Terrestrial Timing System

SECURE, RESILIENT SOLUTION FOR POSITION, NAVIGATION, AND TIMING

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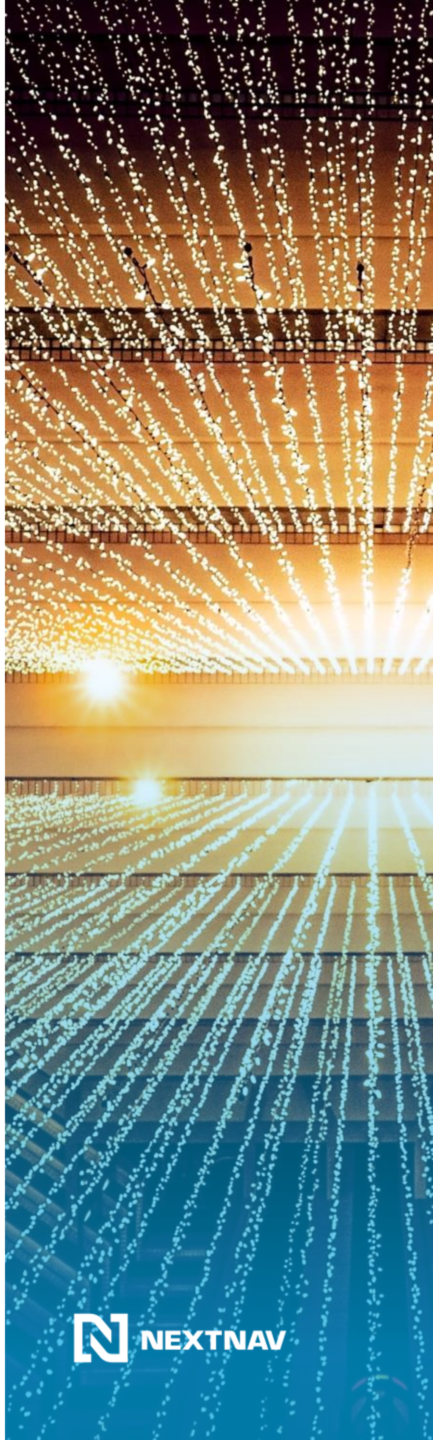
Agenda

- > Need for resilient timing
- > TerraPoiNT system
- > Network and beacon timing
- > Timing in urban areas with multiple hops
- > Trials and results
- > Conclusion

Resilient Timing

- Timing has become critical for major infrastructure and requires a resilient timing system
  - Most of the timing systems utilize GNSS receivers to derive and provide timing information
- GNSS-based Timing systems are susceptible to the following problems:
  - Low GNSS signal strength creates constraints in antenna placement & cable calibration
  - Easily prone to interference: weak signals can be easily jammed
  - Spoofing: Various incidents have indicated that GPS system is vulnerable to spoofing which can cause more damage than undesired interference
- The NextNav TerraPoiNT system provides a better timing solution that overcomes the challenges of existing systems



System Attributes

- Provides full position, navigation and timing capabilities in urban and indoor environments with or without the presence of GPS
  - Timing only services offered with 1-2 beacon overlap
  - Full PNT services with 4 beacon overlap
  - Resilient timing and operation in absence of GPS
- "Mission critical" reliability: support for an encrypted signal and resistant to spoofing/jamming
- Nationwide spectrum owner (920 – 928 MHz) – 95% urbanized POPs
- Supported in global cellular standards - 3GPP (Rel. 13+) and OMA (SUPL 2.0.3) as "MBS", a type of terrestrial beacon system (TBS), as well as at other SDOs
- PNT IC based capability available from 1H 2022

System Architecture

- **Beacons** deployed throughout the coverage area
- Each beacon has an **onboard timing source**
- Beacons share time with each other to **maintain local synchronization**
- UTC sync to a small subset of beacons can be provided using:
  - Any absolute alternate timing source (eg. ToF, LEO satellite, TWSTT) and can also be maintained across outages using a local Cesium.
  - Or… holdover from GNSS maintained using local Cesium during GNSS outages
- **Signal is encrypted** to enable user authentication and to provide a level of spoofing protection

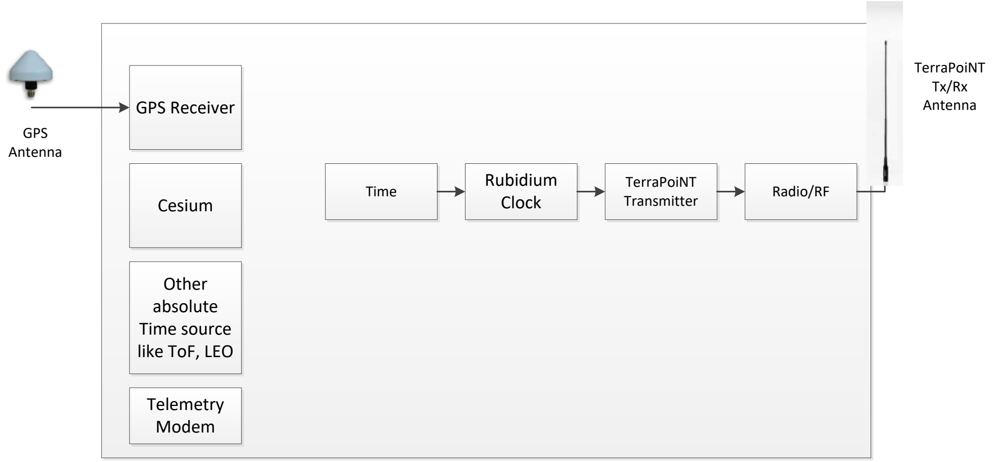
Resilient mesh architecture:

if any beacon is compromised, the service will continue

Timing Fusion Technology

Leader Beacon

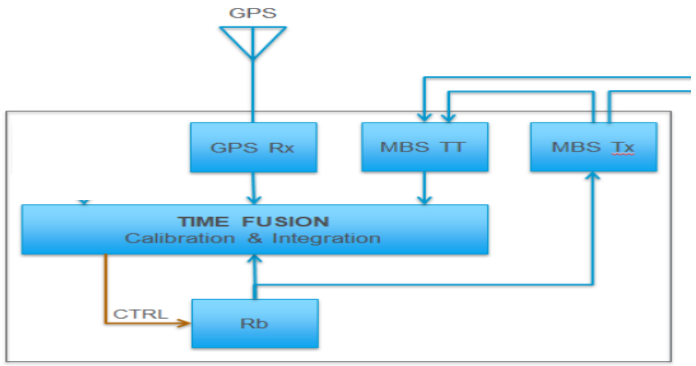
- Can accept multiple absolute time sources: i.e GPS, Time-Over-Fiber (TOF), Low-Earth Orbit satellites
- Rb atomic clock provides ST-2 holdover and ability for an extended holdover source such as Cesium



* Note that the beacon can operate completely GPS free

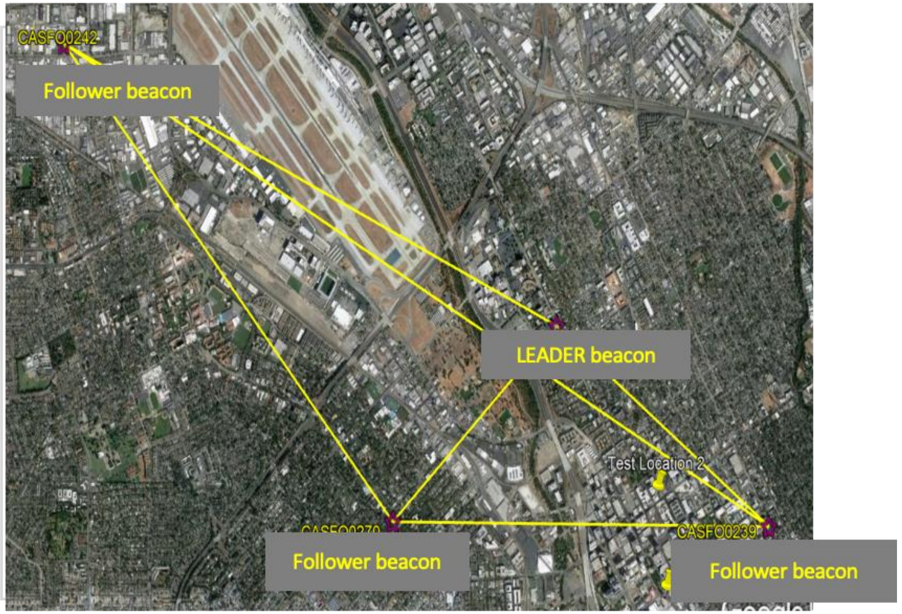
Follower Beacon

- All beacons have a two-way time transfer receiver synchronizing through measured paths from other beacons
- Follower-Leader timing is maintained through two-way time-transfer based corrections
- Follower control loop with mix of centralized and distributed control which applies the corrections to the Rb clock



Mesh Network Wireless Sync of Beacons

- **The network** is a mesh of beacons (transmitters) consisting of Leader beacon(s) and Follower beacons
  - Leader beacon(s) have access to one or more absolute time sources (UTC)
  - Follower beacons listen to one or more Leader and Follower beacons, and compute ToA measurements for time transfer purposes
- **TWTT technology** is used to take ToA measurements and compute synchronization information for each beacon



APNT Demo Network
at SJ

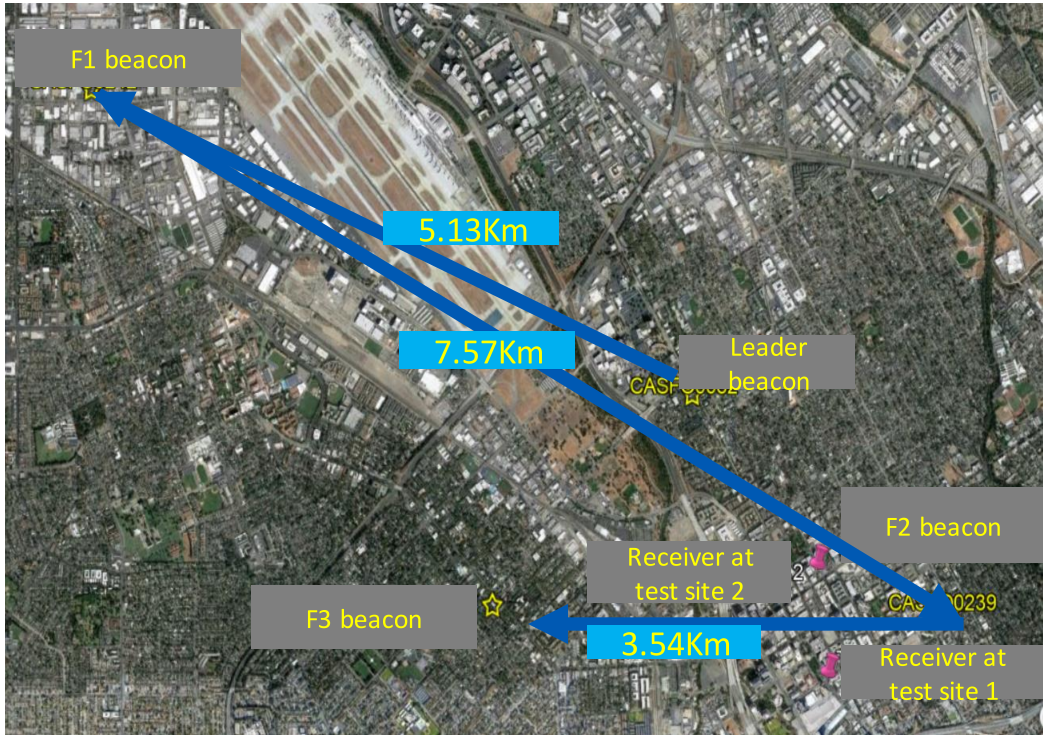
Time transfer over multiple-hops

- **In a network,** the follower beacon can derive timing using another follower resulting in multiple hops to synchronize the beacon with leader which has the UTC time
  - The mean of the time transfer error between a pair of beacons (one hop) can be positive or negative
  - When time is transferred across multiple hops, the cumulative mean time error need not grow always. However, the variance of time error grows as the number of hops increase
  - TerraPoiNT network can have multiple time transfer beacon paths where the best path can be pre-selected during installation or dynamically to get minimum time error growth
- **In this APNT network,** the follower beacons were able to maintain time within 10ns of the absolute time

Time Distribution Demonstration

- **A network of 4 beacons in SanJose (SJ) downtown:**
  - Leader, Follower 1 (F1), Follower 2 (F2) and Follower 3 (F3)
  - F1 follows Leader, F2 follows F1 and F3 follows F2 beacon.
- **Total time transfer distances:**
  - First hop distance (L→F1) is 5.13 km
  - Two-hop distance (L → F1 → F2) is 12.7 km
  - Three-hop distance (L → F1 → F2 → F3) is 16.24 km
- **Two test locations**, in challenging indoor environments
- NextNav Timing Receiver (NTR) configured to track F1, F2 or F3 depending on the scenario.

Network and Test Sites



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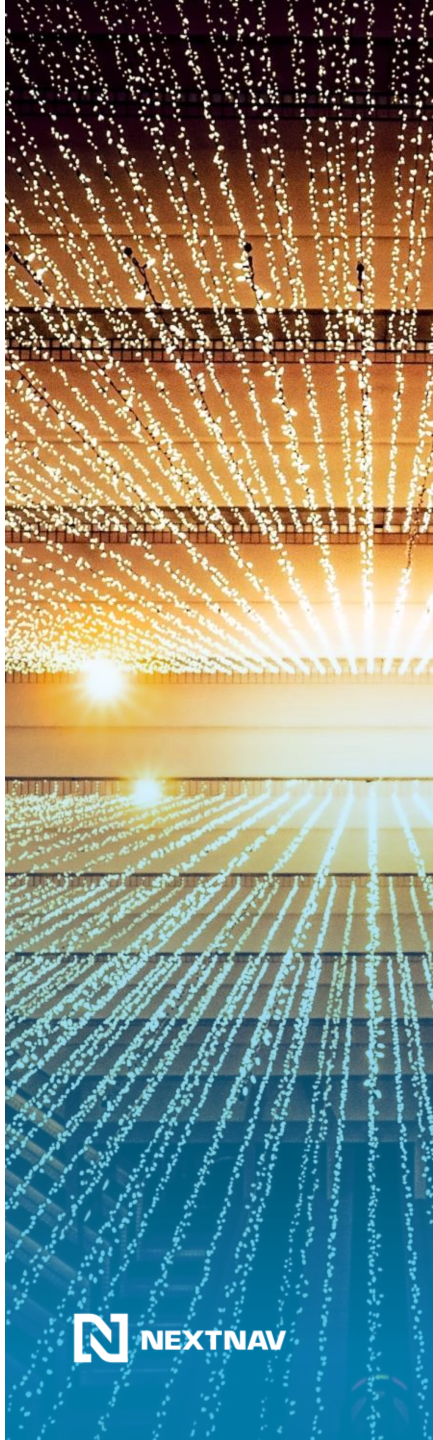
Demo Timing Receiver Capabilities

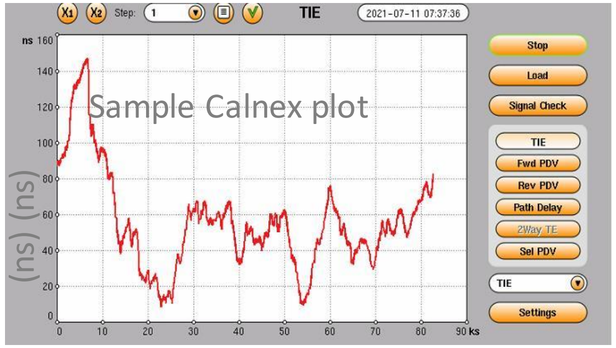
- Provides HW based PPS + 10MHz + time of day (TOD) message including residual time corrections
- Performs self-survey or accepts pre-surveyed location as input
- Automatically selects the best beacon signal for extracting timing
- Based on an OCXO
- Present receiver takes ~10 minutes to provide a valid PPS output after the receiver is configured/powered-on
- Configuration and monitoring is through a serial port



Demo Performance Assessment Methodology @ Timing Receivers

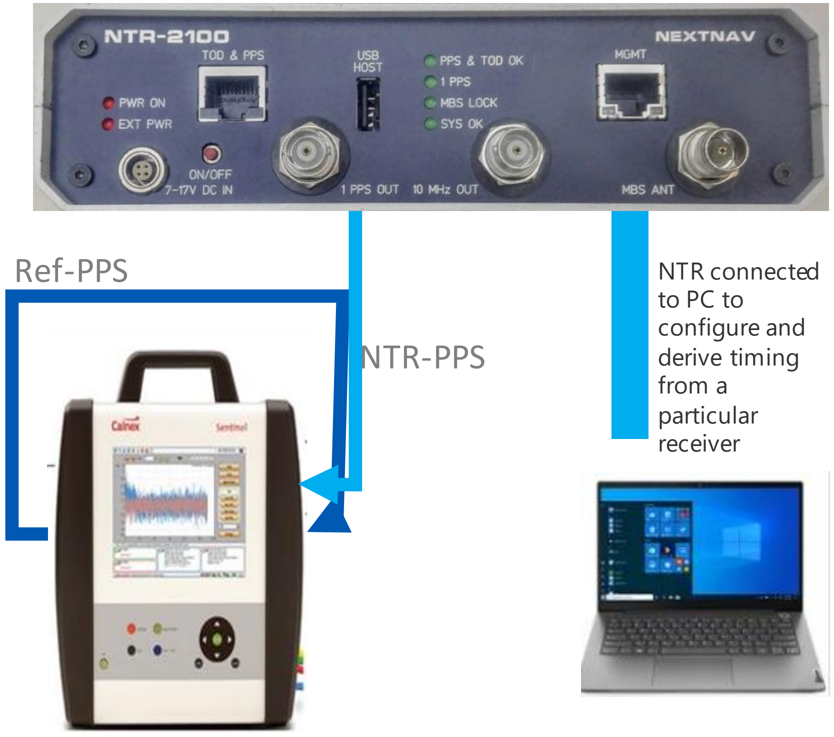
- Timing receiver is used in this demo to derive timing from a specific beacon
- Performance of the receiver against timing truth is measured using Calnex or an equivalent system
- The Calnex or equivalent system measures and displays the time error of timing receiver pps with respect to timing truth

Time Error (ns)



Time Elapsed (Ks)

NextNav Timing Receiver (NTR)



Calnex or Equivalent system

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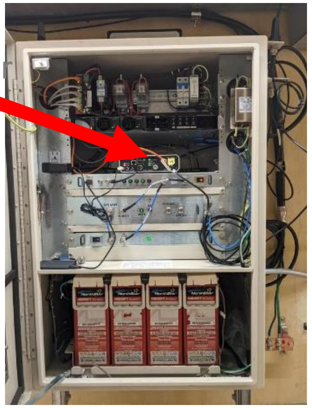
Test Setup at Site 1

The test location is in San Jose downtown

Antenna for timing receiver

Timing receiver



The timing receiver and its antenna are located inside a sheltered equipment room on the top floor of a 14-story building.

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Test Setup at Site 2

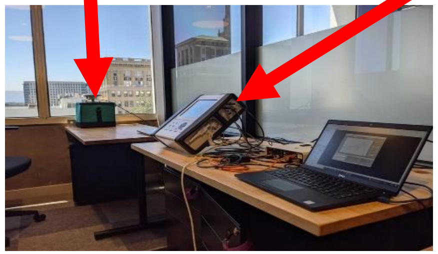
The test location is in San Jose downtown.

The timing and its antenna are located inside the office space, on the 8th floor of a 12-story building.

The office is in a deep indoor location, ~25 ft from the window.

Calnex GPS antenna

Calnex



NTR

NTR Antenna

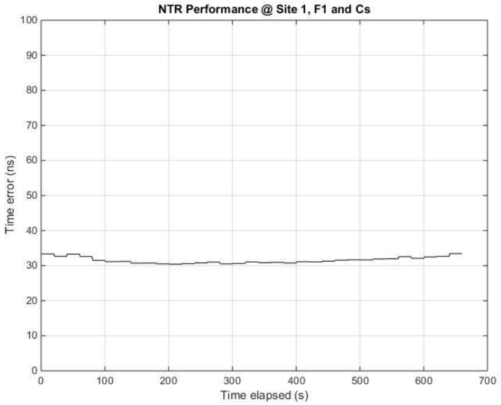
Results @ Test Sites

- Short Term tests over 1 hour duration were performed

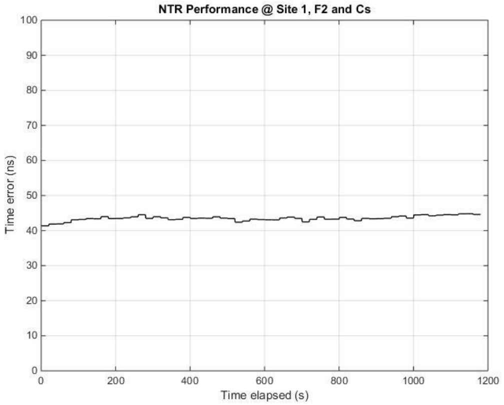
High accuracy @ errors well under 100 ns

Stable performance @ less than 20 ns variability

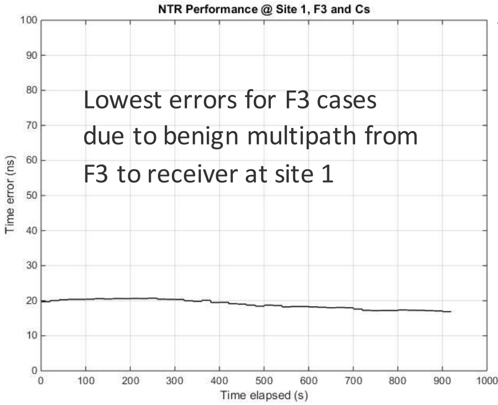
Test Site1



F1



F2

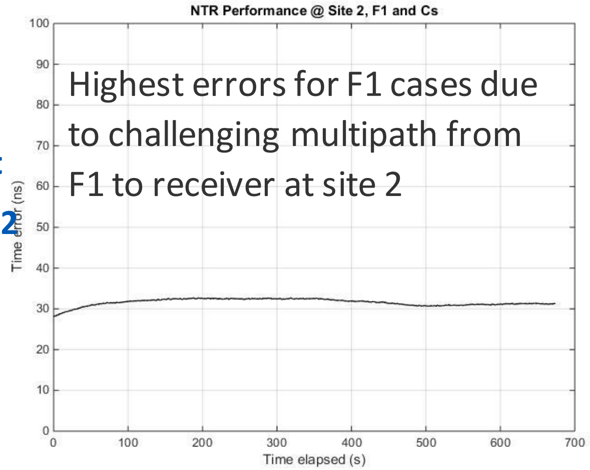


Lowest errors for F3 cases due to benign multipath from F3 to receiver at site 1

100 ns

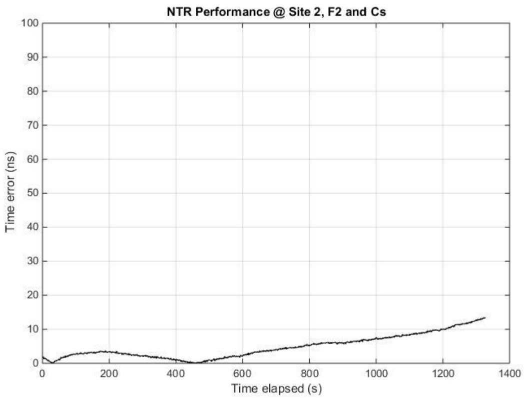
F3

Test Site2

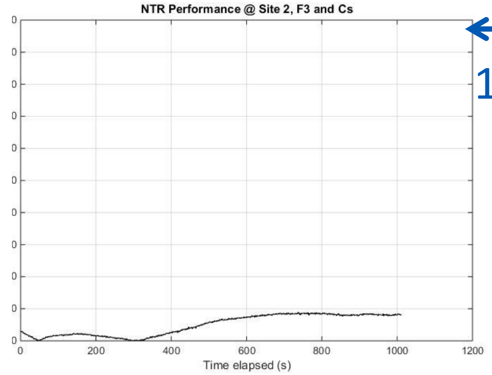


Highest errors for F1 cases due to challenging multipath from F1 to receiver at site 2

F1



F2



100 ns

F3

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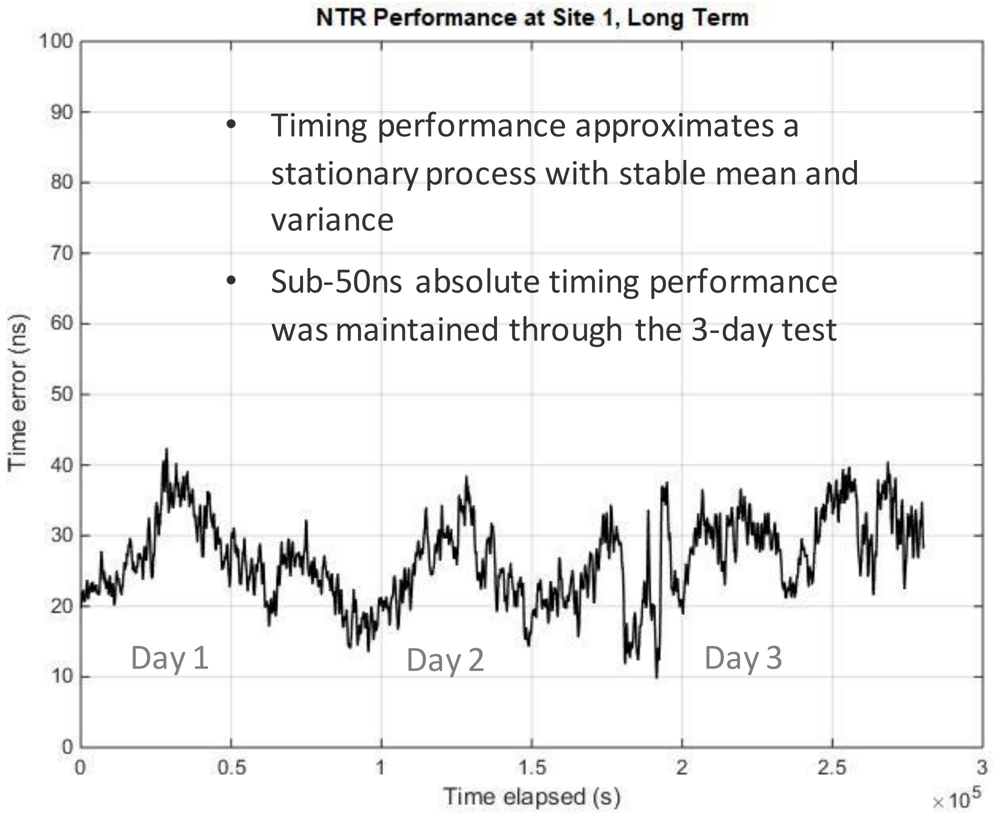
Long Term Test

- A test was performed over 72 hour long to determine the performance over a long term
- The results indicate absolute accuracy within 50ns
- This indicate TerraPoiNT timing is stable over long term



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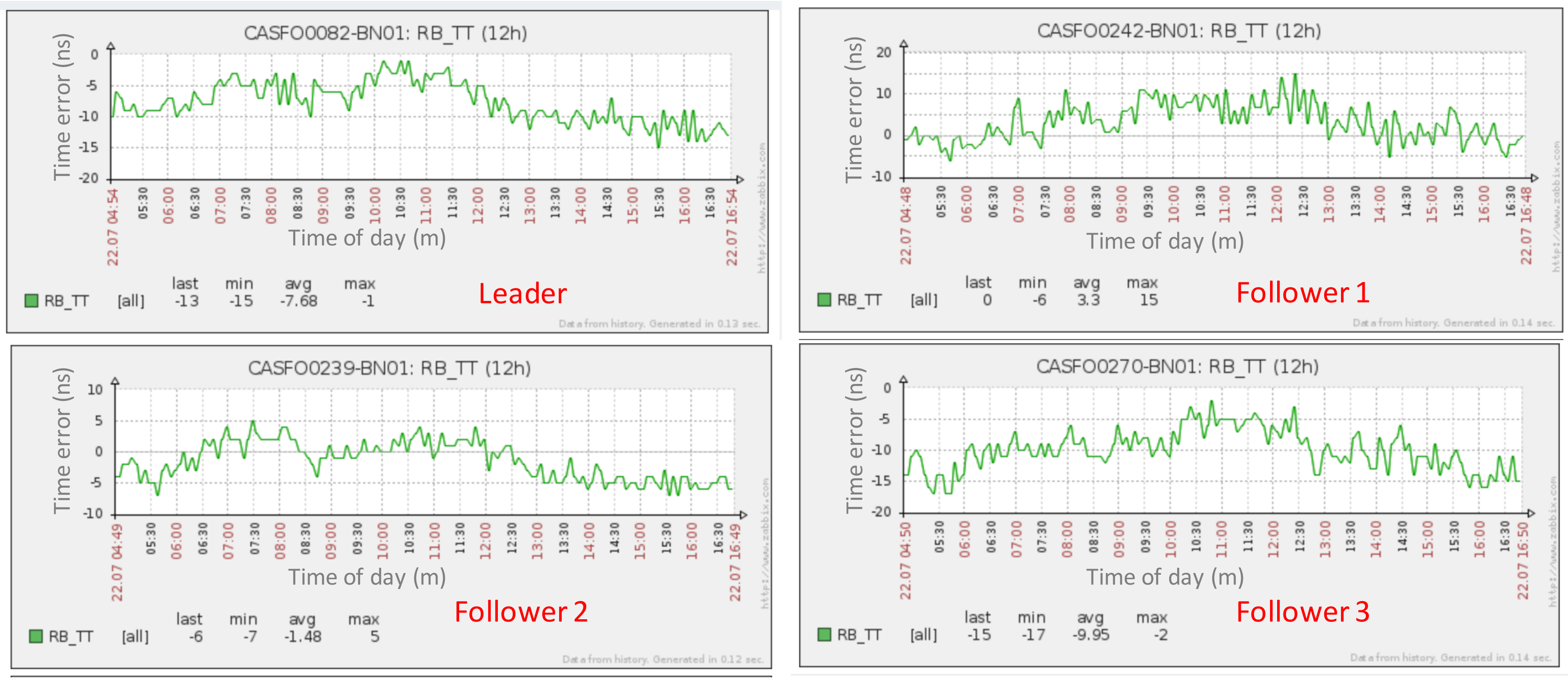
Beacon Time Sync Performance

Beacon timing compared to the GPS Timing truth



Followers track the Leader

Timing errors within [-15 ns to +15 ns]

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Conclusions

- **Demonstration showed** a functional, stable and **high precision timing system that is independent of GPS, in a real-world environment**
- Time transfer system, combined with a Cesium clock or other time source can deliver high precision timing **wirelessly across a wide coverage area**
- The demonstration showed **the system can accept multiple time references and maintain relative and absolute sync** across the beacon network and in a robust manner
- Beacon network timing for end user timing applications was delivered in **difficult urban environments** using a **timing receiver accurate within 50ns**, which could be built with the same form factor as a GPS chipset-based solution
- Demonstration shows the TerraPoiNT system provides the capability to distribute the UTC time wireless with accuracy required to support applications such as 5G time sync, timing for automotive applications