Locata®

Precise Time and Frequency Using the TimeLoc Technique

Paul Benshoof

NIST-ATIS Workshop on Sync and Timing Systems

Agenda

- Background
- Locata Technology
- TimeLoc
- USNO Testing
  - Urban Environment: Washington, DC
  - Long Range: White Sands Missile Range, NM
- Conclusions/Summary

Background

- Precise network synchronization is critical for nearly all digital networks
  - More stringent network stability requirements are expected to emerge as the user base for these applications continues to grow
- Typical applications require:
  - Accurate time synchronization ranging from 10 µs down to 100 ns
  - Stratum 1 telecommunication frequency accuracy of $1x10^{-11}$ (one-day Allen deviation)
- Free availability of GPS time has enabled a plethora of time-dependent applications
  - Significant capability advancement
  - Cost savings for companies that depend on precise time
- However, reliance on GPS for critical timing applications poses two significant problems:
  - GPS is vulnerable to interference and is unreliable indoors, under dense foliage, and in some urban environments
  - GPS may actually be limiting our ability to improve time transfer and frequency stability beyond current capabilities
- GPS Vulnerability remains a growing concern among industry experts
  - Many are actively seeking alternative means of providing precise time transfer and frequency stability across wide areas

Locata Technology

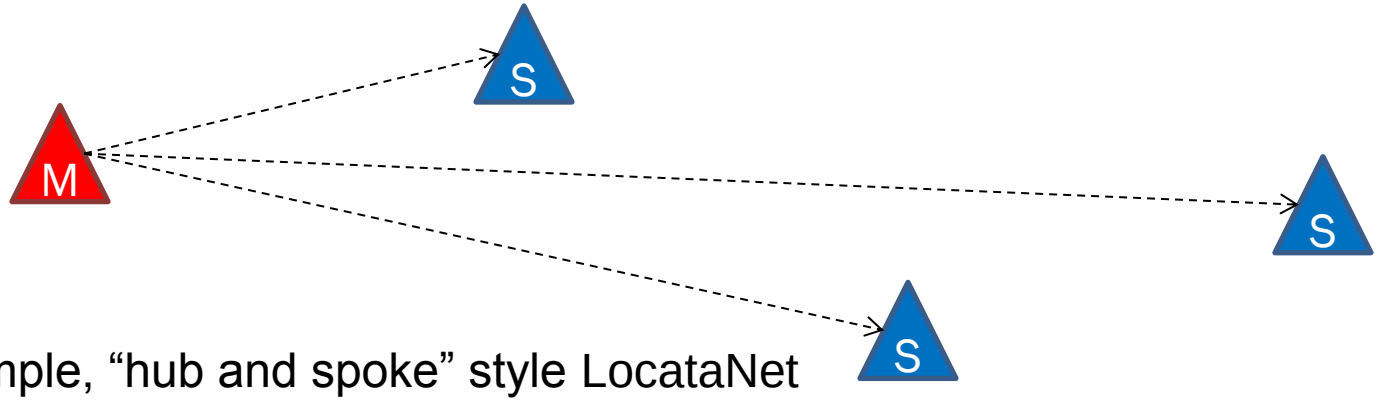
- Locata Corporation
  - Invented a new non-GPS-based radiolocation technology that provides precise PNT in many environments where GPS coverage is marginal, unavailable, or denied
  - Locata Networks (LocataNets) provide ground-based PNT capabilities that deliver positioning advances which, in many scenarios, exceed the performance and reliability available from space-based GNSS signals
  - LocataNets function as "local ground-based replicas" of the traditional space-based GPS position and timing services, and they can be designed to reliably deliver a powerful, controllable, tailored signal as required by different user applications
- Demonstration of accurate time transfer using Locata:
  - In late 2013, Professor Chris Rizos and his team from the University of New South Wales (UNSW) demonstrated Locata's time transfer capability
  - Results showed that LocataNet provided accurate time transfer (~5ns) and frequency stability (~1 ppb) across a large 73 km (45.4 mile) area
  - Accomplished without the use of atomic clocks

Encouraged by these results, the USNO conducted several independent frequency synchronization experiments using Locata

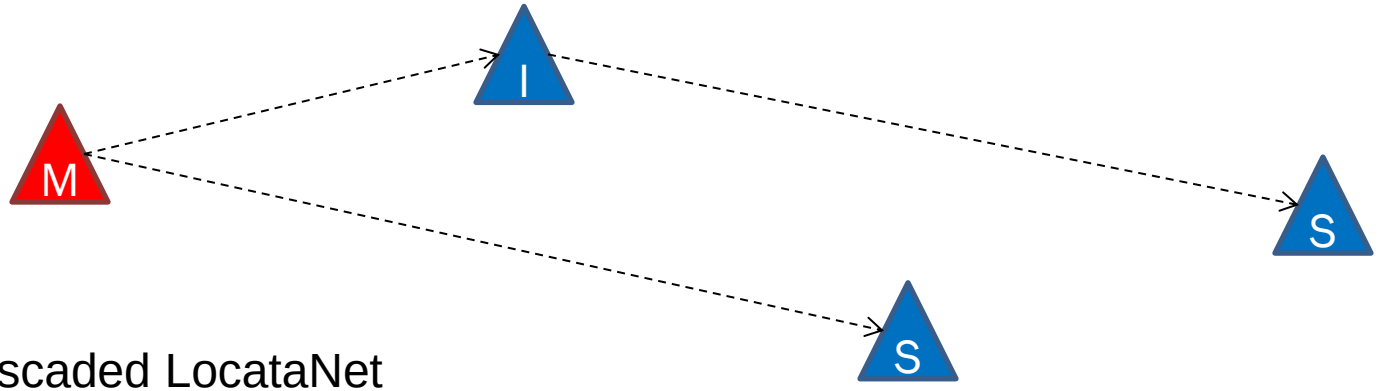
Locata Technology

- Locata Signals
  - Broadcast from “LocataLite” transceivers
  - Industrial, Scientific and Medical (ISM) 2.4GHz radio band (Wi-Fi band)
  - Total radiated power of 200 – 500 mW
  - Line-of-Sight (LOS) System
- TimeLoc
  - Locata’s patented high-accuracy wireless synchronization method
  - Allows LocataLites to achieve high levels of synchronization without external dependencies (i.e. atomic clocks, differential GNSS corrections)
    - Requires meteorological data for best performance over large areas
  - In theory, there is no limit to the number of LocataLites that can be synchronized together using TimeLoc
  - Allows a LocataNet to propagate into difficult environments or over wide areas
    - Cascading

TimeLoc

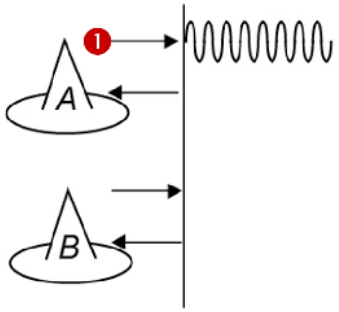


Simple, “hub and spoke” style LocataNet

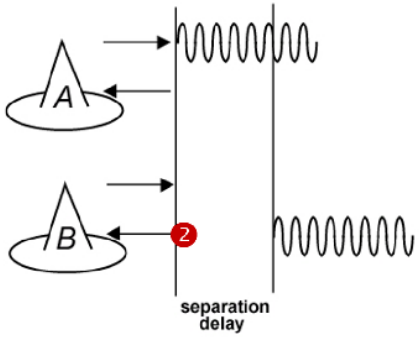


Cascaded LocataNet

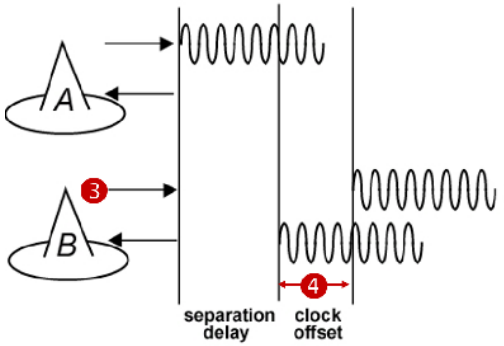
TimeLoc



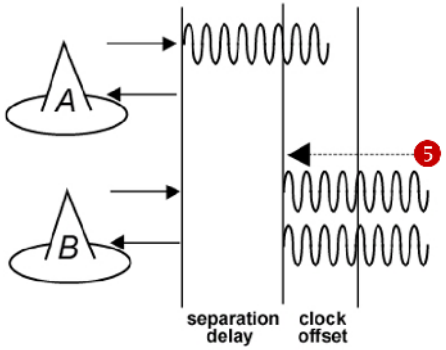
STEP 1 LocataLite A transmits a unique signal (code and carrier)



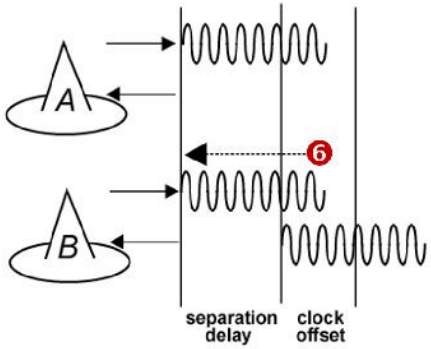
STEP 2 LocataLite B acquires, tracks and measures the signal generated by A



Step 3. LocataLite B generates its own unique signal (code and carrier) which is transmitted in the normal manner, but is received by the receiver section of LocataLite B as well.
Step 4. LocataLite B computes difference (clock offset) between transmitted and received signals.



STEP 5 LocataLite B adjusts its local oscillator to bring the differences between its own signal and LocataLite A's received signal to zero

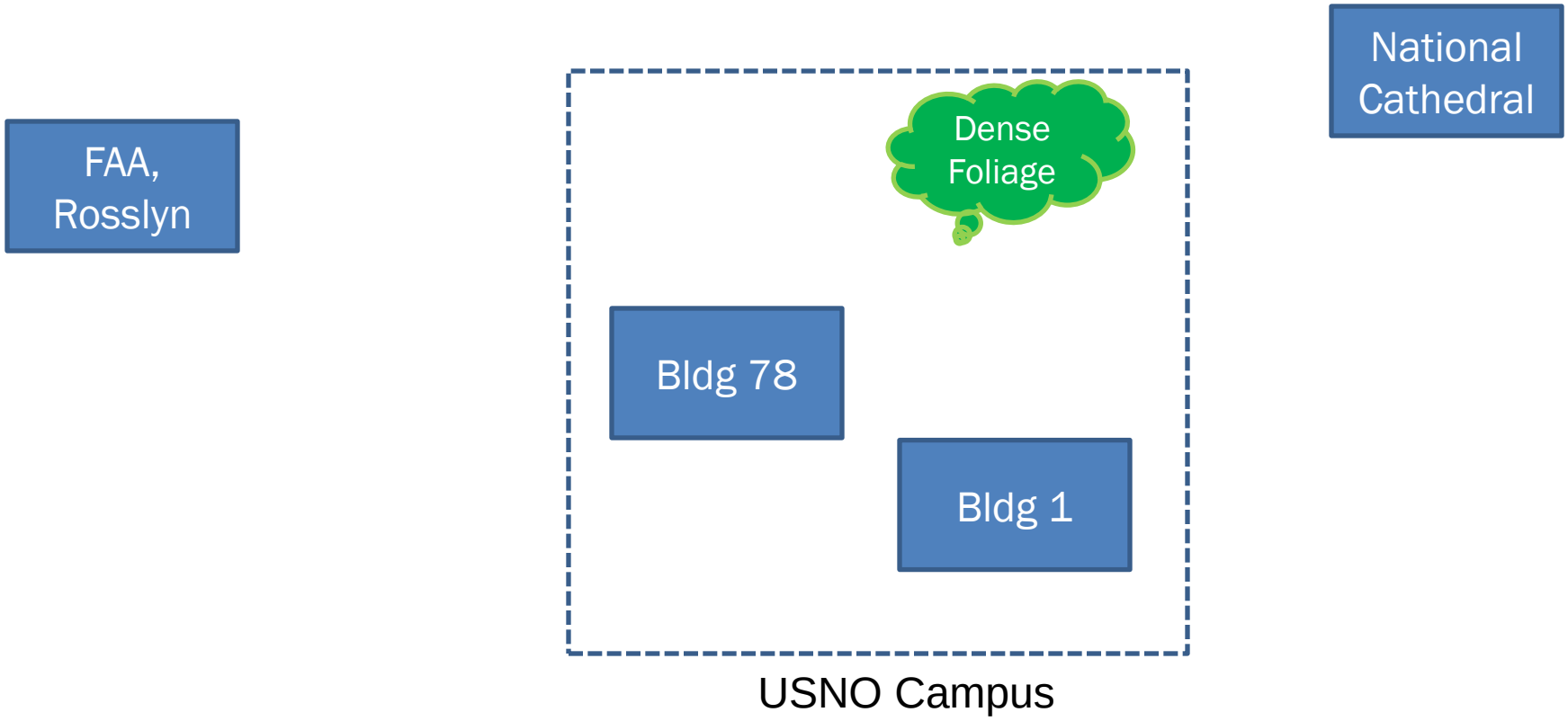


STEP 6 The system corrects for the geometrical offset (range) between LocataLite A and B, using the known coordinates of the LocataLites' antennas. When this step is accomplished, TimeLoc has been achieved.

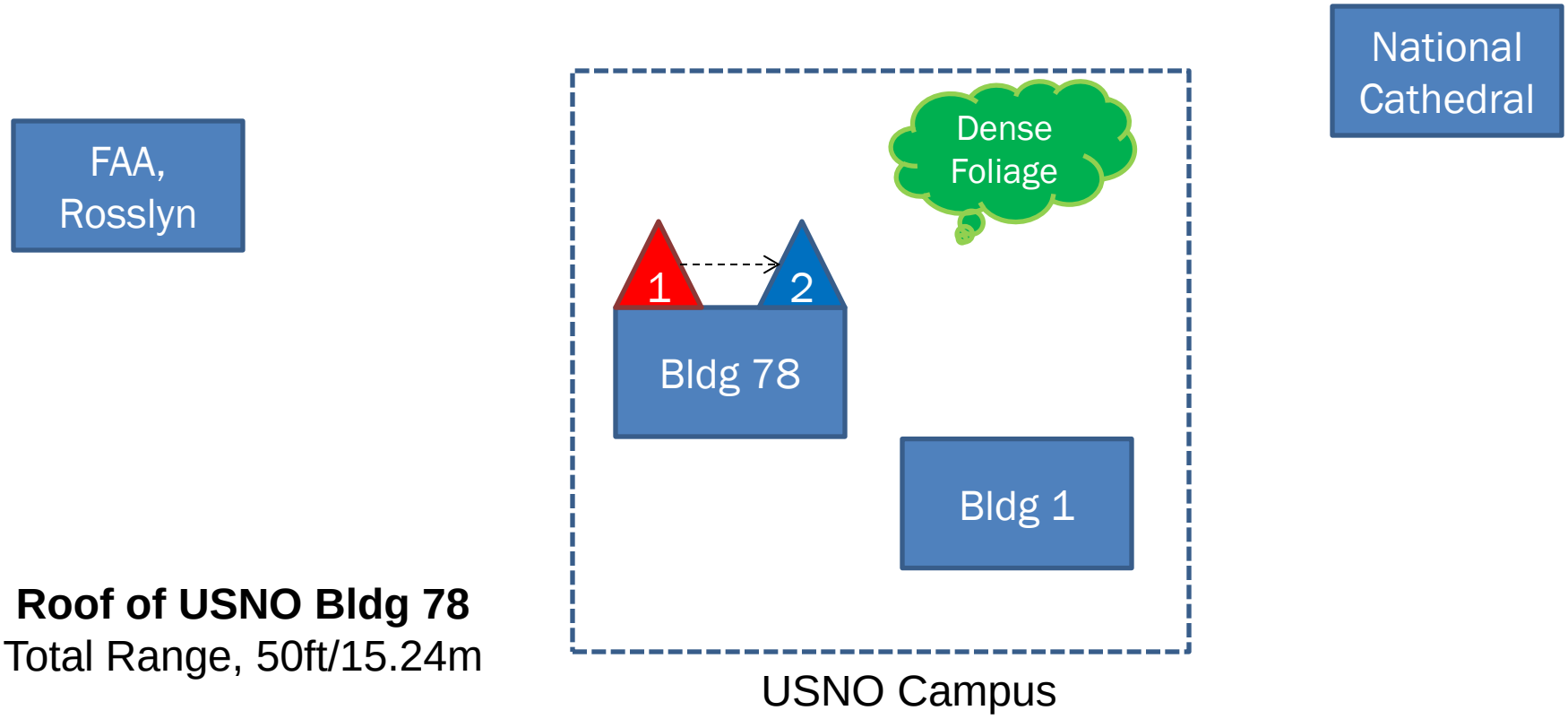
USNO Testing

- The USNO conducted several independent frequency synchronization experiments using Locata in multiple network configurations
  - Special interest in evaluating “cascading” TimeLoc
  - Method could potentially cover substantially large urban areas
- LocataLites and their respective antennas were installed at locations that permitted LOS between units
- In each configuration, the Master LocataLite (LocataLite 1) was synchronized to the USNO Master Clock
  - Master Clock’s time was propagated through the LocataNet
- Master and terminal Slave LocataLite 1PPS signals were collected into a time interval counter
  - Time difference between their rising edges was measured
  - Collected minimum of 30,000 seconds (8.33 hours) of data for each test (in Washington, DC)
- Meteorological (MET) station collocated with Master LocataLite
  - Measures temperature, pressure and relative humidity in LocataNet
  - Permits modeling to mitigate the tropospheric effects
  - Unmodeled tropospheric delay is approximately 280 parts per million (ppm), which equates to nearly one nanosecond over each kilometer of transmission

LocataLite Sites (in DC)

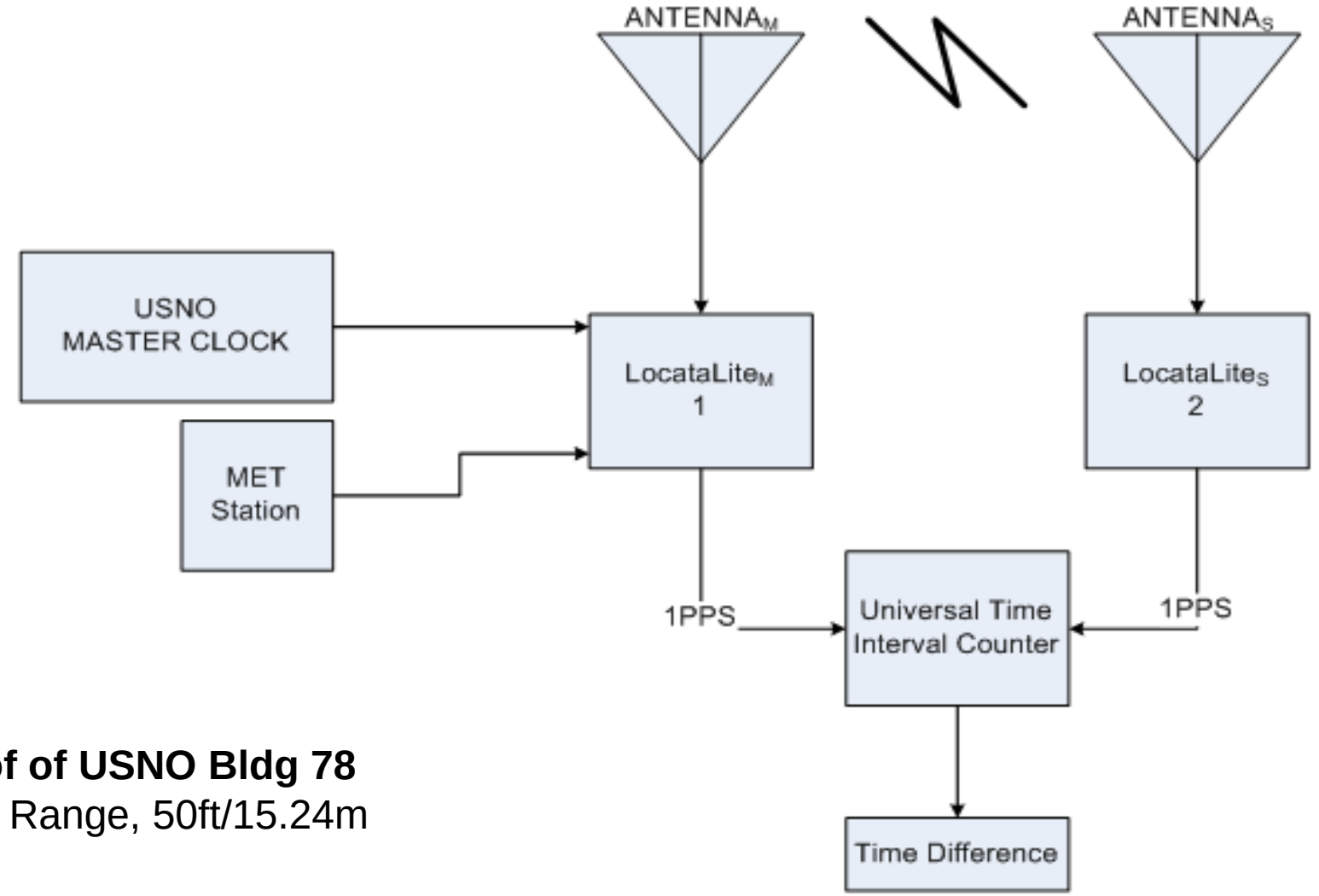


Two-Node Set-up



Roof of USNO Bldg 78
Total Range, 50ft/15.24m

Two-Node Set-up

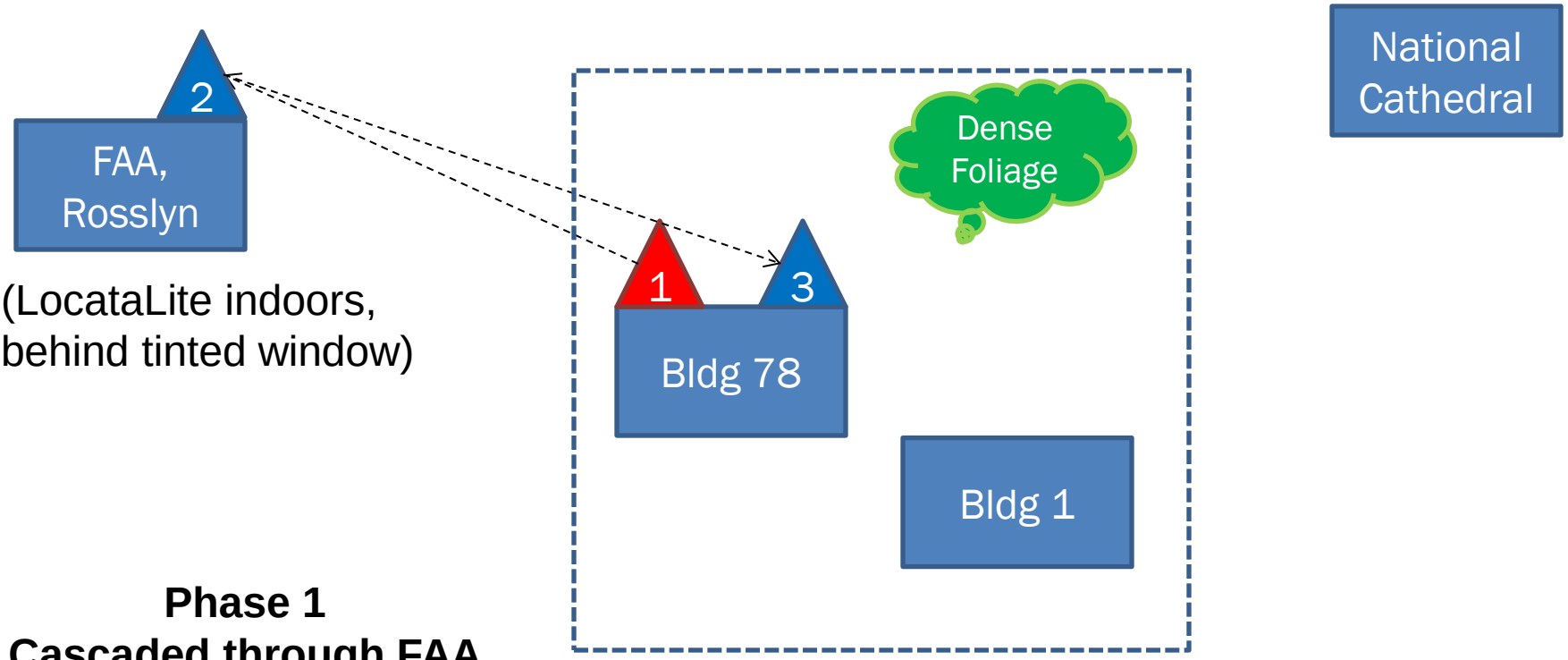


Roof of USNO Bldg 78
Total Range, 50ft/15.24m

Two-Node Set-up

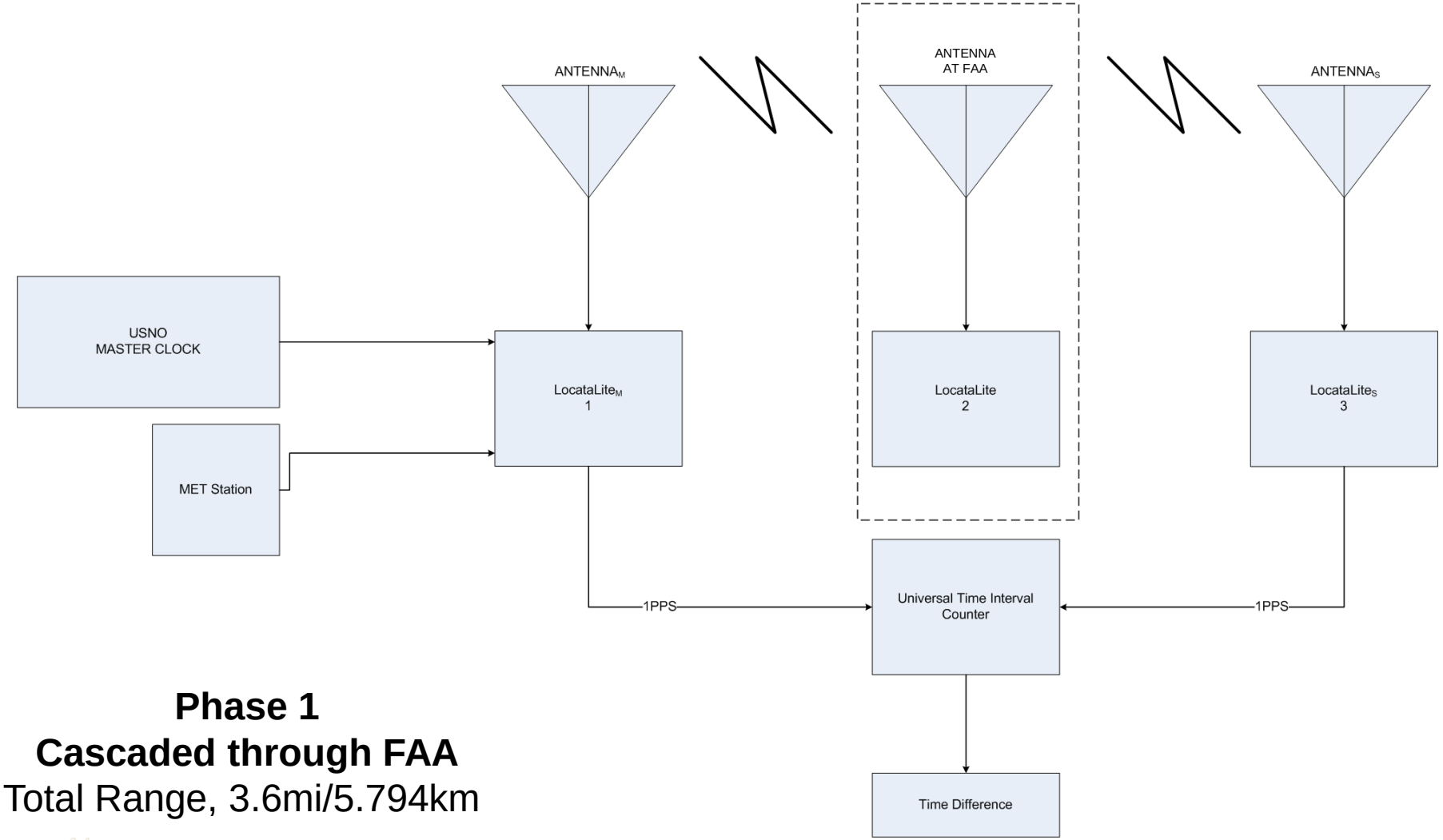
Two LocataLites under Evaluation at USNO

Three-Node Set-up



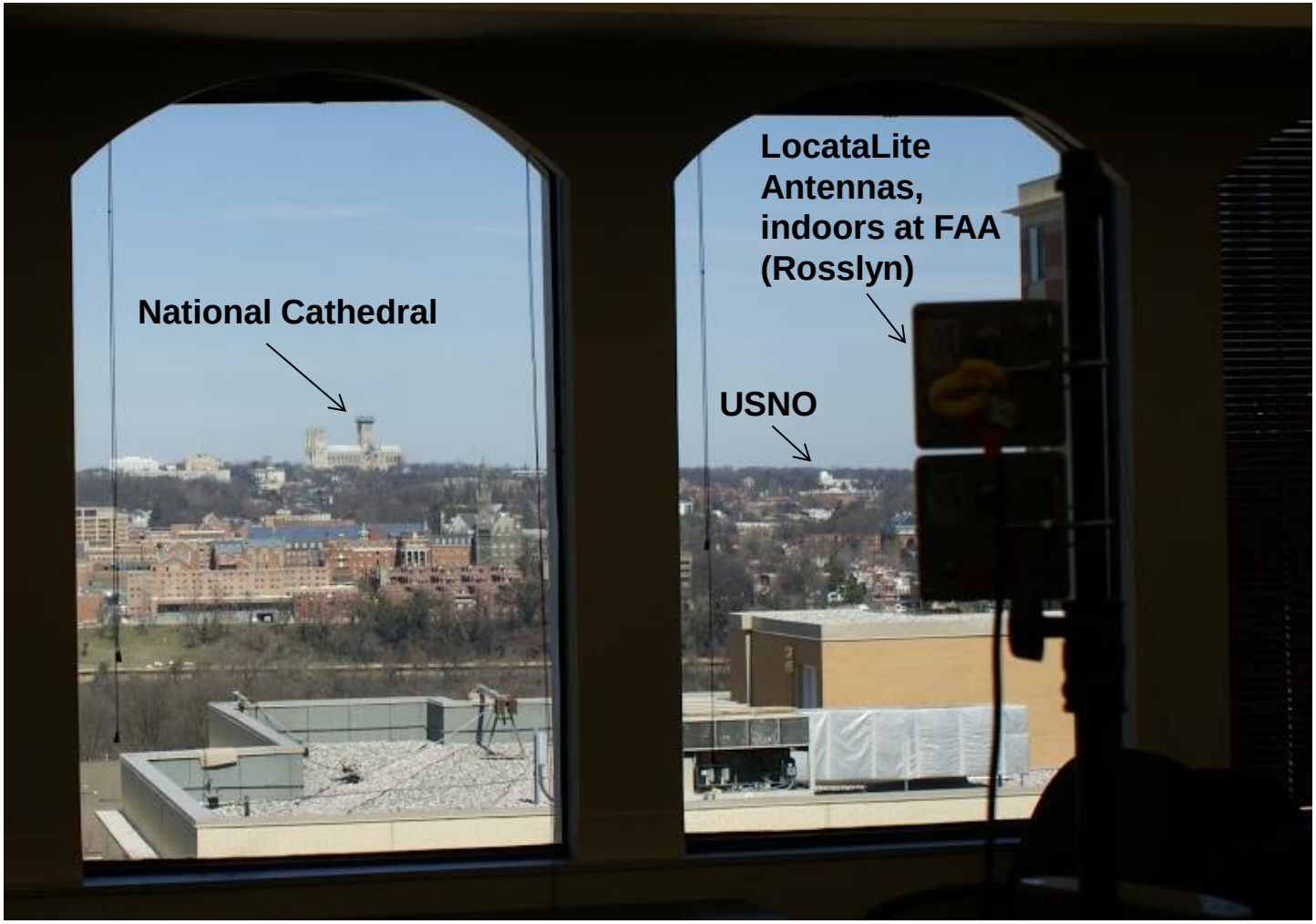
Phase 1
Cascaded through FAA
Total Range, 3.6mi/5.794km

Three-Node Set-up

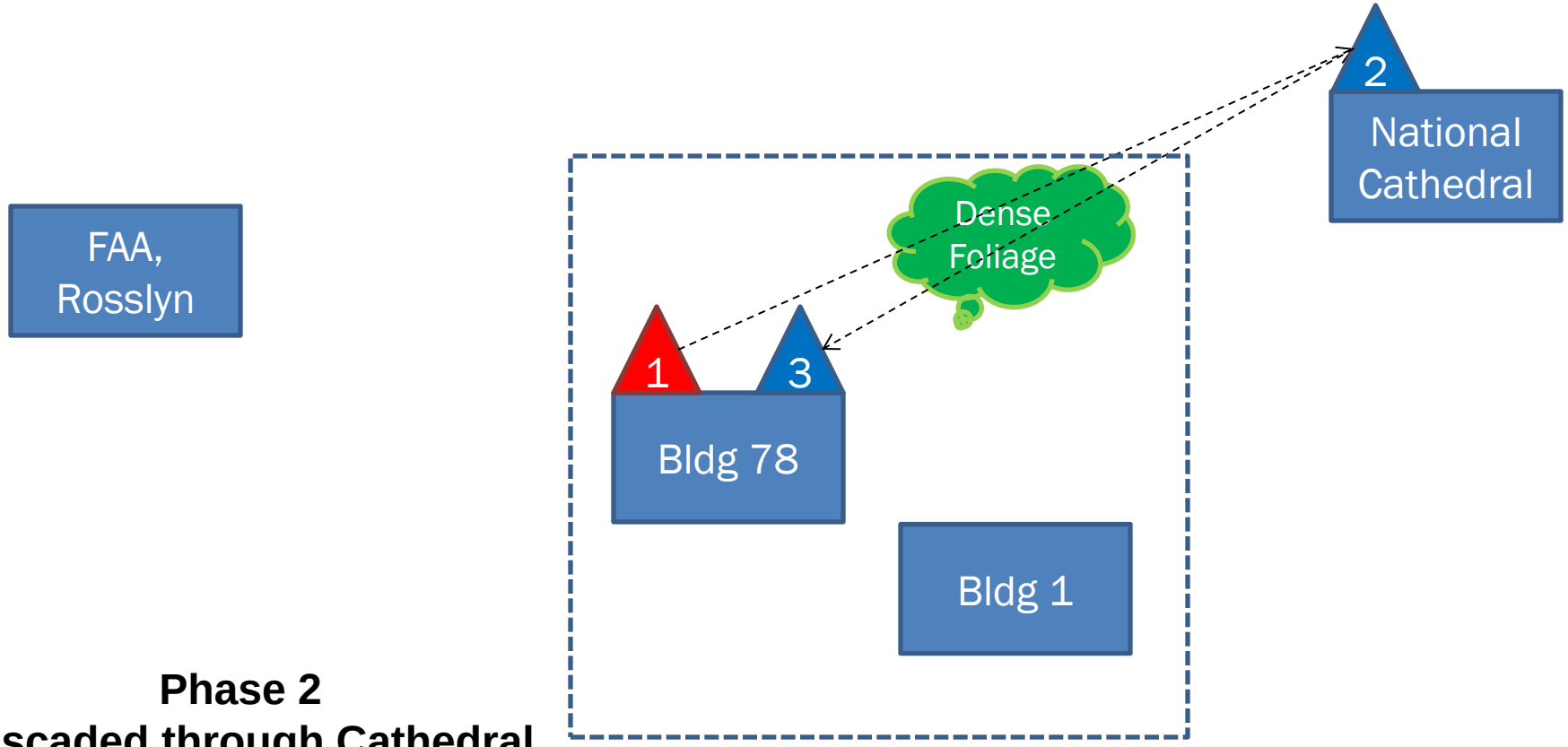


Phase 1
Cascaded through FAA
Total Range, 3.6mi/5.794km

Three-Node Set-up

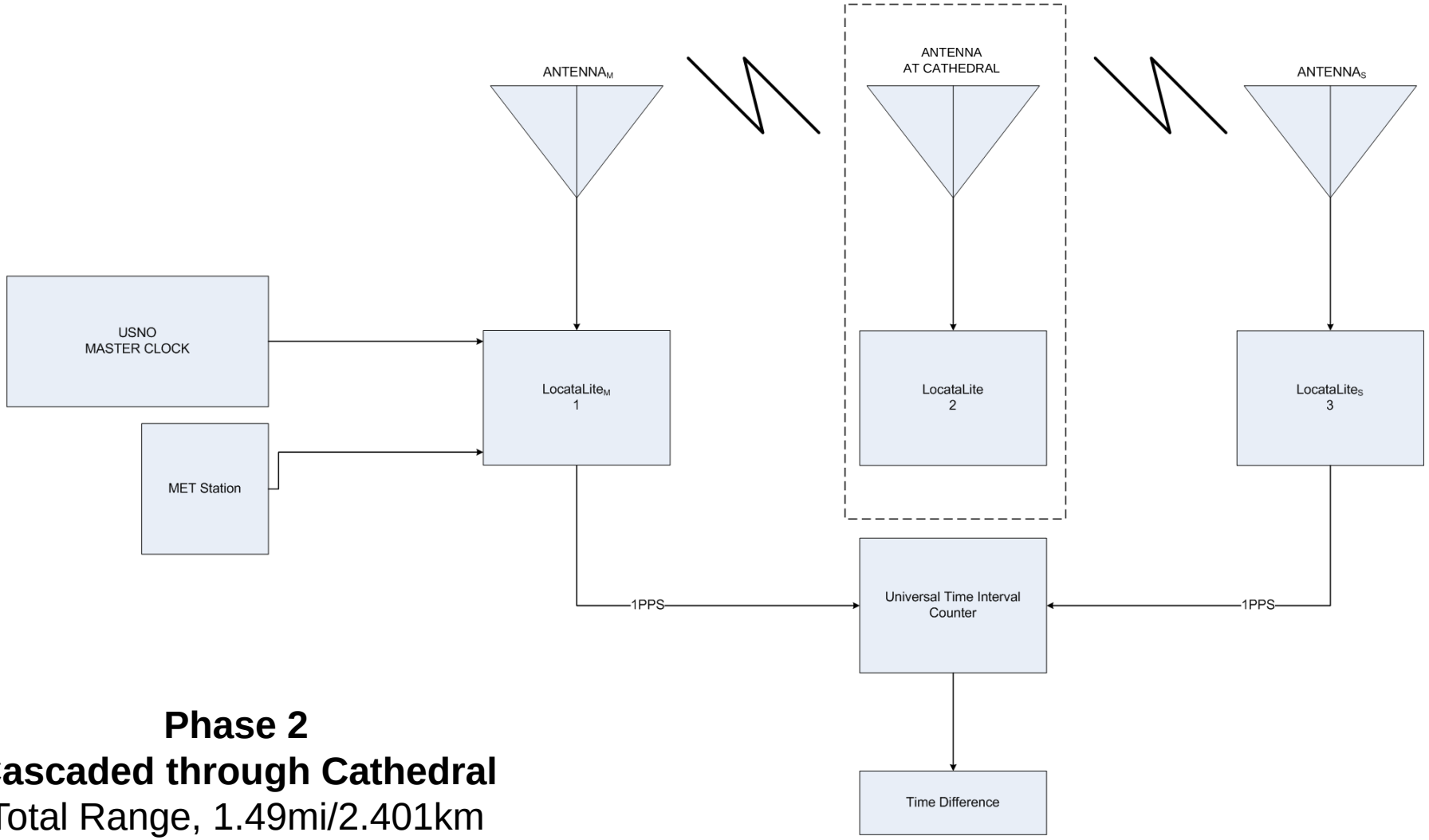


Three-Node Set-up



Phase 2
Cascaded through Cathedral
Total Range, 1.49mi/2.401km

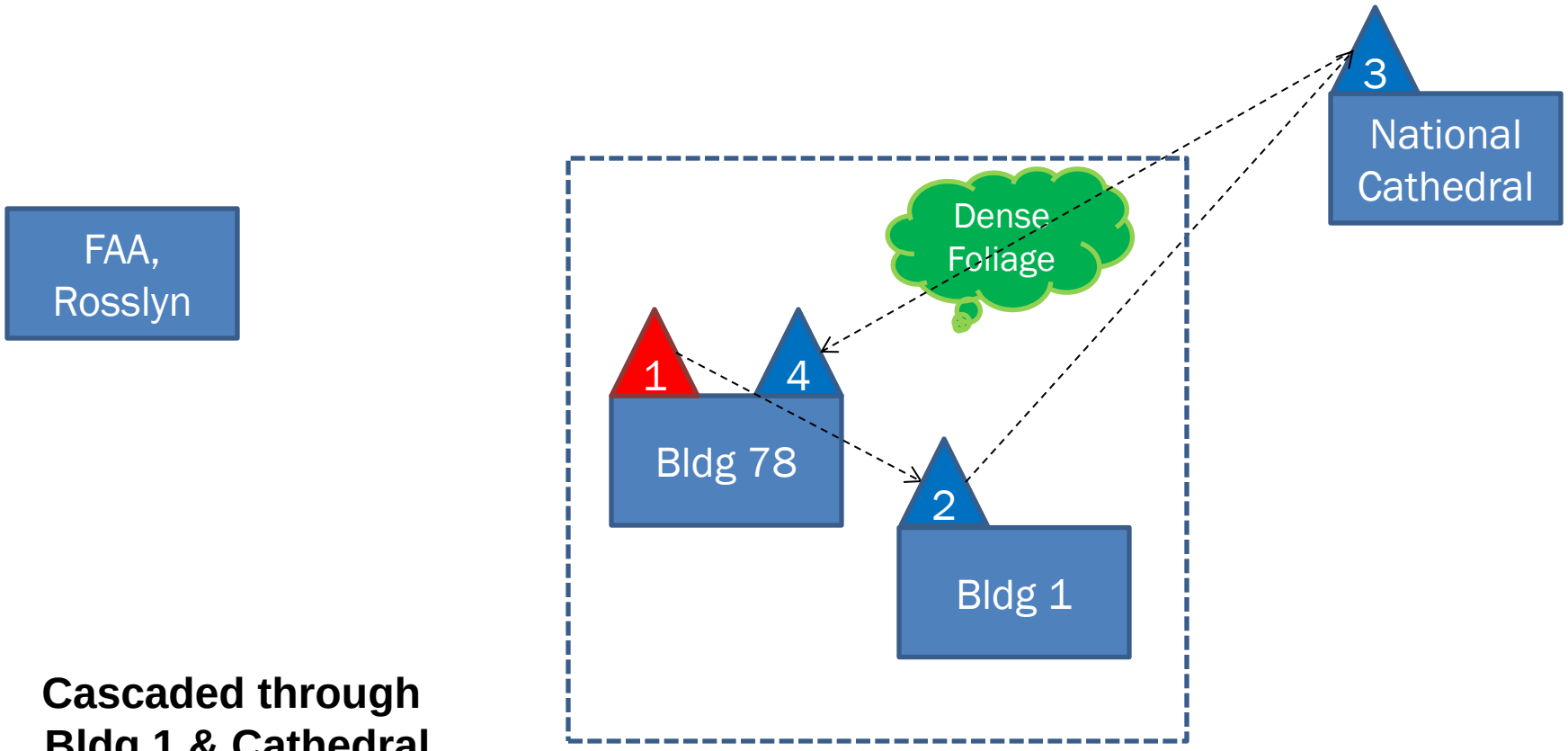
Three-Node Set-up



Phase 2
Cascaded through Cathedral
Total Range, 1.49mi/2.401km

Three-Node Set-up

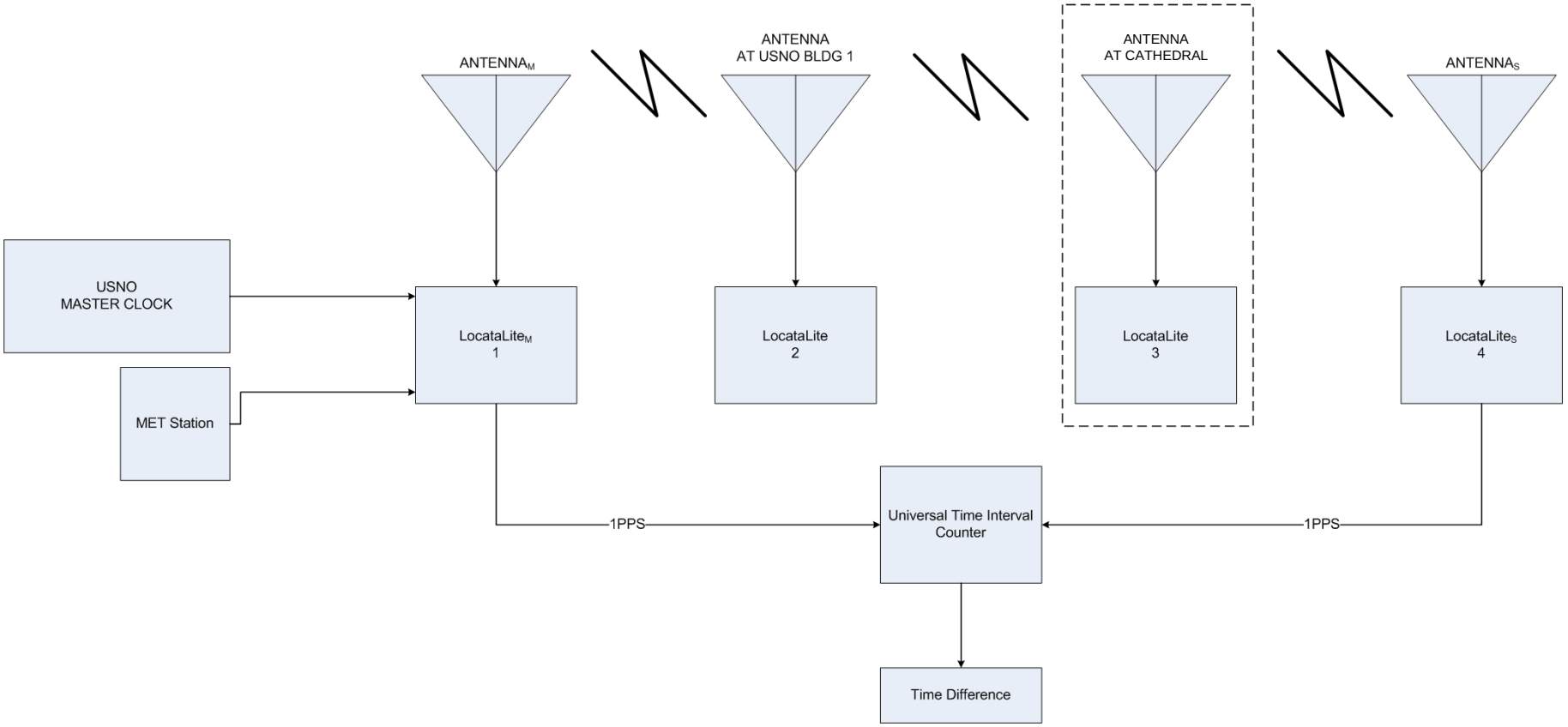
Four-Node Set-up



Cascaded through Bldg 1 & Cathedral

Total Range, 1.5mi/2.413km

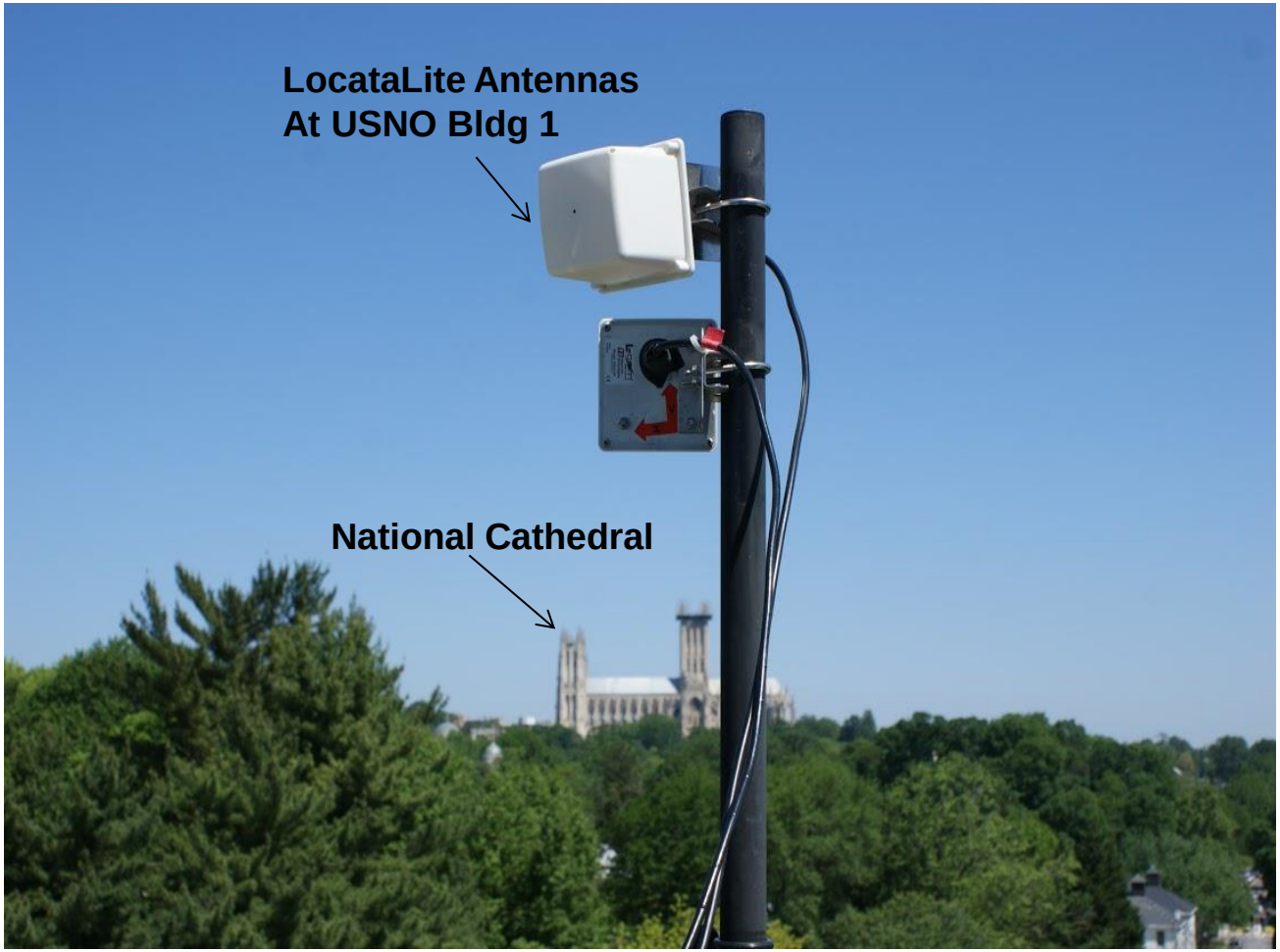
Four-Node Set-up



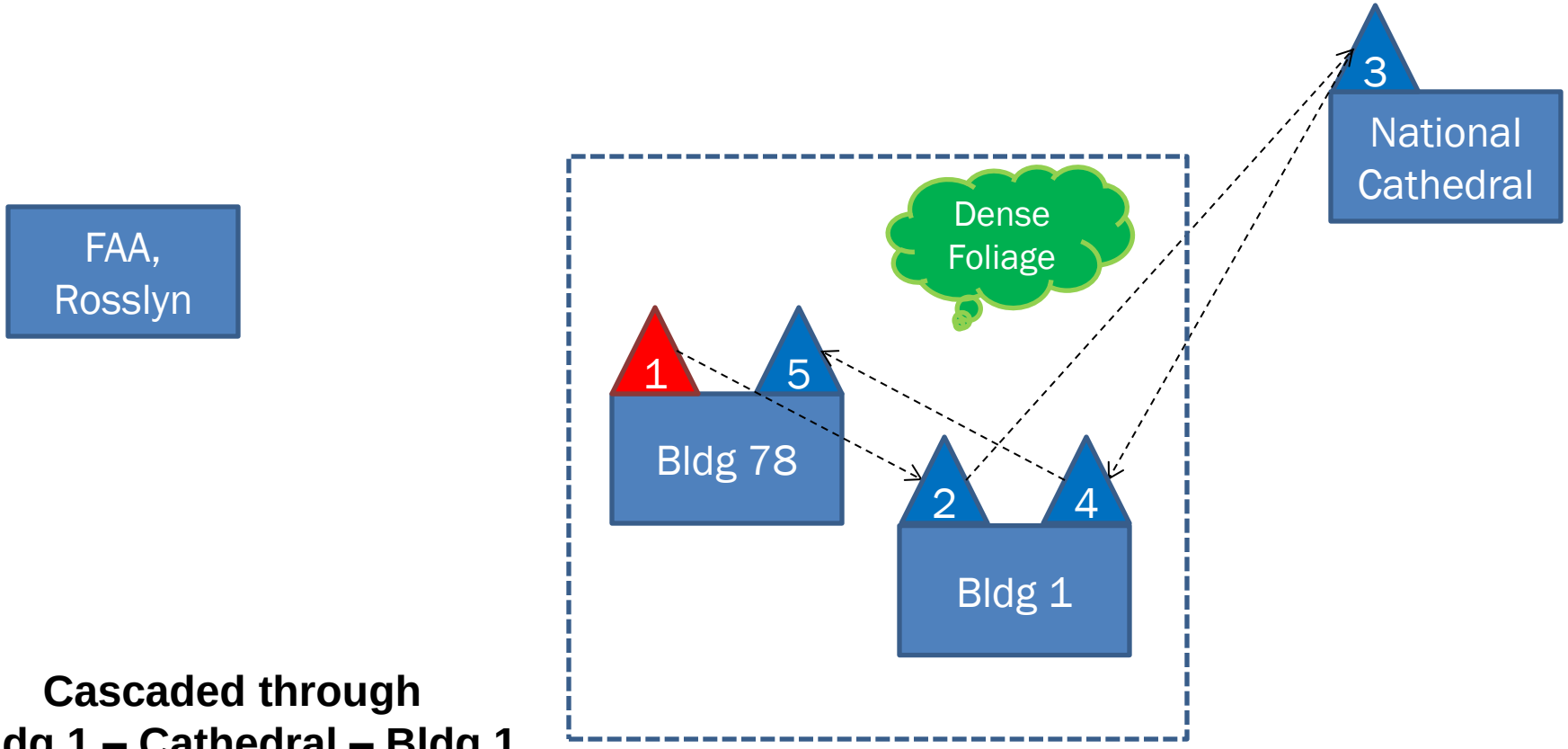
Cascaded through Bldg 1 & Cathedral

Total Range, 1.5mi/2.413km

Four-Node Set-up

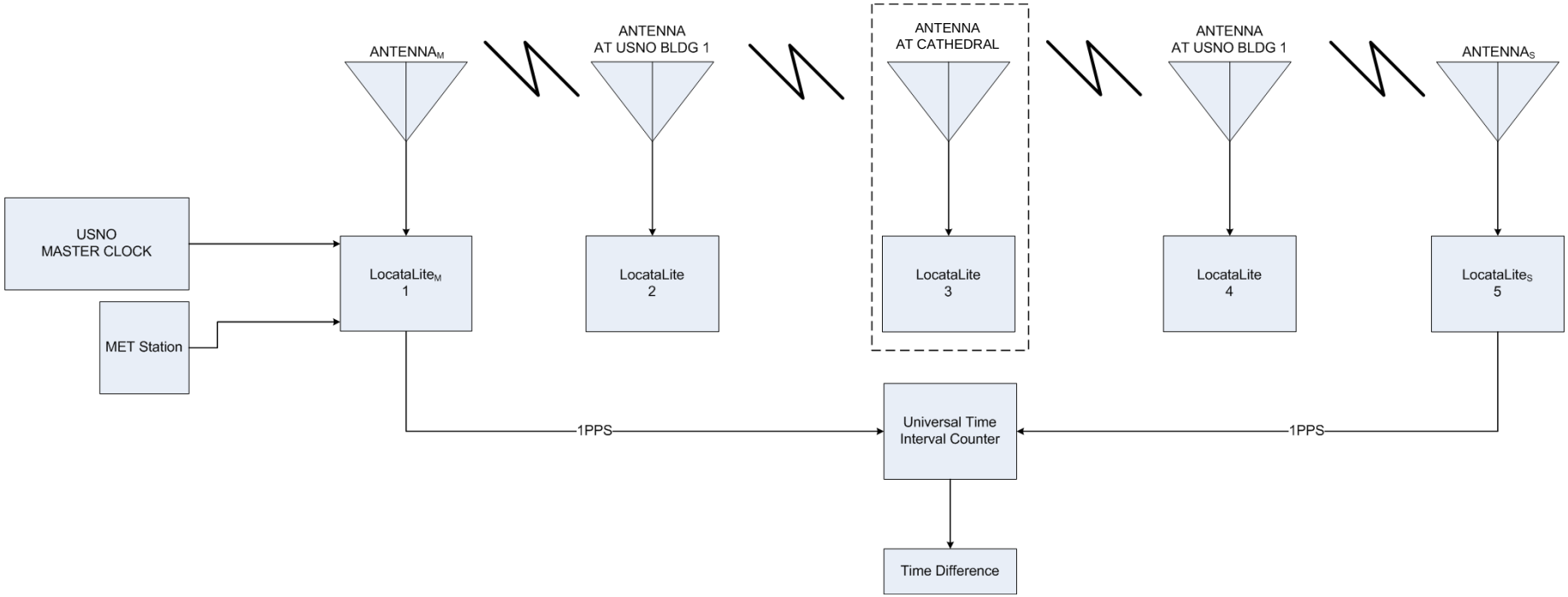


Five-Node Set-up



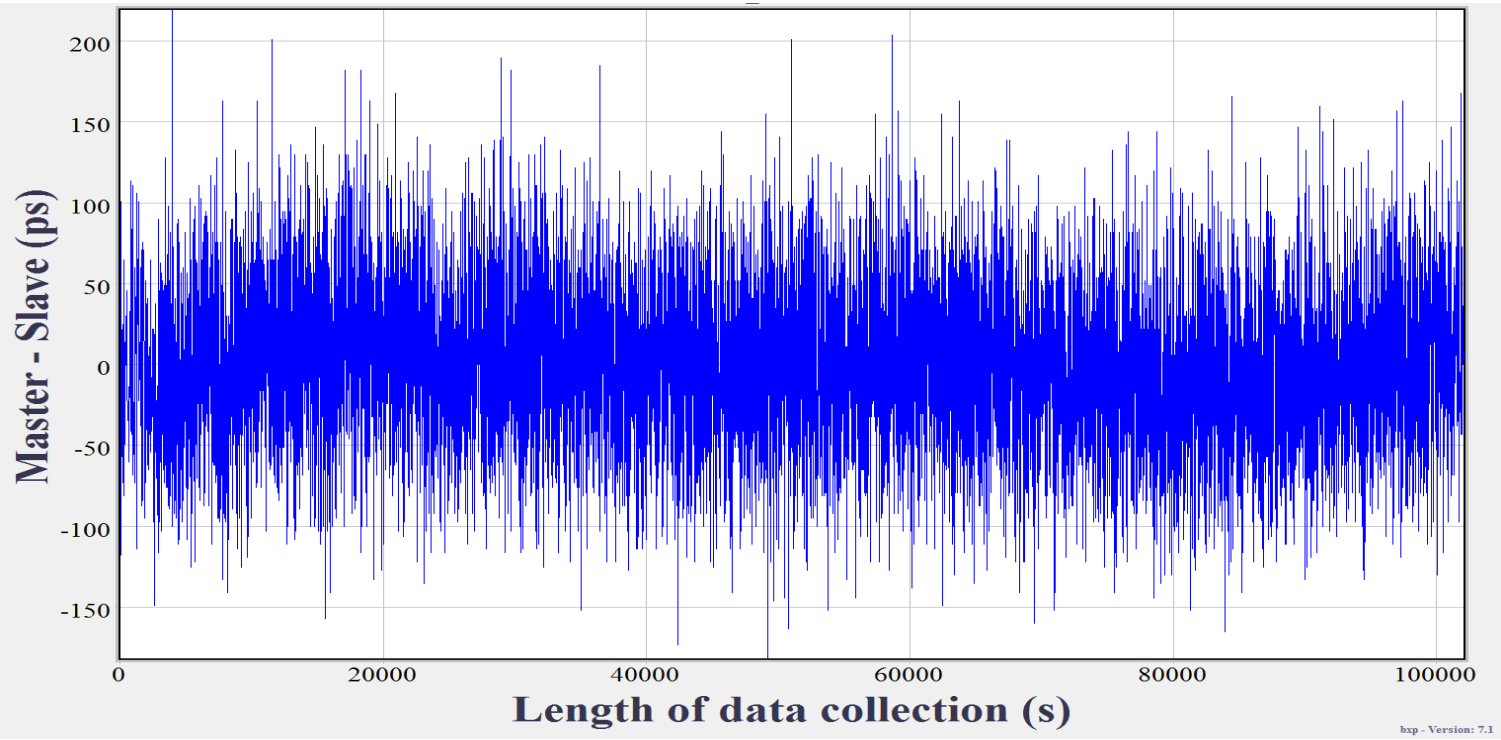
Cascaded through
Bldg 1 – Cathedral – Bldg 1
Total Range, 1.51mi/2.427km

Five-Node Set-up



Cascaded through
Bldg 1 – Cathedral – Bldg 1
Total Range, 1.51mi/2.427km

Collected Data (Example: Two-Node)



- Zero-mean 1PPS time difference between the Master LocataLite and the terminal Slave LocataLite
  - Removes errors due to unsurveyed antenna locations and uncorrected cable delays
  - Highlights the frequency coherence of the network

Results

Setup	Total Signal Distance from Master to terminal Slave LocataLite	Standard Deviation (picoseconds)	Change in RMS from short 2-node setup (picoseconds)
2-node	50ft/15.24m	51.095	N/A
3-node (FAA Bldg.)	3.6mi/5.794km	127.333	76.238
3-node (National Cathedral)	1.49mi/2.401km	171.325	120.230
4-node	1.5mi/2.413km	145.247	94.152
5-node	1.51mi/2.427km	197.766	146.671

Results

- 2-node setup
  - Measured precision standard deviation was 51.095 picoseconds
  - Culmination of the total Locata noise budget
    - Expected to consist of TimeLoc noise, residual tropospheric error, multipath change (signal scattering/diffusion), PPS generation, and PPS measurement
- 3-node setups
  - FAA building (3.6 mile / 5.794km): 127.333 picoseconds
  - National Cathedral (1.49 mile / 2.401km): 171.325 picoseconds
  - Better Synchronization over longer distance?
    - Hypothesis: Due to dense foliage between USNO Building 78 (Master and terminal Slave) and the National Cathedral (intermediate cascade), obscuring LOS
    - This configuration required the signal to pass through the foliage twice
    - Hypothesis seems reasonable, since the 4-node setup only required the signal to pass through this foliage once, and the recorded performance was better than the 3-Node Setup despite the fact that an additional cascade point was introduced

Each signal cascade through an intermediate LocataLite introduced ~25ps of jitter into the solution

Results

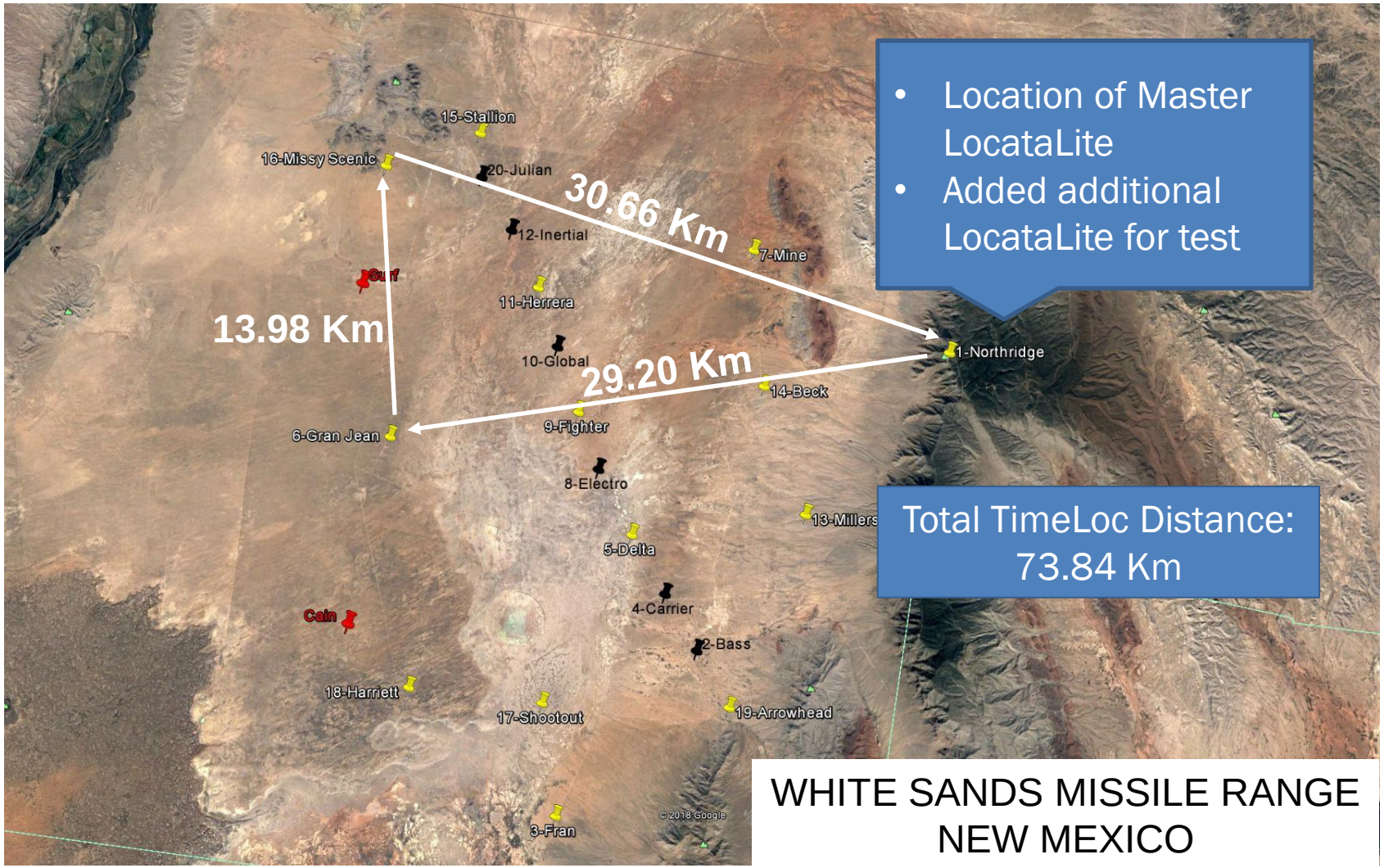
- Frequency Stability
  - Best measured over long periods
  - Because all equipment in the 2-node setup was located on USNO premises, it could run undisturbed for a longer period of time than other configurations
    - Length of this data set was 28 hours, 22 minutes, and 40 seconds
    - Locata's measured frequency deviation was $1x10^{-15}$
- Stratum 1 is defined as a source of frequency with an accuracy of $1x10^{-11}$
  - The usual source of Stratum 1 timing is an atomic standard (Cesium Beam) or a GPS steered reference oscillator (OCXO)
  - Although atomic standards such as Cesium clocks can typically provide even better performance, they are seldom stable to better than 1×10^{-13}
  - Locata's link stability—which is achieved without the use of atomic clocks—is capable of distributing Stratum 1 frequency and precise time
- This measured performance is excellent
  - A stable network is an essential prerequisite for precise time and frequency transfer
  - For many traditional timing applications and developing applications, stability is more important than accuracy

Long Range TimeLoc

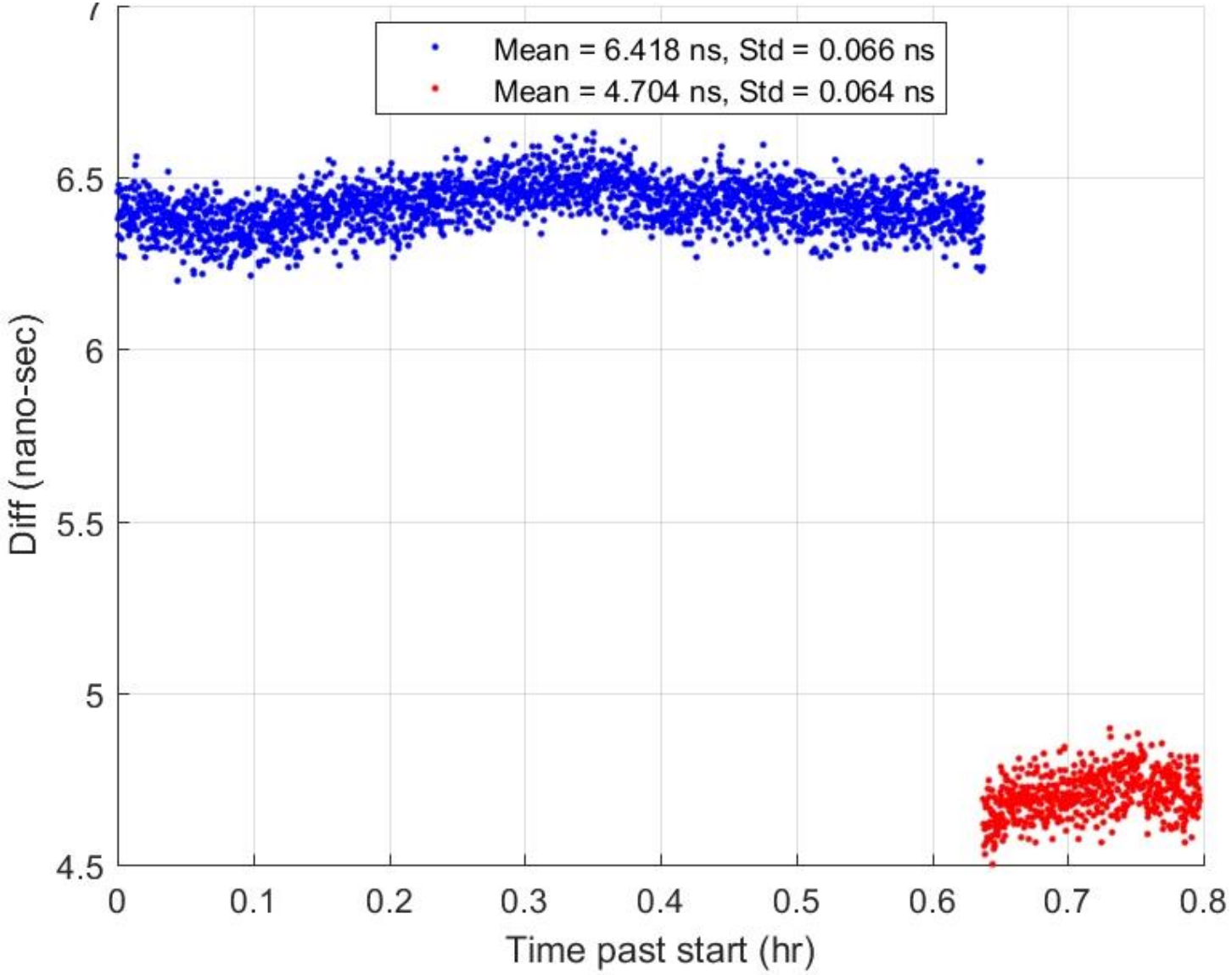
WHITE SANDS MISSILE RANGE
NEW MEXICO

- USNO was interested in evaluating TimeLoc over greater distances
- Leveraged the Wide-Area Locata Network at White Sands Missile Range
  - Owned and operated by USAF
  - Core of the Ultra High Accurate Reference System (UHARS)
- Reconfigured LocataNet to invoke TimeLoc cascading
  - Up to 4 Nodes
- Data Collected 9-10 May 2018

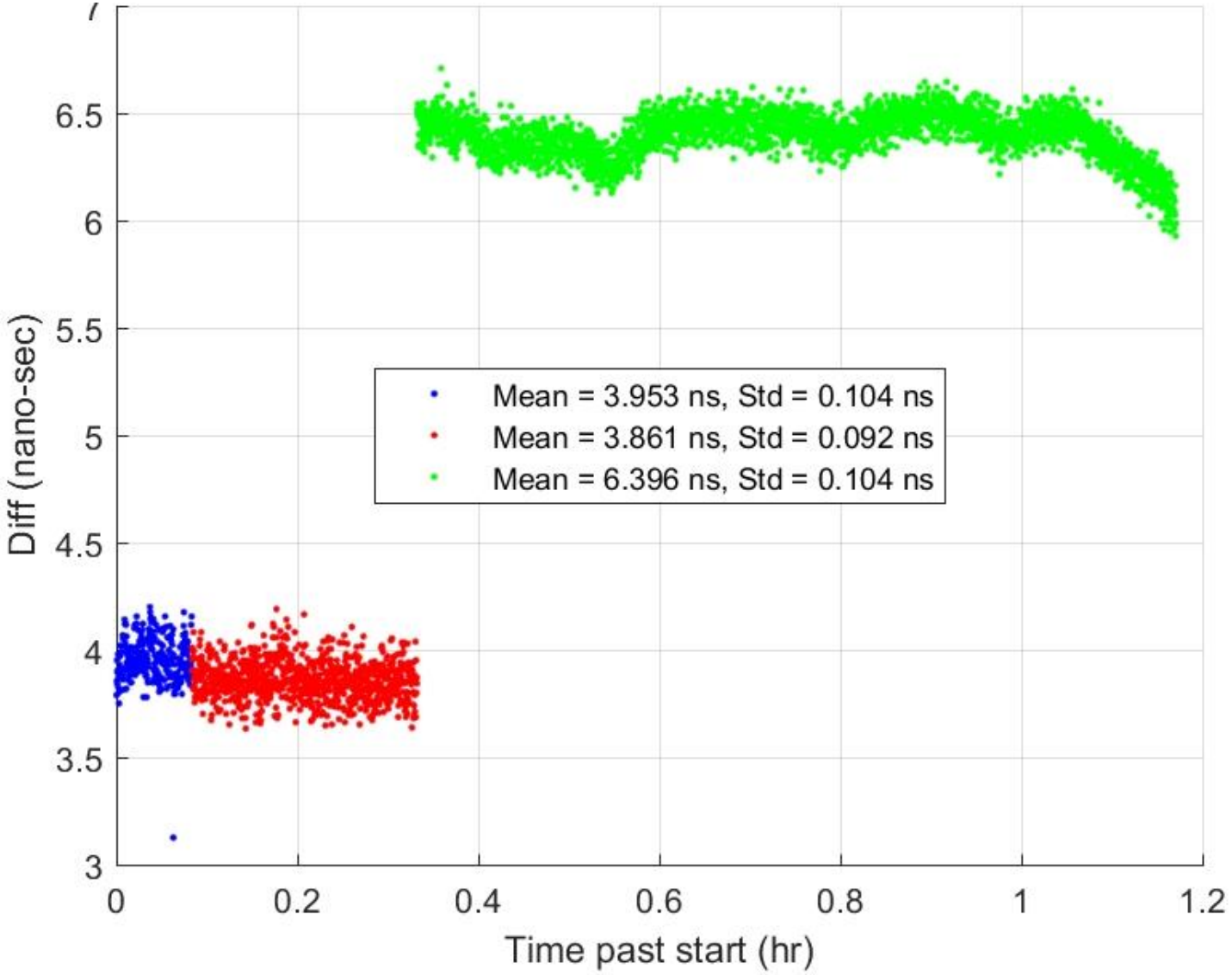
Long Range TimeLoc



WSMR 2-Node TimeLoc



WSMR 4-Node TimeLoc

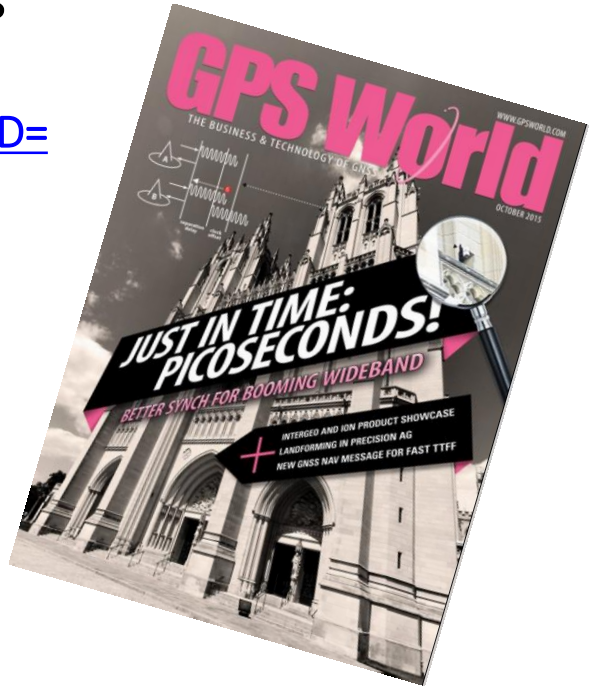


Conclusions/Summary

- The USNO tests highlighted the capability of the LocataLite as a viable option for a stable 1PPS distribution setup within an urban environment
  - All tested configurations demonstrated frequency synchronization of less than 200 picoseconds
  - If clear LOS is available between a Master and Slave LocataLite, precision has been shown to be on the order of 50ps, and it is stable to $1x10^{-15}$
  - These results suggest that distance between nodes is not a significant factor, provided that sufficient signal quality is maintained
  - There are no theoretical or technical problems with scaling LocataNets to very large areas
- This demonstration shows that the Locata system can provide sub-nanosecond frequency synchronization over large areas, urban and rural
  - Capable of supporting current user applications that depend on precise frequency synchronization

References

- UNSW ION Technical Paper: Time Transfer Performance of Locata--Initial Results
  - https://www.ion.org/publications/abstract.cfm?articleID=11584
- USNO ION Technical Paper: Wide Area Wireless Network Synchronization Using Locata
  - http://www.ion.org/publications/abstract.cfm?articleID=13051
- GPS World: Timing Accuracy Down to Picoseconds
  - http://gpsworld.com/timing-accuracy-down-to-picoseconds/



Locata.

Questions?