indoor low power RAN, small cells, and femtocells on ceilings and walls

5G Requires Accurate UTC Timing

TDD Requirement – Per 3GPP and ITU requirements, 5G eNBs using Time Division Duplex (TDD) transmission must not exceed a timing error of **1500 nsec of UTC** or they must SHUT DOWN the transmitter to prevent interfering with neighbor sites

Time as a Service – 3GPP 5G release 16 introduces “Time as a Service,” allowing enterprise and commercial services to synchronize to UTC via 5G broadcast messages



☞ *These are only two among multiple 3GPP 5G New Radio (NR) timing requirements*

GNSS Synchronization

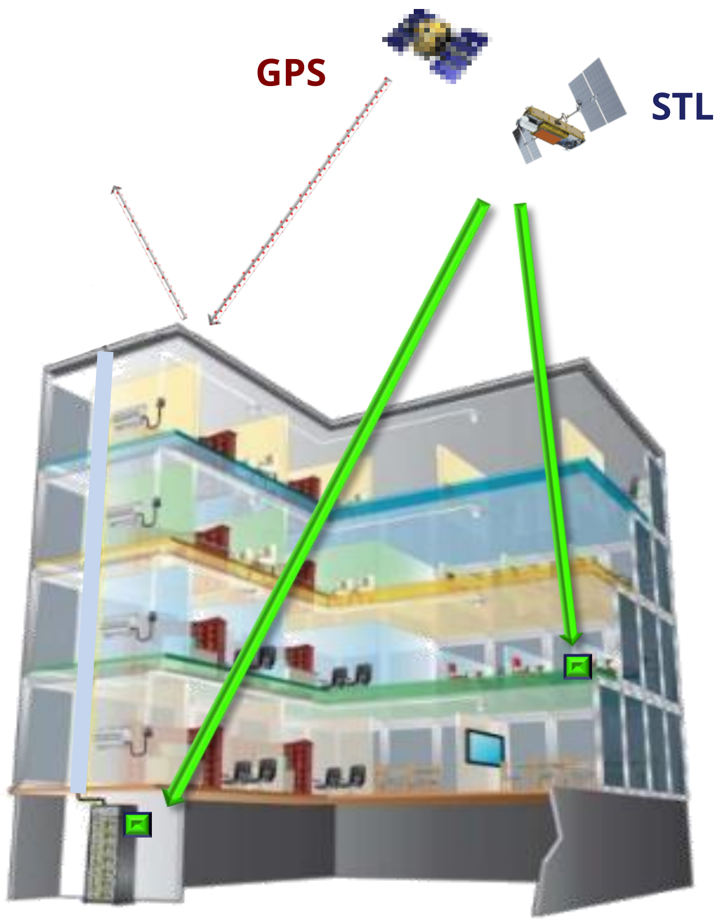
GNSS synchronization **is the most accurate method** to meet 5G timing requirements

However, it works poorly or not at all in:

- **Urban canyons (limited sky view)**
- **High multipath environments (signal shredding)**
- **Indoors (excessive attenuation)**
- **Where jamming or spoofing exists**

With 10-15 GNSS satellites commonly in view, urban multipath could easily result in 15-25 signal paths to the GNSS antenna resulting in signal shredding (complete loss of all correlations)

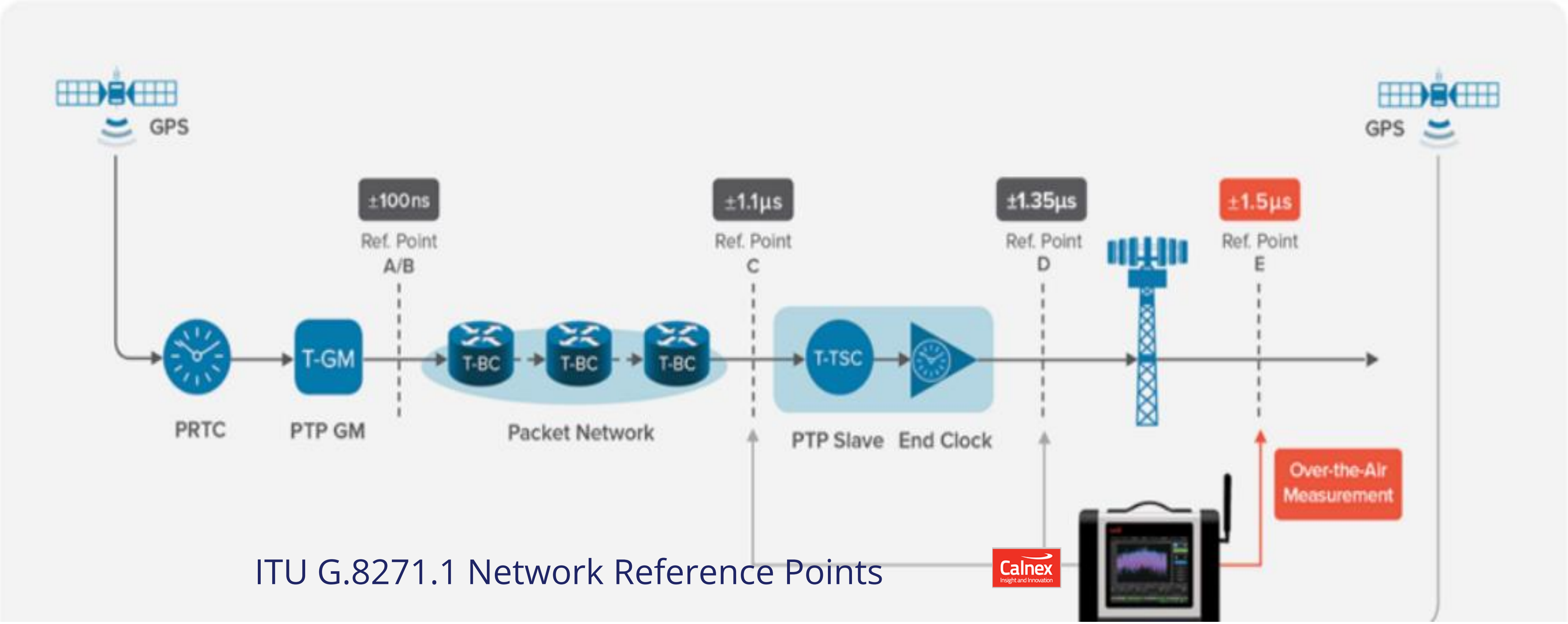
Due to the slow movement of GNSS satellites, urban multipath scenarios can often disable a receiver for many hours



NOTE: Image depicts indoor reception of STL compared to GPS. Orbital altitudes not to scale.

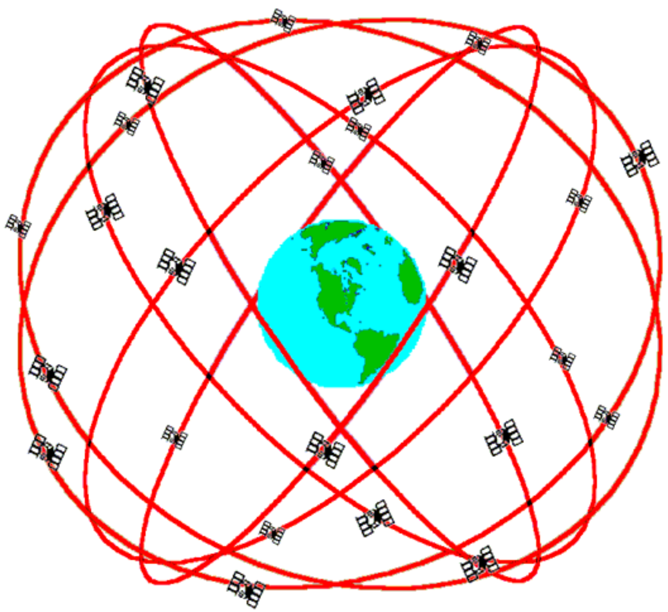
PTP Synchronization

PTP distributed timing using partial timing support (ITU G.8275.2) often cannot meet 5G timing requirements when there are too many hops, and full timing support (G.8275.1) is very expensive and not always feasible or possible to implement



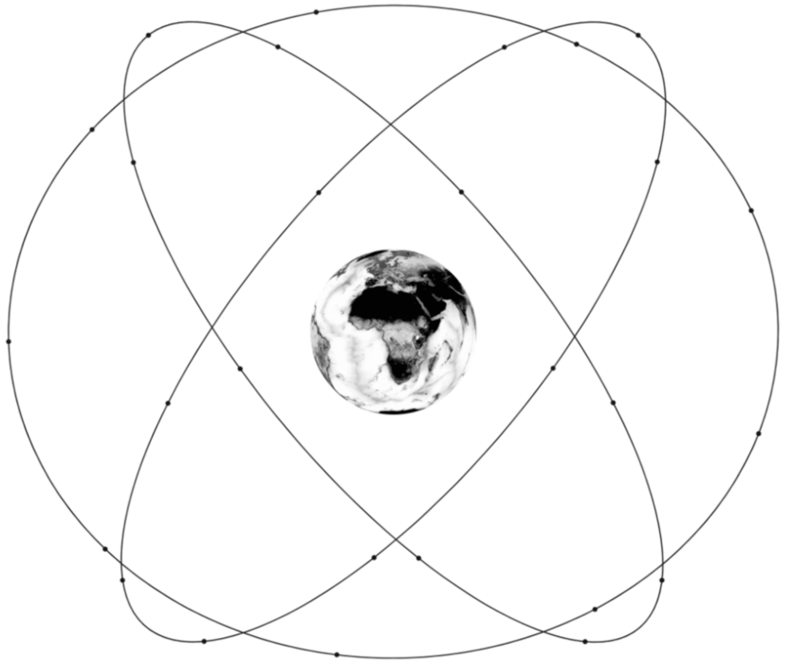
ITU G.8271.1 Network Reference Points

GNSS (MEO) Constellations vs Iridium (LEO) Constellation



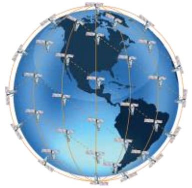
GPS Constellation

24+ Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,180 km Altitude, 55 Degree Inclinations
Orbital speed 14,000 km/hr (9k mph)
Orbital period 12 hours (2x/day)
Different satellite in each plane every 3 hrs



Galileo Constellation

24+ Satellites in 3 Orbital Planes
8 Satellites in each Plane
23,222 km Altitude, 56 Degree Inclinations
Orbital speed 13,200 km/hr (8k mph)
Orbital period 14 hours (~2x/day)
Different satellite in each plane every ~1.5 hrs

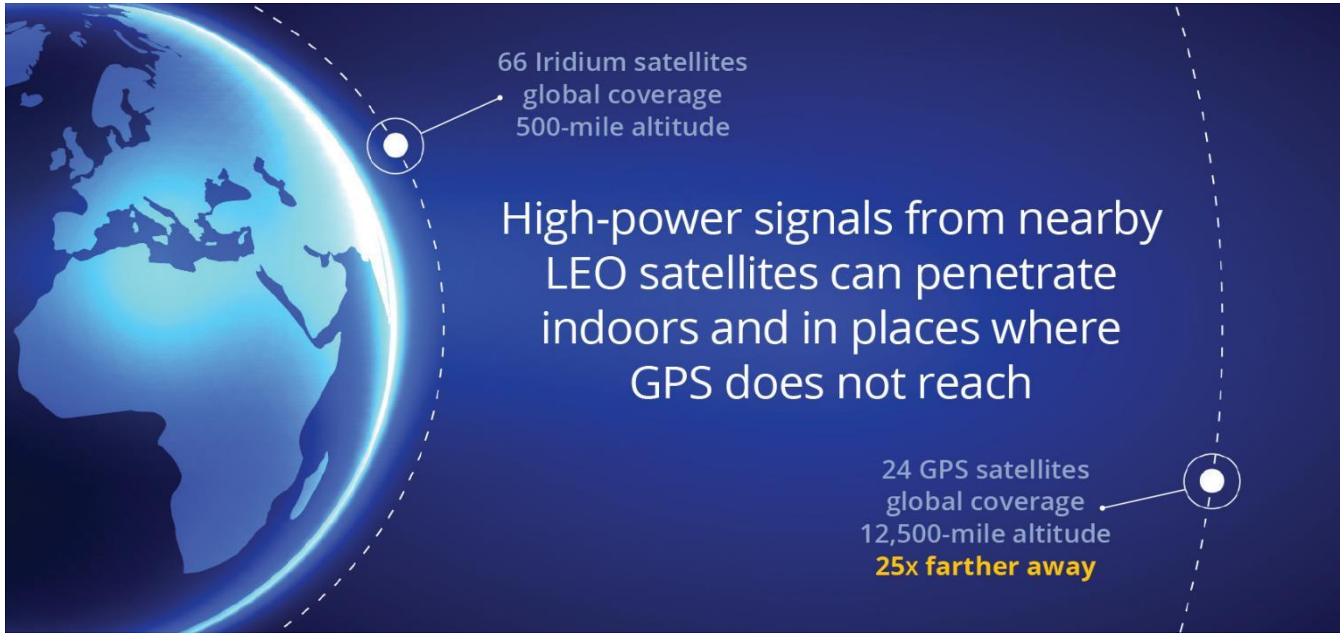


Iridium Constellation

66 Satellites in 6 Orbital Planes
11 Satellites in each Plane
781 km Altitude, Polar orbits (86.4 degrees)
Orbital speed 27,000 km/hr (17k mph)
Orbital period 100 minutes (14x/day)
Different satellite in each plane every 9 min

PNT from the Iridium LEO Constellation (Satelles STL Service)

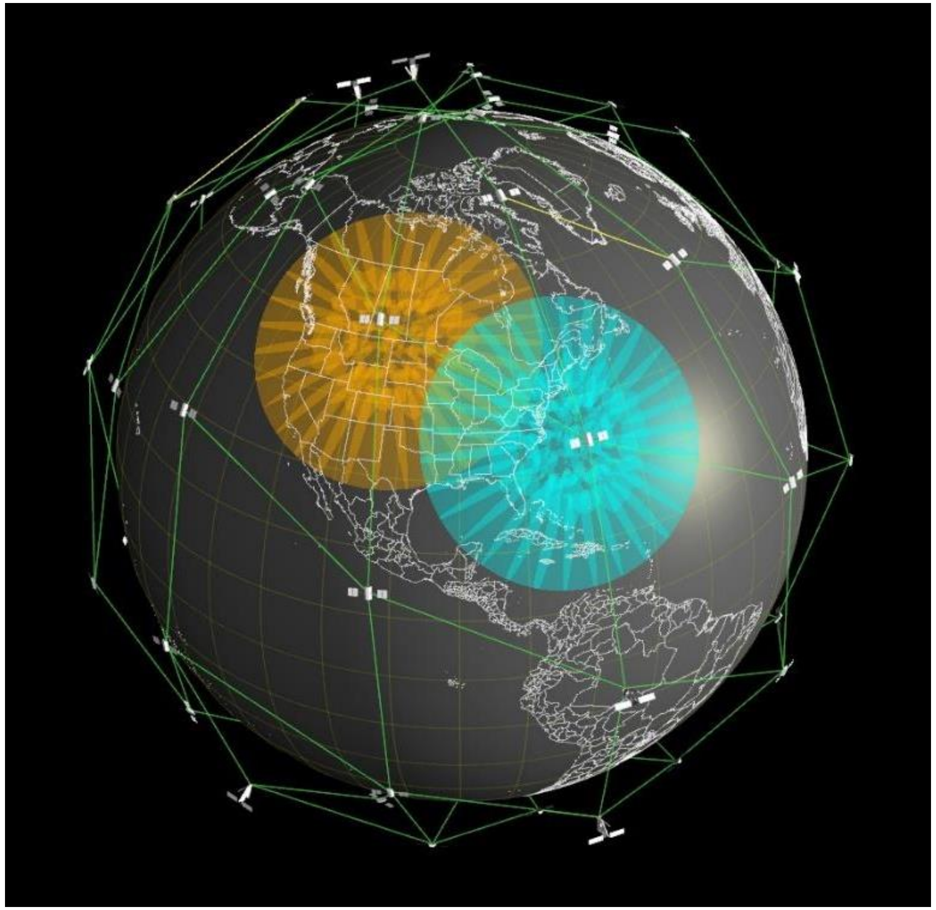
Satelles uses the Iridium LEO constellation to transmit a UTC traceable PNT signal called **STL** (Satellite Time and Location)



- **Higher Power –** STL is an L-band signal approximately **30 dB stronger** than MEO GNSS allowing it to penetrate through walls and windows to indoor receivers
- **Robust Signal –** The STL signal is not a CDMA overlay of multiple systems (like GPS+Galileo+SBAS), so there are no uncorrelated signals from other systems, and the orbital velocity is so fast that multipath signal cancellations are almost non-existent

LEO PNT (STL) Works Differently Than MEO GNSS

- Unlike GNSS, LEO satellites are much closer to the Earth, so their footprints are much smaller. This results in fewer satellites in view, but that is not a problem because LEO satellites provide PNT differently than GNSS.
- The lower altitude and faster velocity of LEO satellites result in an orbital period of only 100 minutes. This allows for many new position calculations (doppler assisted ranging) in less than a minute using only a few LEO satellites (GNSS can't do that).
- A Kalman filter is used to integrate these measurements and quickly converge the position and time states to their true values.
- It is typical for a location anywhere on Earth to have 2 to 4 Iridium satellites in view, which is more than enough to achieve and maintain PRTC-A clock accuracy and authenticated position.



Summary of 5G Synchronization Methods

Source	Delivery	Accuracy (typ. 1-sigma)	Indoor Availability?	Urban Canyon Availability?	Solution Cost
GNSS	MEO Satellites	10-20 ns	**No**	**Poor**	Very low
PTP	Remote PNT via Fiber optic distribution network	50-**1500** ns	Yes	Yes	**Very high**
STL	LEO Satellites	10-50 ns	Yes	Yes	Med-Low

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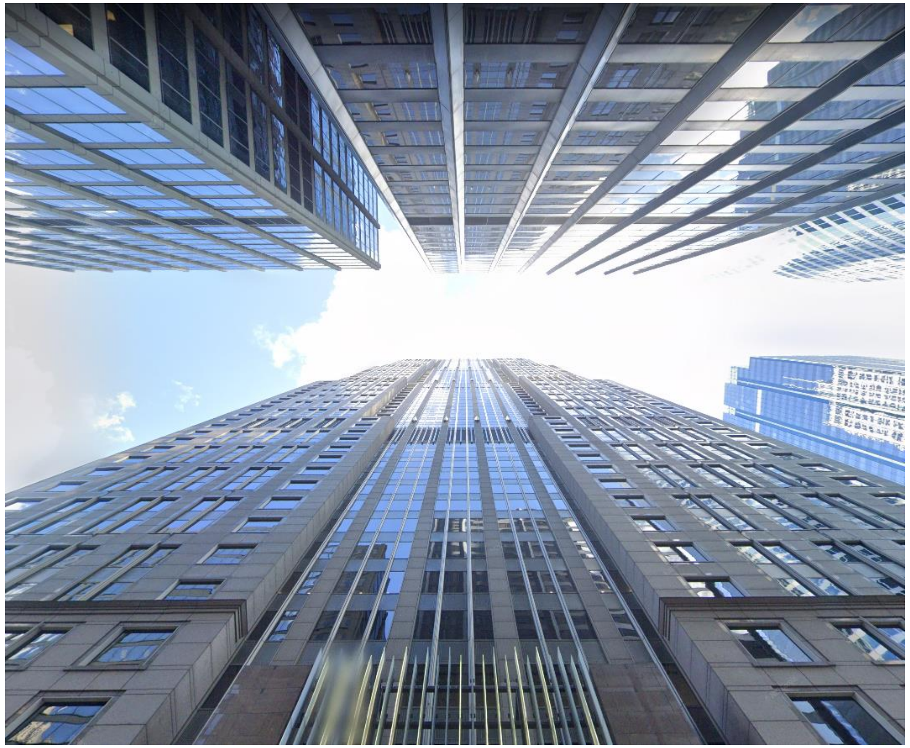
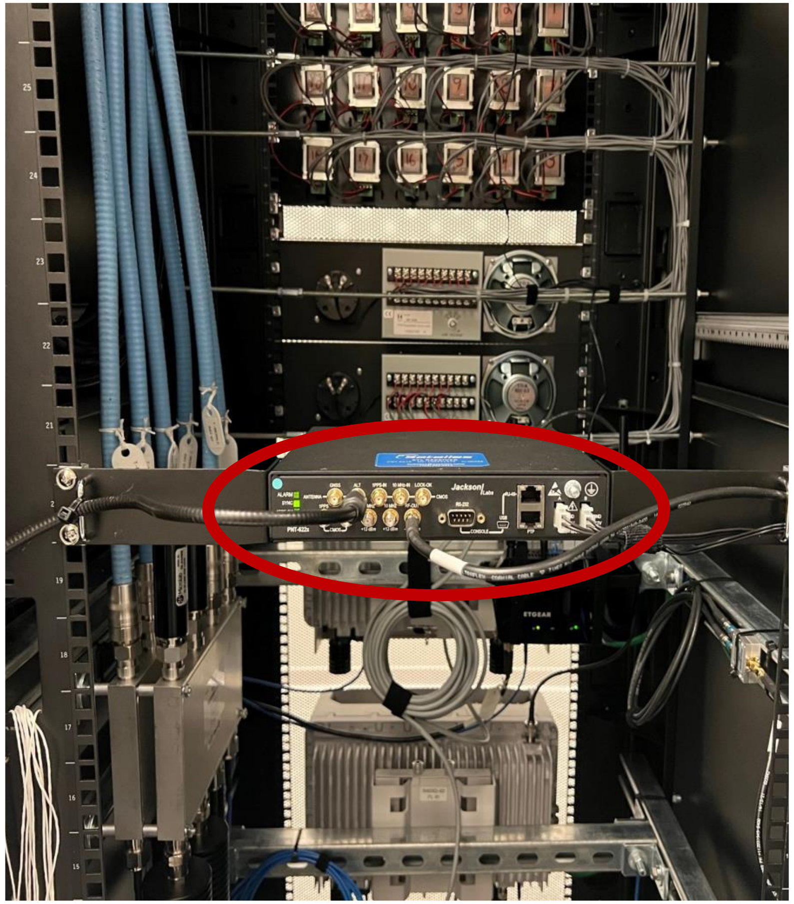
LEO PNT EXAMPLE: Urban High-Rise Building

STL LEO receiver used to synchronize two Nokia 5G Micro BTS RANs on 40th floor of office building

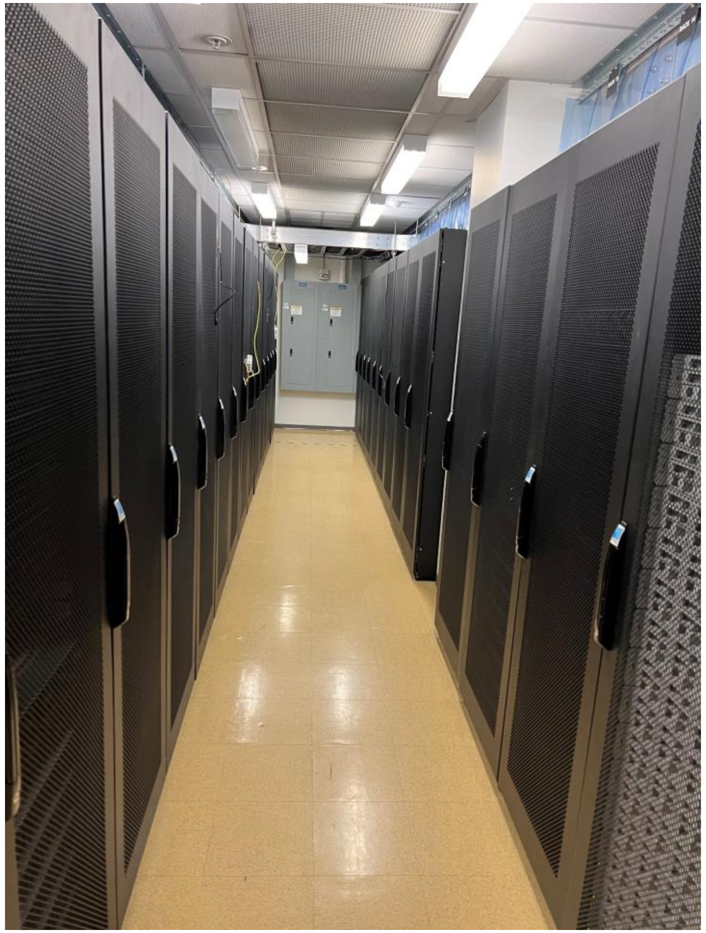
LEO Antenna mounted in office area ceiling

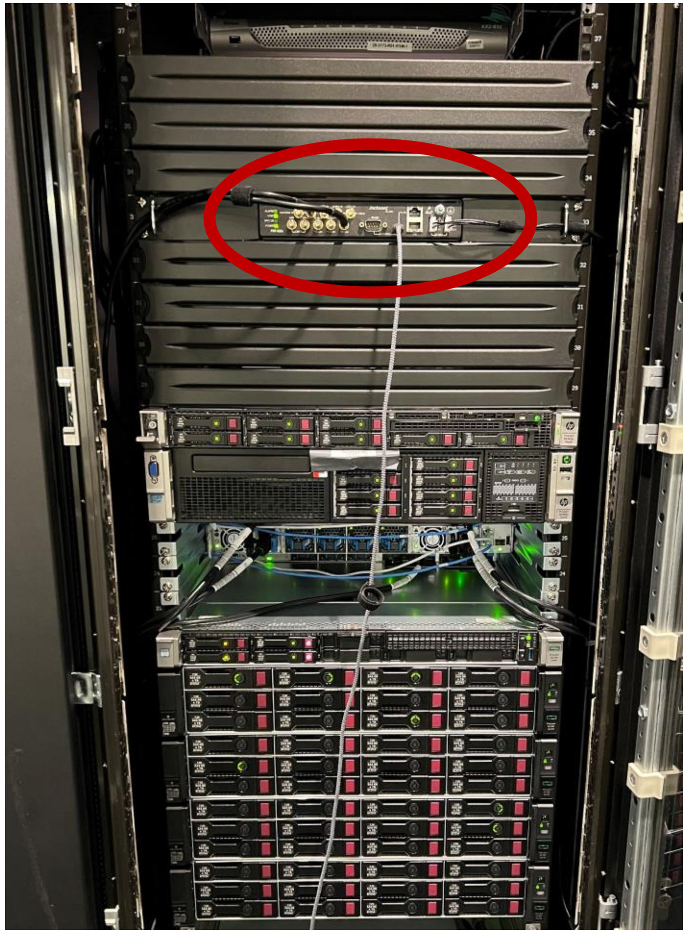




LEO PNT EXAMPLE: Data Center

STL LEO receiver used to synchronize data center servers

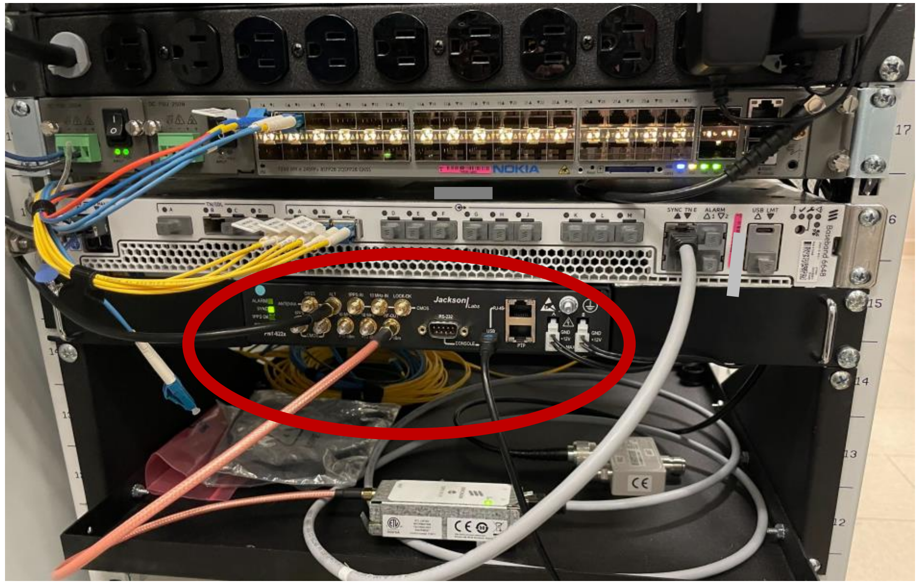




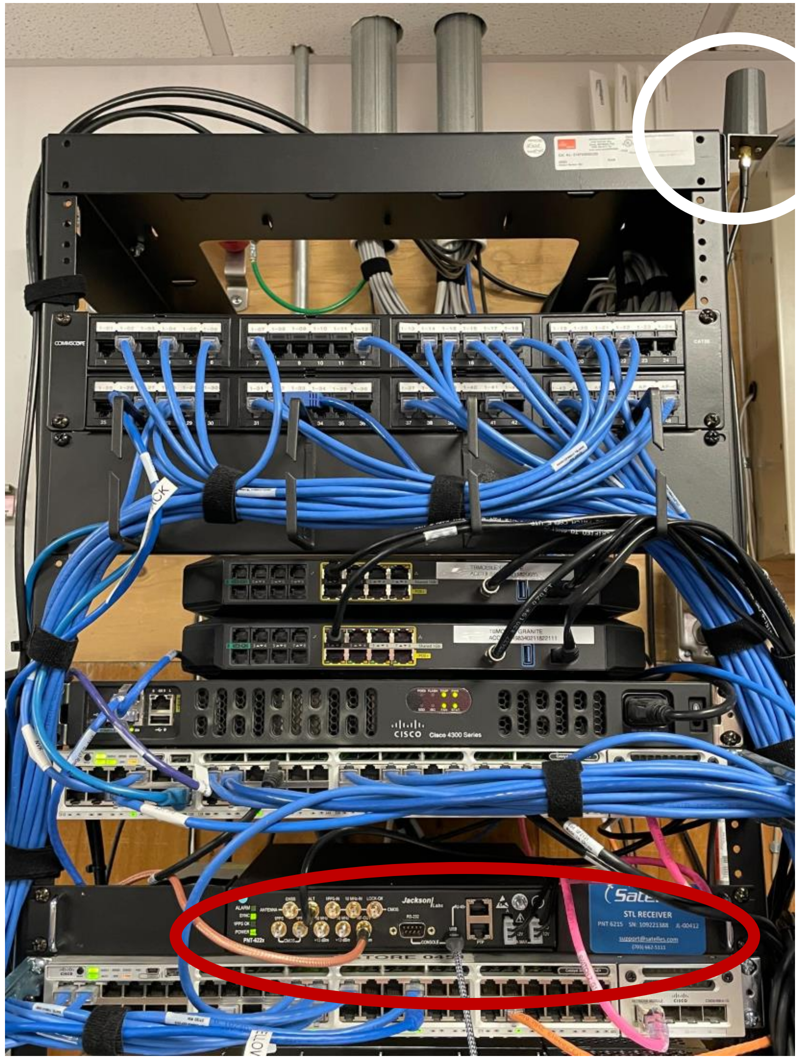
LEO Antenna mounted inside server room at the top of the server rack

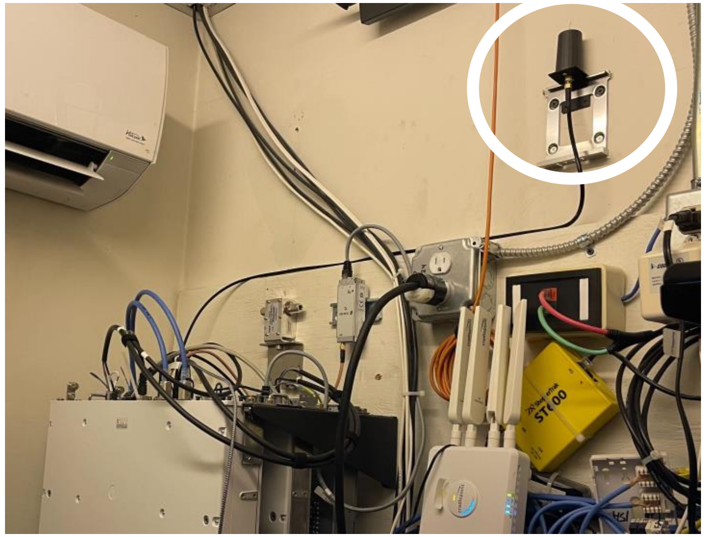
LEO PNT EXAMPLE: Hospital Installation

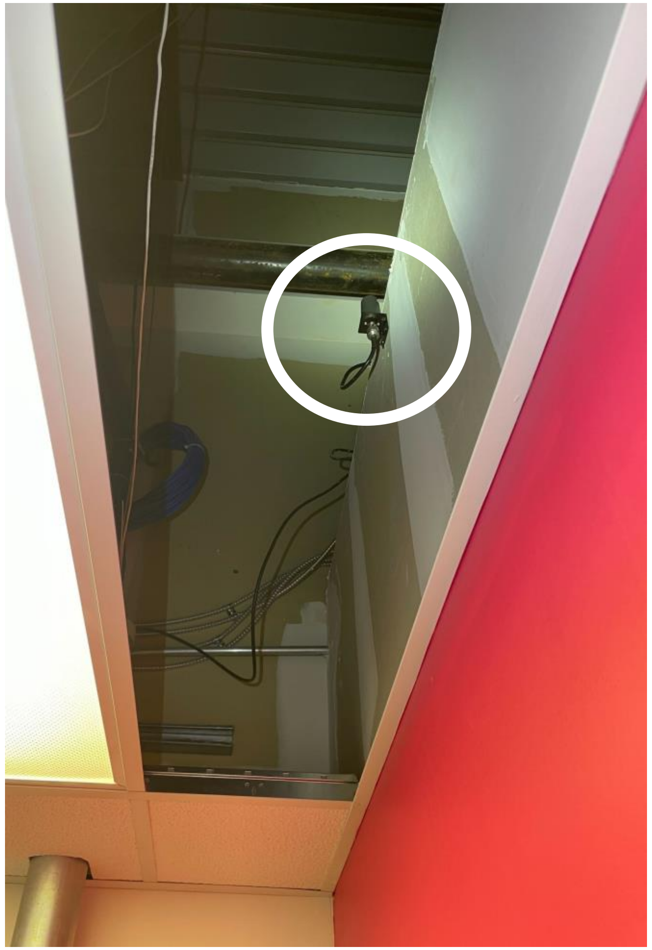
STL LEO receiver used to synchronize Ericsson 5G Micro BTS RANs in hospital data center



LEO PNT EXAMPLE: Shopping Malls (multiple indoor 5G sites)







LEO Antenna mounted above ceiling

STL UTC Accuracy and Traceability

- STL is a NIST-verified Stratum 0 UTC source of timing that can be used to create a Stratum 1 timing clock compliant with the ITU-T G.8272 PRTC-A performance standard
- Timing stabilities of 10-50 nanoseconds (1-sigma) are available depending on oscillator type
- STL timing is traceable and maintained to UTC(USNO) and UTC(NIST) via multiple geographically distributed tracking stations

	OUTDOOR ANTENNA		INDOOR ANTENNA	
Oscillator Type	**Stability (ns 1-sigma)**	**Max Error (ns)**	**Stability (ns 1-sigma)**	**Max Error (ns)**
TCXO (Stratum 3)	42	218	53	241
OCXO	41	176	43	152
DOCXO	31	96	35	82
Rubidium (MAC)	15	35	33	81
Rubidium (lamp)	10	27		

Examples of STL timing performance by oscillator type

Note: Testing performed at room/lab temperature

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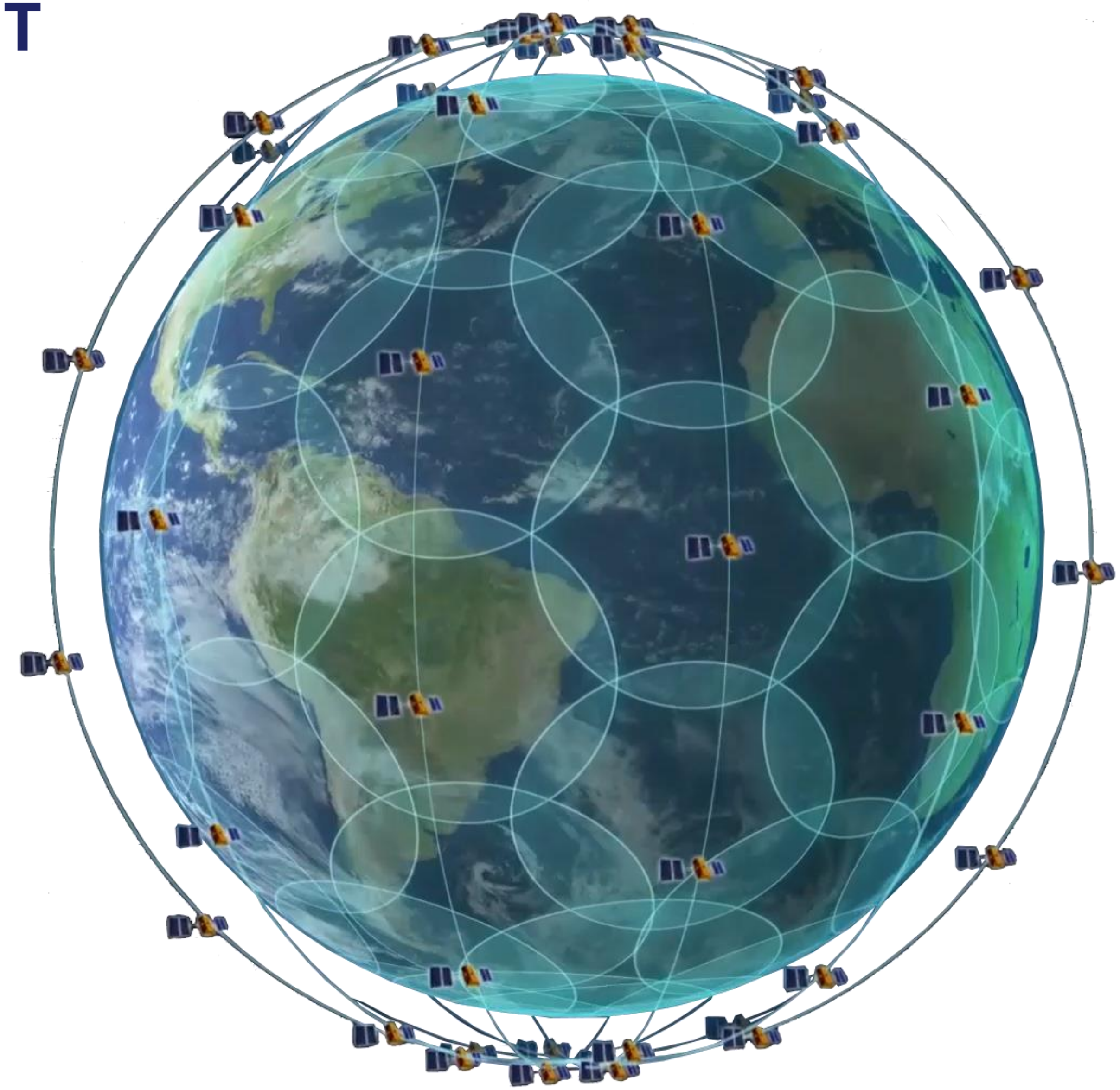
Additional Benefits of STL LEO PNT

- ✓ Resilient Backup for GNSS
- ✓ Authenticated Time and Position
- ✓ Spoof-proof features
- ✓ Available worldwide now



Questions?

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Additional considerations for Indoor operations

- Although LEO PNT (STL) does not require an outdoor antenna, there are many possible indoor scenarios and consideration should be given to the location of the antenna
- Locating the antenna too deep inside a building or surrounding it by metal walls will excessively attenuate the signal
- To optimize performance, an antenna installation should consider the path loss to the outside of the building or structure.
- For most indoor locations, locating the antenna near or within sight of a window, skylight, or outside wall will provide very good performance
- Some indoor antenna locations will receive a reflected or indirect signal, resulting in an unknown path delay "offset" (usually less than 100 ns)

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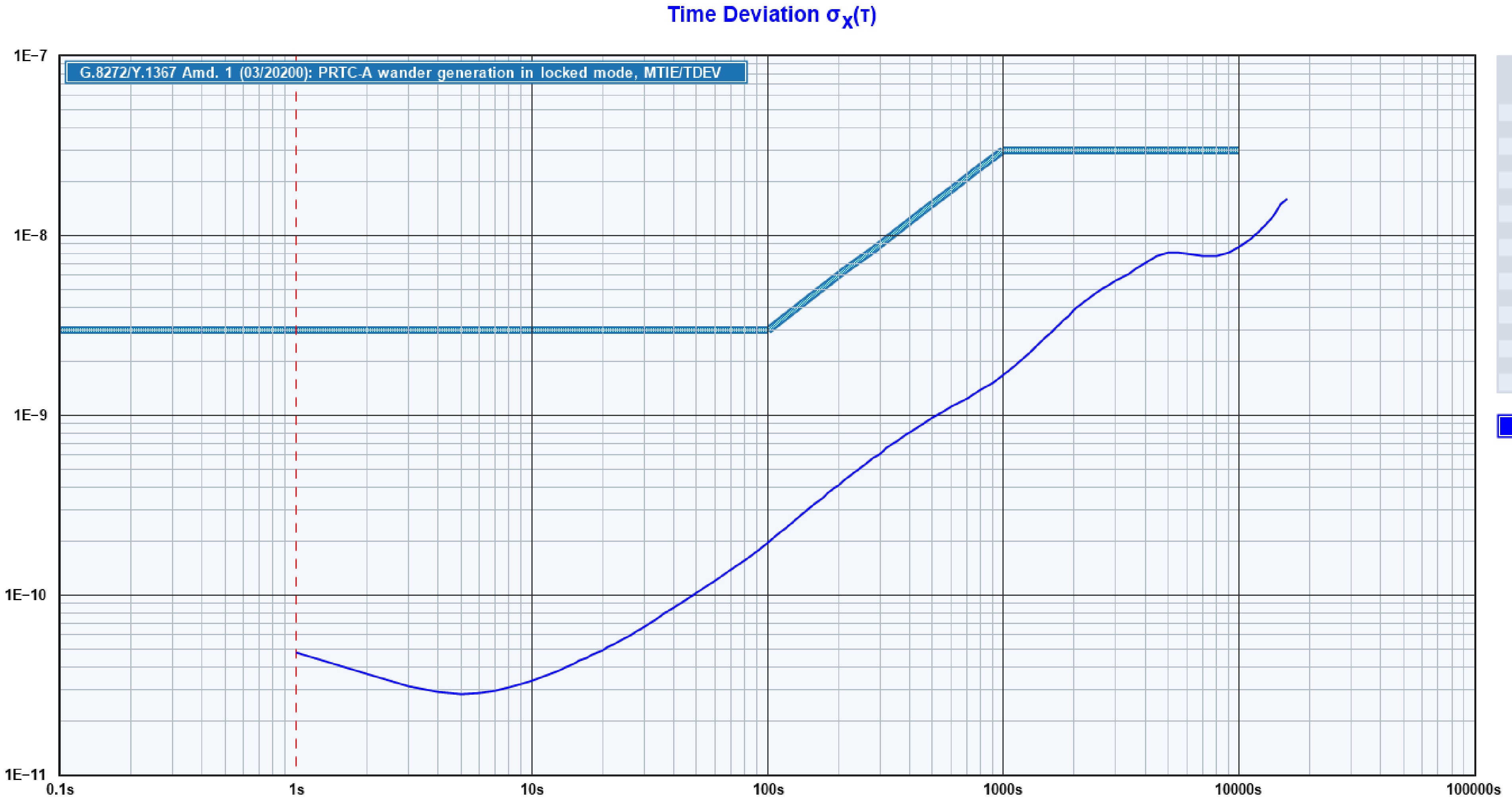
STL TDEV (Rb oscillator, outdoor antenna), stability 15 ns, 1-sigma



Tau	Sigma(Tau)
1s	4.81E−11
2s	3.63E−11
4s	2.90E−11
8s	3.05E−11
10s	3.34E−11
20s	4.96E−11
40s	8.51E−11
80s	1.57E−10
100s	1.96E−10
200s	4.12E−10
400s	8.07E−10
800s	1.38E−9
1000s	1.69E−9
2000s	3.85E−9
4000s	7.06E−9
8000s	7.76E−9
10000s	8.67E−9

Trace	Notes	Input Freq	Sample Interval	TDEV at 1s	Duration	Elapsed	Acquired	Instrument
PNT-6235 Rb-MAC (Unsaved)	STL 15 ns 1-sigma	1.0 Hz	1.000 s	4.81E−11	100 d	19h 22m 36s	49202 pts	Agilent 53230A

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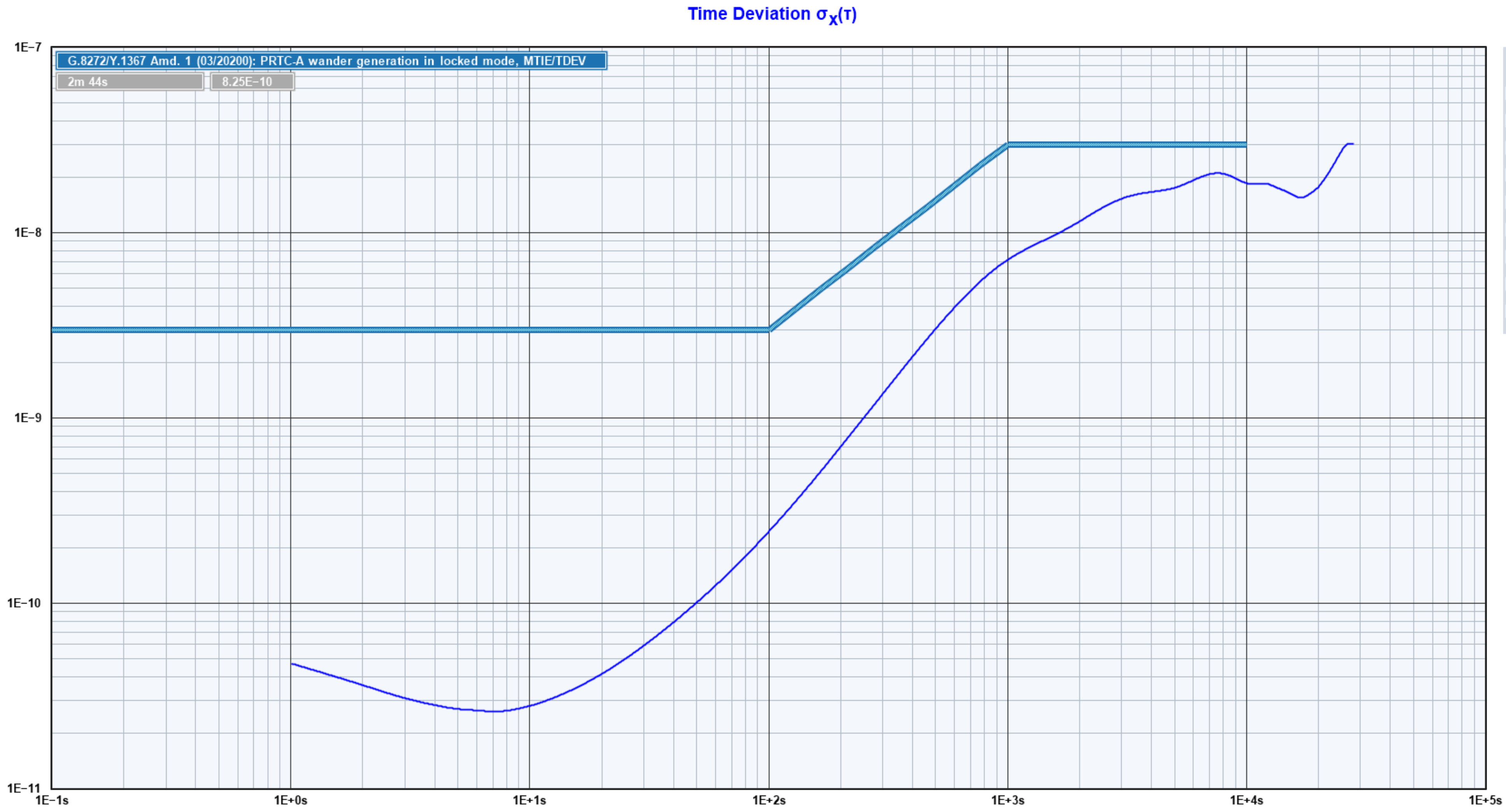
STL TDEV (Rb oscillator, indoor antenna), stability 34 ns, 1-sigma



Tau	Sigma(Tau)
1E+0s	4.76E−11
2E+0s	3.63E−11
4E+0s	2.84E−11
8E+0s	2.65E−11
1E+1s	2.82E−11
2E+1s	4.21E−11
4E+1s	8.02E−11
8E+1s	1.83E−10
1E+2s	2.48E−10
2E+2s	7.12E−10
4E+2s	2.19E−9
8E+2s	5.81E−9
1E+3s	7.23E−9
2E+3s	1.17E−8
4E+3s	1.67E−8
8E+3s	2.09E−8
1E+4s	1.86E−8
2E+4s	1.80E−8

Trace	Notes	Input Freq	Sample Interval	TDEV at 4E+5s	Duration	Elapsed	Acquired	Instrument
PNT-6235 Rb-MAC	STL indoor 34 ns1-sigma	1.0 Hz	1.000 s		1d 0h 0m 23s	1d 0h 0m 23s	86423 pts	Agilent 53230A

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European Commission Alternative PNT Demonstration

PREVIEW

A technical demonstration was recently conducted as part of an evaluation of STL and other technologies by the European Commission's Directorate-General for Defence Industry and Space (DEFIS) in a study conducted by the EC's Joint Research Centre (JRC) in Ispra, Italy.

	STL Performance Summary		
Key Performance Indicator	**1 day**	**14 days**	**100 days**
Timing Accuracy to UTC (1 Sigma)	106.8 ns	144.8 ns	135.4 ns
Timing Accuracy to UTC (3 sigma)	498.4 ns	651.7 ns	355.2 ns
Timing Stability (Allan Deviation)	2.57E-12	2.05E-13	2.28E-13
Availability (%)	100%	100%	100%
Continuity (per hour)	100%	100%	100%
Horizontal accuracy (95%)	25.699 m	26.559 m	23.845 m
Vertical accuracy (95%)	7.200 m	9.670 m	16.800 m
First time to provide continuous services upon cold start-up (including system and receiver contributions)	< 15 min	< 15 min	< 15 min

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