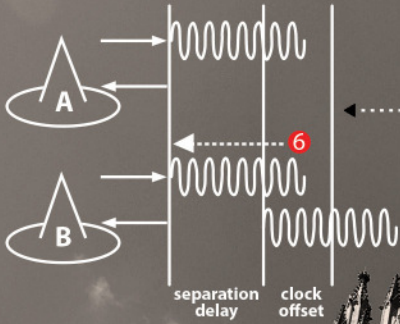


GPS World

THE BUSINESS & TECHNOLOGY OF GNSS

OCTOBER 2015



JUST IN TIME: PICOSECONDS!

BETTER SYNCH FOR BOOMING WIDEBAND



INTERGED AND ION PRODUCT SHOWCASE
LANDFORMING IN PRECISION AG
NEW GNSS NAV MESSAGE FOR FAST TTFF

» COVER STORY

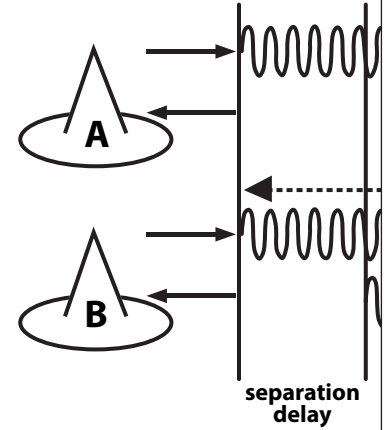
ALTERNATIVE PNT

Timing Accuracy Down to Picoseconds 28

Wide-Area Wireless Network Synchronization with LocataNets

By Edward Powers and Arnold Colina

The United States Naval Observatory conducted several independent frequency synchronization experiments in Washington, D.C., using an alternative PNT technology in multiple network configurations. The results suggest that sub-nanosecond time transfer using this technology may be possible over wide urban areas, and that it could thus serve as a GPS augmentation or back-up solution over wide areas for critical applications that depend on precise time.



GEOSPATIAL

Have Accuracy, Will Travel 38

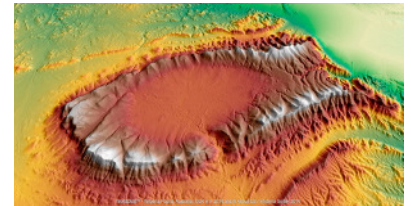
BYOD Sub-Meter Positioning for Mapping and GIS Professionals

By Matt van Doorn

Employees bringing their own mobile phones and tablets to their jobs in the field enables them to complete more tasks using fewer devices. However, this introduces operational and security vulnerabilities.

GEOSPATIAL

High Above Down Under 11



PRECISION AGRICULTURE

Precision Ag's New Frontier 41

OPINIONS & DEPARTMENTS

Out in Front 6

IOU on IOE

By Alan Cameron

THE SYSTEM 8

Galileo Turning Ten; European SBAS Advances, Improves; GAO Report Spotlights OCX Delays, Cost Increases

THE BUSINESS 12

INTERGEO's Massive Marketplace; Antenova Shows off GNSS Antenna Intergration; What Mattered Most at Super Mobility Week; UAV, Survey Market Key to Maxtena's Growth; Broadcom's New Chip for Internet of Things; Autonomous Vehicles, Drones Next Big Thing for u-blox; PCTEST Expands Antenna Testing Capabilities with Rohde & Schwarz; Spirent Test Framework Evaluates Threats to GNSS



INTERGEO PRODUCT SHOWCASE 18

ION GNSS + PRODUCT SHOWCASE 27



EVENTS 40

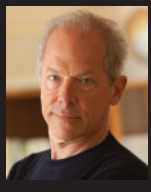
INNOVATION Faster, Higher, Stronger 44

Proposed GNSS Navigation Messages for Improved Performance
By Wentao Zhang and Yang Gao

IOU on IOE

Here it comes right at ya, down the cable into your living room, over the radio waves into the coffee shop or airport and your car: the Internet of Everything (IOE).

We are headed further in a lot of new directions, and GNSS can't get us there alone. Aided and abetted by other PNT, it can.



The term connotes adding connectivity and intelligence to just about every tech device in use at home, office, or out on the street, to enable special functions, reporting, and command/control. From kitchen appliances to cars, it's anything with "smart" in front of its name, tied to the Internet and interconnected to tech-ecosystems of software, services, data warehouses, and yet other smart devices, starting but certainly not ending with your phone, watch, tablet, or PC.

Most semiconductor companies have fielded new processors aimed at IOE. Broadcom's new chip, reported in this issue, folds GNSS into the digital cake mix. **Market research predicts 220 billion connected devices in use by 2020, and market size in the trillions. Trillions.**

The bandwidth to run this new ecosystem is truly staggering. Available spectrum just won't do it, not in the way we're using it. Far more precise timing of data packets shot through the cloud will be necessary.

Thus our cover story. GNSS — well, GPS so far — is tightly woven into the fabric of financial and security infrastructure because it furnishes micro- and nanosecond synchronization. Nanos ain't where it's at in another eyeblink more. Picoseconds will be the new standard.

GNSS as currently constituted cannot do picoseconds. Another technology or technologies will be required.

This is true on nearly every front, every sector in which GNSS has enabled so much that previously was inconceivable or just plain unconceived. We're headed further in all those directions, and GNSS can't get us there alone. Aided and abetted by other positioning, navigation, and timing (PNT) technologies, it can.

The magazine has long covered other PNT technologies, but starting in November you'll see a whole lot more of this. Every PNT technology, in every issue, in some way. That's my IOU. Because, after all, it's a World of Everything.

Alan Cameron

Pink for a Cure

Our cover logo this month signals that North Coast Media (NCM) is doing something to help make a difference. Because October is our company's largest revenue month each year, our leadership team has committed to donate a portion of the company's October revenues to cancer research. In 2014, NCM donated \$8,000 to this very worthy cause. The disease has touched the lives of nearly everyone on the NCM team; we're very excited to be able to do something that matters.

GPS World

www.gpsworld.com

EDITORIAL

Editor-in-Chief and Group Publisher Alan Cameron | editor@gpsworld.com
Managing Editor Tracy Cozzens | tcozzens@northcoastmedia.net

Art Director Charles Park

EDITORIAL OFFICES

1360 East 9th St, Suite 1070
 Cleveland, OH 44114, USA
 847-763-4942 | Fax 847-763-9694
www.gpsworld.com | gpsworld@gpsworld.com

CONTRIBUTING EDITORS

Innovation Richard Langley | rlang@unb.ca
Defense PNT Don Jewell | djewell@gpsworld.com
European GNSS Tim Reynolds | treyolds@gpsworld.com
Professional OEM Tony Murfin | tmurfin@gpsworld.com
Geospatial Eric Gakstatter | egakstatter@gpsworld.com
Geointelligence Art Kalinski | akalinski@gpsworld.com
Survey Dave Doyle and Dave Zilkoski
Wireless LBS Insider Kevin Dennehy | kdennehy@gpsworld.com
 Janice Partyka | jparyka@gpsworld.com

BUSINESS

International Account Manager
 Michelle Mitchell | mmitchell@northcoastmedia.net | 216-363-7922
Digital Operations Manager
 Bethany Chambers | bchambers@northcoastmedia.net | 216-706-3771
Senior Digital Editor
 Diane Sofranec | dsfranec@northcoastmedia.net | 216-706-3793
Digital Editor
 Joelle Harms | jharms@northcoastmedia.net | 216-706-3780
Web Developer
 Jesse Malcmacher | jmalcmacher@northcoastmedia.net | 216-363-7925
Marketing Manager
 Scott Gebler | sgebler@northcoastmedia.net | 216-363-7932

PUBLISHING SERVICES

Manager, Production Services
 Chris Anderson | canderson@northcoastmedia.net
Sr. Audience Development Manager
 Antoinette Sanchez-Perkins | asanchez-perkins@northcoastmedia.net

PRODUCTION OFFICE

1360 East 9th St., Suite 1070, Cleveland, OH 44114
 216-978-5341

CIRCULATION/SUBSCRIBER SERVICES

gpsworld@halldata.com | USA: 847-763-4942

NORTH COAST MEDIA, LLC.

President & CEO
 Kevin Stoltman | kstoltman@northcoastmedia.net | 216-706-3740
Vice President of Finance & Operations
 Steve Galperin | sgalperin@northcoastmedia.net | 216-706-3705
Vice President Graphic Design & Production
 Pete Seltzer | pseltzer@northcoastmedia.net | 216-706-3737

MANUSCRIPTS: *GPS World* welcomes unsolicited articles but cannot be held responsible for their safekeeping or return. Send to: 1360 East 9th St, Suite 1070, IMG Center, Cleveland, OH 44114, USA. Every precaution is taken to ensure accuracy, but publishers cannot accept responsibility for the accuracy of information supplied herein or for any opinion expressed. **REPRINTS:** Reprints of all articles are available (500 minimum). Contact 877-652-5295, Wyndell Hamilton. **Wright's Media**, 2407 Timberloch Place, The Woodlands, TX 77380. **SUBSCRIBER SERVICES:** To subscribe, change your address, and all other services, e-mail gpsworld@halldata.com or call 847-763-4942. **PERMISSIONS:** Contact 877-652-5295, Wyndell Hamilton. **Wright's Media**, 2407 Timberloch Place, The Woodlands, TX 77380. **INTERNATIONAL LICENSING:** Contact e-mail info@gpsworld.com. **ACCOUNTING OFFICE and OFFICE OF PUBLICATION:** 1360 East 9th St, Suite 1070, IMG Center, Cleveland, OH 44114, USA.

GPS WORLD does not verify any claims or other information appearing in any of the advertisements contained in the publication and cannot take any responsibility for any losses or other damages incurred by readers in reliance on such content.

Published monthly

A NORTH COAST MEDIA PUBLICATION



Internet of Everything Ups Timing Requirements

Many critical modern systems such as 4G mobile phone networks, banking, and electricity grids demand high-accuracy time and frequency stability across specified areas. Precise network synchronization is critical for nearly all digital networks, and more stringent network stability requirements are expected to emerge as the user base for these applications continues to grow. To date, the preferred method to achieve this performance is via synchronization from GPS. However, the vulnerability of GPS signals causes growing concern among industry experts. Many actively seek alternative means of precise time transfer and frequency stability across wide areas.

Alternative position, navigation, and timing (PNT) technologies such as chip scale atomic clocks (CSAC), precision time protocol (PTP), and enhanced long range radio navigation (eLoran) are proposed or operational today, with each serving different markets.

Meanwhile, timing needs for wireless protocols continue to increase with the proliferation of mobile phones and other wireless communication devices. To accommodate a booming user base, wireless spectrum must be carefully managed to improve bandwidth and channel efficiency. Wireless communication performance is fundamentally dependent upon precise time and frequency, so improvements in highly accurate timekeeping methods will permit better spectrum utilization, which in turn permits more users and more bandwidth per user.

Clearly, synchronization is a core enabling technology for

modern digital systems, both for radiopositioning and the world's telecommunications highways. But synchronization is taken for granted because, when it works well, it is effectively invisible. Without it, however, everything is likely to fall apart.

Synchronization will become even more crucial for the next generation of digital systems. A recent paper by the U.S. National Institute of Standards and Technology (NIST) states that we stand at the advent of a revolutionary new economy fueled by a global Internet of Everything (IoE), in which 37 billion *new* things will be connected to the Internet by 2020.

This NIST paper adds that "One fundamental enabler of this revolution will be the marriage of timing signals and data that breaks through the existing barriers. Timing is critical for future development and improvements."

Improved wireless synchronization has proved very challenging to realize, as the timer in each network node is derived from an independent oscillator that is affected by long/short term frequency drifts and jitter. Many alternative timekeeping methods present serious limitations in terms of precision or network size.

Encouraged by earlier published results showing that Locata Corporation's radio-based PNT technology enables network synchronization at the nanosecond level, and suggesting that it could perform comparably across large urban areas, the United States Naval Observatory (USNO) conducted its own synchronization experiments on Locata technology.

Timing Accuracy Down to Picoseconds

Wide-Area Wireless Network Synchronization with LocataNets

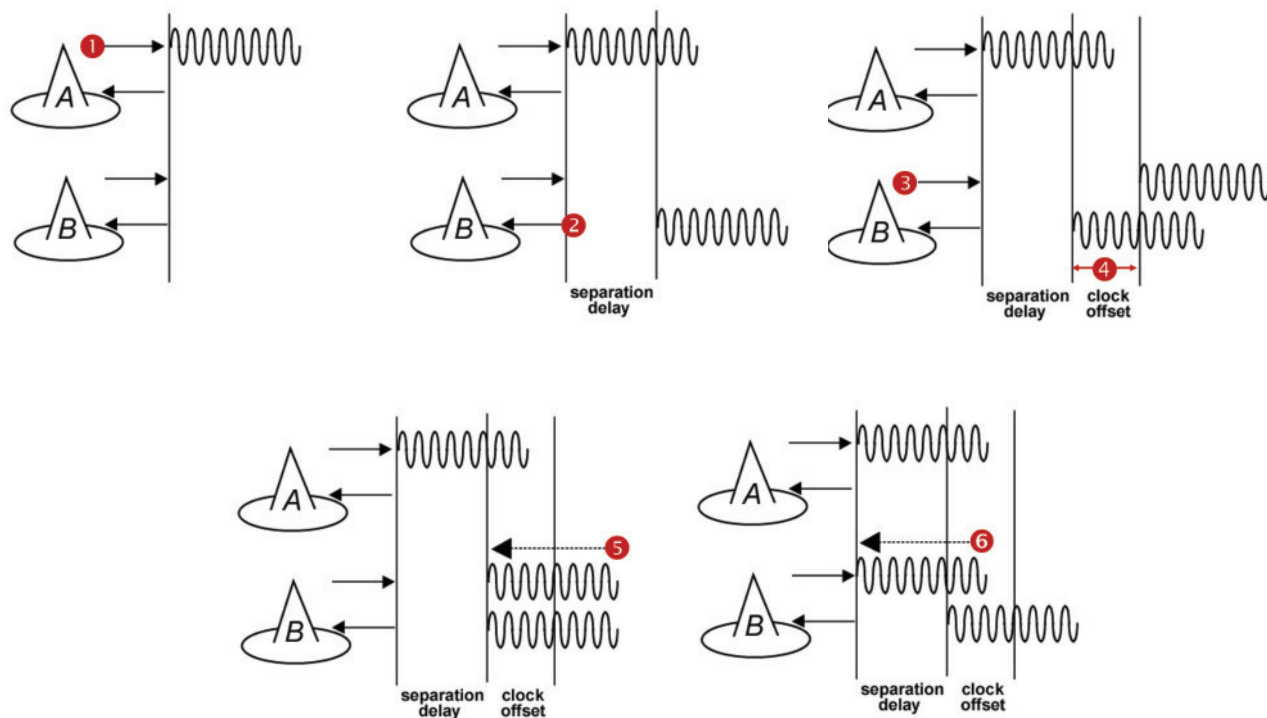
The United States Naval Observatory conducted several independent frequency synchronization experiments in Washington, D.C., using an alternative PNT technology in multiple network configurations. **The results suggest that sub-nanosecond time transfer using this technology may be possible over wide urban areas, and that it could thus serve as a GPS augmentation or back-up solution over wide areas for critical applications that depend on precise time.**

Edward Powers and Arnold Colina

Because of the great responsibility of being the prime source of time for many critical national systems, the United States Naval Observatory's (USNO's) clock system must be at least one step ahead of the demands expected to be made on its accuracy. Therefore, innovative methods of transferring precise time and frequency must

continually be anticipated, investigated and supported.

The USNO has developed one of the world's most accurate and precise atomic clock systems, used by many systems requiring highly precise time. The USNO operates the U.S. Master Clock, which provides the precise time source for the GPS satellite constellation run by the Air



▲ FIGURE 1 THE TIMELOC PROCESS.

- 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. Importantly, the transmitted signal is received by the receiver section of LocataLite B as well.
- STEP 4** LocataLite B calculates the difference between the signal received from LocataLite A and its own locally generated and received unique signal. Ignoring propagation errors, the differences between the two signals are due to the difference in the clocks between the two devices, and the geometric separation between them.
- STEP 5** LocataLite B adjusts its local oscillator to bring the differences between its own signal and LocataLite A's received signal to zero. The signal differences are continually monitored and adjusted so that they remain zero. In other words, the local oscillator of B follows precisely that of A.
- 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.

Force; it is also the time standard for the U.S. Department of Defense. Along with its sister organization, the National Institute of Standards and Technology (NIST), it provides the official time for the entire nation.

To investigate new precise time transfer methods, the USNO desired to independently test Locata's TimeLoc methodology as a possible technology for maintaining precise frequency synchronization across an urban or wide-area network — the foundation for supporting precise time transfer.

Real-World Challenges

The USNO campus is situated about 4 kilometers northwest of the White House in Washington DC. The grassy tree-lined campus is, unfortunately, a relatively small area for testing wide-area synchronization capabilities.

It became apparent that realistic long-distance tests would necessitate extending the LocataNet outside USNO boundaries. This meant coordinating access to other facilities in the Washington, DC area to allow remote housing of LocataLites and their antennas. As many researchers



▲ FIGURE 2 LocataLites under test at USNO

will confirm: when real-world testing requires access to multiple external sites and their disparate administrations, the coordination required to keep everything on track can quickly become the most

The TimeLoc Process

LocataNets function as local ground-based replicas of the satellite-based GPS position and timing networks. A LocataNet can be designed and configured by the user to deliver a powerful, local, controllable, tailored signal as required by different applications.

The easiest LocataNet layout to describe is a hub-and-spoke model consisting of a single master LocataLite transceiver and one or more slave LocataLites. More complex network configurations have been deployed in many commercial systems in use today. The patented process by which slaves are synchronized to the master (or other slaves) is known as TimeLoc.

In 2013, a University of New South Wales team demonstrated that Locata's radio-based TimeLoc technology provided accurate time transfer (~5ns) and frequency stability (~1 ppb) across a large distance of 73 kilometers (45.4 miles). This significantly outperforms GPS for wireless time transfer. Given this demonstrated radius of transmission in a rudimentary configuration, Locata was shown as being able to supply nanosecond-accurate time to a 146 km diameter circle, which would cover 16,750 km² — almost 200 times the size of Manhattan. Ranges greater than this can be deployed if required for safety-of-life, military or government-mandated systems.

As TimeLoc is accomplished without the use of atomic clocks, this represents a new league in precision network synchronization of this scale. It could conceivably serve as a GPS augmentation or back-up solution over wide areas for critical applications that depend on precise time.

Since Locata technology was

originally developed as a high-accuracy non-GPS-based positioning and navigation solution, the time synchronization accuracy requirements for a LocataLite transceiver are very high. If sub-centimeter positioning precision is desired for a Locata receiver, every smallest fraction of a second is significant; for example, a 1-nanosecond error in time equates to an error of approximately 30 centimeters.

TimeLoc wireless synchronization enables LocataLites to achieve high levels of synchronization without atomic clocks, without external control cables, without differential corrections, and without a master reference receiver.

In theory, there is no limit to the number of LocataLites that can be synchronized together. TimeLoc allows a LocataNet to propagate into difficult environments or over wide areas. For example, if a third LocataLite C can only receive the signals from B (and not A) then it can use these signals from B for time synchronization instead. The only requirement for establishing a LocataNet using TimeLoc is that LocataLites must receive signals from one other LocataLite. This does not have to be the same central or master LocataLite, since this may not be possible in difficult environments with obstructions, or when propagating the LocataNet over wide areas.

This method of cascading TimeLoc through intermediate LocataLites has been proven in a growing number of real-world operational LocataNets, including a network in use today by the U.S. Air Force which is configured to cover up to 2,500 square miles (6,500 square kilometers) of the White Sands Missile Range in New Mexico.

daunting challenge of the exercise. We needed to find cooperative facilities, preferably with line-of-sight (LOS) to the USNO and its Master Clock in order to establish the best TimeLoc link between facilities. As we also wanted to exercise TimeLoc's ability to cascade its synchronization through multiple LocataLites, ever more DC facilities would need to be involved. Predictably, it transpired that not many facility managers in the Washington district were eager to help the USNO broadcast and receive new and unknown signals in or around their government buildings! And those who were amenable to support the demonstration either lacked a LOS, or were not willing to assist without considerable monetary compensation.

After months of attempts to secure appropriate partners for this demonstration, we finally found some supporters in the shape of the Federal Aviation Administration Building in Rosslyn, Virginia and the National Cathedral in Washington, DC. Regrettably, it turned out that these facilities were not going to be available at the same time! Logistic challenges never end. This scheduling reality necessitated spreading the TimeLoc demonstration over several months in three different blocks of trials. Nevertheless, we were eventually able to devise a plan which leveraged access to the USNO and still accommodated the timetables of the supporting external facilities.

A series of experiments were planned to measure and evaluate the stability between master and slave LocataLite 1-pulse per second (PPS) signals in several urban LocataNet configurations. Many of the trials were specifically designed to measure TimeLoc's ability to cascade multiple times through multiple LocataLites, exercising the technology's capabilities over increasing distances and hence correspondingly larger notional coverage areas.

Locata signals were broadcast

in the Industrial, Scientific and Medical (ISM) 2.4 GHz radio band, commonly known as the Wi-Fi band, with a total radiated power of 200–500 mW. LocataLites and their respective antennas were installed at locations that permitted LOS between units, according to whichever specific LocataNet configuration was being evaluated at the time. In each configuration, the master LocataLite, designated as LocataLite 1, was synchronized to the USNO Master Clock so that the Master Clock's time would be propagated through the LocataNet. Both the master and slave LocataLite 1PPS signals were collected into a time interval counter and the time difference between their rising edges was measured.

When tracking radio frequency signals over a significant distance, tropospheric delay becomes an important error source for measurements used in timing solutions. The speed of light can only be assumed to be universally constant in a vacuum, so atmospheric temperature, pressure and humidity materially changes the speed of light when propagating through air. In fact, using standard atmospheric parameters, the unmodeled tropospheric delay is surprisingly large — approximately 280 parts per million (ppm), which equates to slowing down almost one

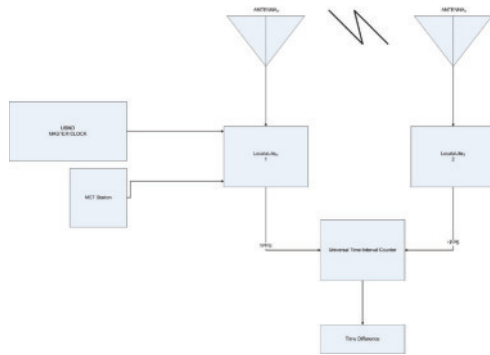
nanosecond over each kilometer of radio transmission. Obviously, as transmission distances increase, tropospheric error becomes a substantial factor which must be accounted for in hyper-accurate timing systems. Devising methodologies that effectively mitigate large tropospheric errors becomes essential.

To help solve this problem, Locata developed new tropospheric models that use relatively inexpensive meteorological (MET) stations which measure temperature, pressure and relative humidity at the LocataLite sites. This modeling alone is able to mitigate the tropospheric effects to within just few parts per million. This proved to be an essential feature, as the weather during the course of the entire months-long testing campaign varied significantly among the separate trials.

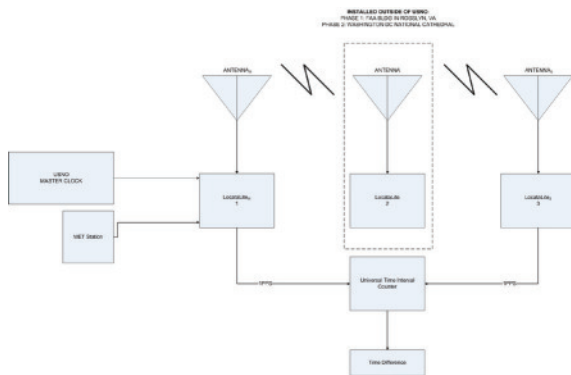
In large networks where extremely high synchronization accuracies are required, it is useful to incorporate a meteorological sensor at each LocataLite to monitor the change in weather over considerable distances. This is certainly the case for long-range systems such as the USAF LocataNet installed at the huge White Sands Missile Range, where distances of over 50km can be found between LocataLites. However, for the purposes of these



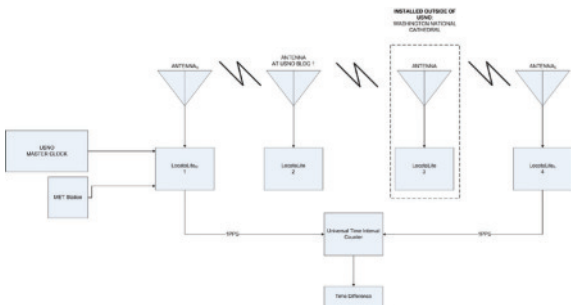
**One team with one goal:
accurate and reliable GNSS positioning anywhere**



▲ **FIGURE 3** Two-node setup (total range: 15.24m/50ft)



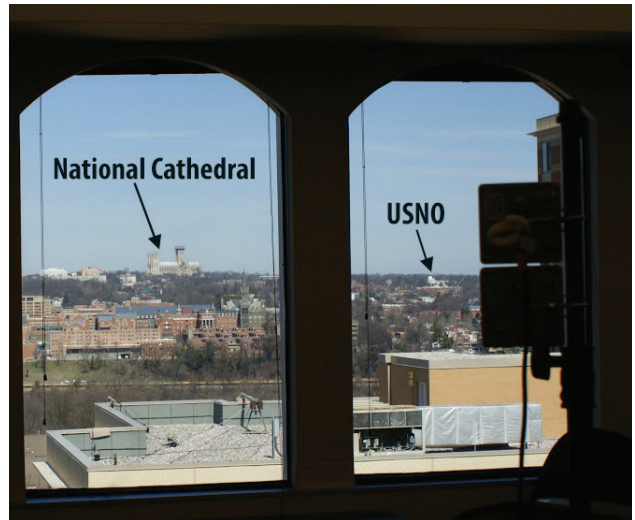
▲ **FIGURE 4** Three-node setup (total range: 5.794km/3.6mi & 2.401km/1.49mi)



▲ **FIGURE 6** Four-node setup (total range: 2.413km/1.5mi)

USNO Washington experiments, where the longest point-to-point transmission distance was 2.9km, it was assumed that weather parameters would be virtually identical at all LocataLite locations. Therefore only one MET station was employed within the entire network, which for these trials was collocated with the master LocataLite.

The very first experiment conducted by the USNO to gain some familiarization with TimeLoc was run entirely within the grounds of the USNO campus. It employed two LocataLites with their respective antennas on the roof of USNO Building 78. In this initial configuration the antennas were positioned 15.24m apart. It was intended to use the measured result as a baseline against which TimeLoc synchronization over longer distance could be



▲ **FIGURE 5** Intermediate LocataLite 2 antennas inside FAA building. In the distance, both the USNO and the National Cathedral are visible.

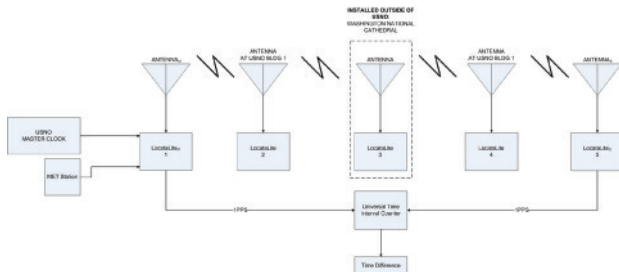


▲ **FIGURE 7** LocataLite antennas outside the Ringing Chamber of the National Cathedral Spire.

compared. This first arrangement is referred to as the two-node setup. A diagram of this configuration is shown in **FIGURE 3**.

Second and third experiments demonstrated LocataLite’s ability to cascade the master 1PPS signal to an intermediary slave LocataLite, which in turn transmits a signal to which a third LocataLite can TimeLoc. This LocataNet configuration is referred to as the three-node setup (**FIGURE 4**).

This experiment was conducted twice using two different intermediate LocataLite locations. The first intermediate location was indoors on the top floor of the FAA Building in Rosslyn, VA (**FIGURE 5**). The distance between the master/slave antennas to the intermediate antenna in the FAA building was 2.897km, but since the signal was propagated through a tinted window, the received signal strength inside the building was greatly attenuated, effectively simulating a much longer transmission distance. The second intermediate



▲ **FIGURE 8** Five-node setup (total range: 2.427km/1.51 mi)

(LocataLite 2) location was from the balcony of the National Cathedral’s Ringing Chamber. In this case the distance between USNO LocataLite 1 master/slave to the intermediate antenna in the National Cathedral was approximately 1.183km.

In both cases in Figure 4, the distance between master and terminal slave antennas was 3.048m on the USNO building, but they were intentionally not TimeLoc’d to each other. The timing signal was therefore forced to route through the intermediate LocataLite 2 at either the FAA Building or the National Cathedral.

A fourth experiment included yet another intermediate cascade where the TimeLoc signal was transmitted from the



▲ **FIGURE 9** LocataLite antennas on USNO Building 1. National Cathedral in background.

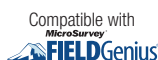
second to a third LocataLite/antenna before arriving at the fourth LocataLite in the chain. This LocataNet configuration is referred to as the four-node setup. A diagram of the setup is shown in **FIGURE 6**, and it now added a LocataLite on USNO Building 1 to expand the set-up, along with the intermediate

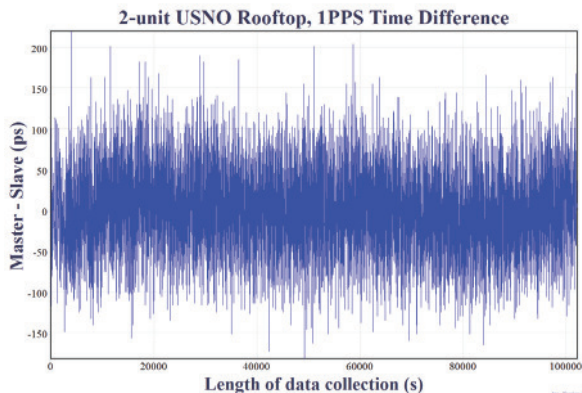
ASK FOR YOUR FREE TRIAL
→ effigis.com/ezsurv

POWER AND PRECISION AT YOUR FINGERTIPS

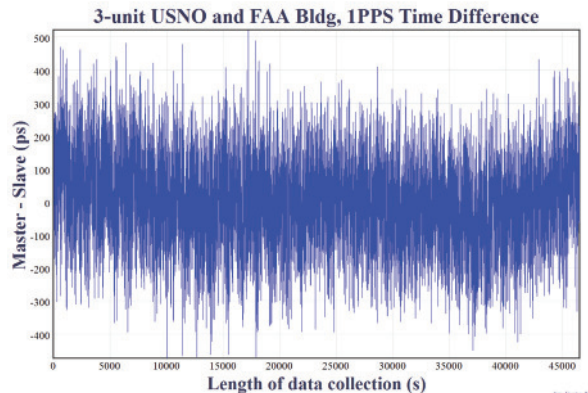
EZSURV® POST-PROCESSING SOFTWARE PROVIDES YOU WITH:

- ▶ Access to more than 8,000 CORS stations data all around the world
 - ▶ Support multiple receiver native data format
 - ▶ State-of-the-art processing engine
 - ▶ Easy-to-use application
 - ▶ Flexible licensing mechanism
- ▶ White Label version available for manufacturers

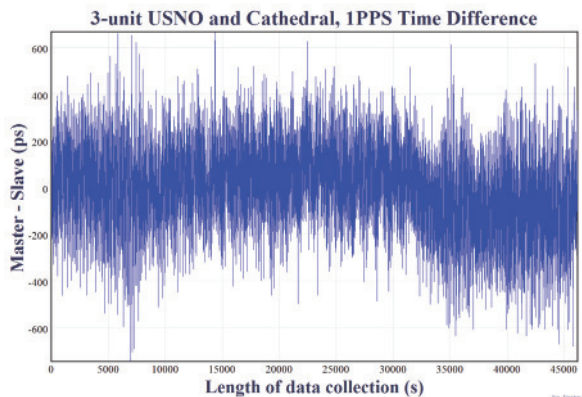




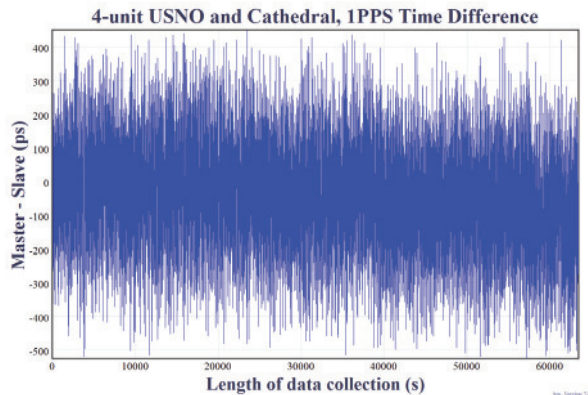
▲ **FIGURE 10** Two-node setup on USNO rooftop, collected for slightly more than 1 day. Distance: 15.24m/50ft. Synchronization Standard Deviation (SSD) = 51.095 picoseconds



▲ **FIGURE 11** Three-node setup at USNO and FAA Building, collected for over 12 hours: 5.794km/3.6mi. SSD = 127.333 picoseconds



▲ **FIGURE 12** Three-node setup at USNO National Cathedral, collected for over 12-hours: 2.401km/1.49mi. SSD = 171.325 picoseconds



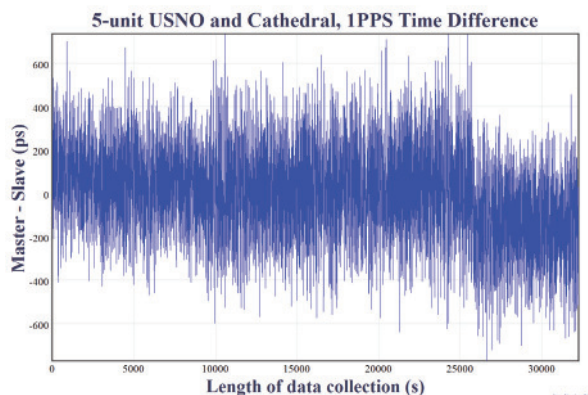
▲ **FIGURE 13** Four-node setup at USNO with cascades at National Cathedral and USNO building 1, collected for over 17-hours: 2.413km/1.5mi. SSD = 145.247 picoseconds

LocataLite installed at the National Cathedral (FIGURE 7).

Referring to Figure 6, the distance between the master LocataLite (antenna 1) at USNO Building 78 and the LocataLite (antenna 2) at USNO Building 1 was approximately 42.672m. The distance between the USNO Building 1 (antenna 2) to the Washington National Cathedral (antenna 3), was approximately 1.144km. The distance between the Washington National Cathedral (antenna 3) back to antenna 4 on USNO Building 78 was approximately 1.183km. The total range in this four-node chain was 2.413km. In this configuration, LocataLites 1 and 4 are intentionally not TimeLoc'd to each other, forcing the 1PPS signal to be routed through LocataLites 2 and 3.

A fifth experiment included yet one more LocataLite and antenna at USNO Building 1 (FIGURE 9), totaling cascaded TimeLoc among five LocataLites and their respective antennas: the five-node setup, shown in FIGURE 8. In this configuration LocataLites 1 and 5 are intentionally not TimeLoc'd to each other, forcing the 1PPS signal to be routed through LocataLites 2, 3, and 4.

Measurement Methodology



▲ **FIGURE 14** Five-node setup with cascades at National Cathedral and 2 hops at USNO building 1, collected for over 8-hours: 2.427km/1.51mi. SSD = 197.766 picoseconds

A measurement of time difference between master and slave LocataLite 1PPS readings was done using a Stanford SR620 universal time interval counter. The rising edge of the 1PPS signals were inspected at 1-Volt trigger level. A 10 MHz reference was provided to the counter from the USNO's Master Clock. Channels A and B on the counter

Setup	Data Collected on Modified Julian Date (MJD)	Total Signal Distance from Master to Terminal Slave LocataLite	Standard Deviation (picoseconds)	Change in RMS from short baseline 2-node setup (picoseconds)
2-node (Fig. 10)	MJD 56948.756 to 56949.937	15.24m/50ft	51.095	N/A
3-node (Fig.11, FAA Bldg.)	MJD 57104.044 to 57104.583	5.794km/3.6mi	127.333	76.238
3-node (Fig. 12, Nat. Cath.)	MJD 57161.922 to 57162.457	2.401km/1.49mi	171.325	120.230
4-node (Fig. 13)	MJD 57162.848 to 57163.583	2.413km/1.5mi	145.247	94.152
5-node (Fig. 14)	MJD 57164.193 to 57164.566	2.427km/1.51mi	197.766	146.671

▲ **TABLE 1** LocataNet frequency stability.

were designated to the master and slave 1PPS signals respectively. Data were collected from the counter through serial connection to a PC. The length of each experiment was time-limited in some way because of limited access to facilities, such as the FAA building or National Cathedral. However, a minimum of at least 30,000 seconds (8.33 hours) of data were collected for each test to characterize the overall stability of the 1PPS signals between master and terminal slave LocataLites.

Collected Data

FIGURES 10 TO 14 show the normalized 1PPS time difference between the master LocataLite and the terminal slave LocataLite. Normalization effectively removes errors due to unsurveyed antenna locations and uncorrected cable delays; hence it highlights the frequency coherence of the network.

Results

The results in TABLE 1 show the 1PPS signal variability for each LocataNet under evaluation. These values represent the frequency coherence between master and terminal slave LocataLite 1PPS signals for each experiment.

The two-node setup used two LocataLite antennas located within 15.24m of each other. The measured precision standard deviation was 51.095 picoseconds. This value is a

culmination of the total Locata noise budget, which is expected to consist of TimeLoc noise, residual tropospheric error, multipath change (signal scattering/diffusion), PPS generation, and PPS measurement. This two-node result can be used as a baseline for Table 1 measurement results over longer distances. The differences are

shown in the last column of Table 1. For example, cascading TimeLoc over the 5.794 km three-node setup introduced an additional deviation of 76.238 picoseconds, compared to the two-node set-up.

The three-node setup tested the effect of adding a TimeLoc cascade wherein the Locata signal from the

Anti-Spoofing
SX3 GPS/GNSS Software Receiver - Black Edition

SX3 - Your perfect tool for defense development

- ✓ Create your own beam-forming algorithms
- ✓ Take advantage of dual-antenna input for anti-spoofing development

GPS | GLONASS | Galileo | BeiDou | SBAS | IRNSS

Dual-RF input with 2 x 2 RF chains (50 MHz RF bandwidth each)
 Develop your own signal processing using API
 Real-time and post-processing capability

For additional information, contact us.

For Americas: IFEN Inc. +1 951 739 7331 M.Wilson@ifen.com
 For EMEA & APAC: IFEN GmbH +49 8121 2238 20 sales@ifen.com

master is routed to an intermediate LocataLite, and then to the terminal slave. When the master LocataLite signal was cascaded through the intermediate LocataLite at the FAA Building, the configuration showed a standard deviation of 127.333 ps across a total signal path length of 5.794 km. Alternatively, when the master LocataLite signal was cascaded through the intermediate LocataLite at the National Cathedral, that three-node configuration showed a standard deviation of 171.325 ps across a total signal path length of 2.401 km.

Interestingly, it appears that in the two different three-node setups, the intermediate cascade to the FAA building (2.9 km from the master and terminal slave LocataLites) delivered slightly better time transfer performance than the configuration which leveraged the closer (1.183 km) National Cathedral intermediate cascade. We believe this is attributable to the fact that the line-of-sight between USNO Building 78 (the site of the master and terminal slave) and the National Cathedral (the intermediate cascade) was completely obscured by heavy foliage seen in Figure 9, and that this particular configuration required the signal to pass through the foliage twice when being transmitted back and forth. Not only does foliage introduce multipath, but the properties of this foliage also changed regularly according to wind and moisture—two weather attributes that varied significantly over the course of the week in which those particular experiments were set up and run. This theory seems reasonable, since the four-node setup only required the signal to pass through this foliage once, and the recorded performance was better than the three-node setup—despite the fact that an additional TimeLoc cascade point was introduced.

The four-node setup included TimeLoc cascades at USNO Building

1 and the Washington National Cathedral. In this configuration, the data from Table 1 shows a standard deviation of 145.247 ps across a total signal path length of 2.413 km.

The five-node setup included yet another TimeLoc cascade between the National Cathedral and Building 1 at USNO before reaching the terminal LocataLite slave. In this configuration, the data from Table 1 shows a standard deviation of 197.766 ps across a total signal path length of 2.427 km.

Frequency Stability

Frequency stability is best measured over long periods. Because all of the equipment in the two-node setup was located on USNO premises, it could be run undisturbed for a longer period of time than configurations which required access to external facilities outside of the USNO's control. Data obtained from the two-node setup were used to calculate the frequency stability between the two TimeLoc'd LocataLites. The length of this data set was 28 hours, 22 minutes, and 40 seconds. During this period, the approximate one-day frequency stability was measured as 1×10^{-15} (1 part per quadrillion).

To put this measurement into a more practical context: Stratum 1 is defined as a source of frequency with an accuracy of at least 1×10^{-11} , hence Stratum 1 performance generally originates from an atomic standard. For example, Cesium beam atomic clocks typically provide better performance than this, with one day Allan deviation stabilities in the mid- $Ex10^{-14}$ (usually stable to between 3×10^{-14} to 6×10^{-14}). Rubidium clocks are typically never more stable than 1×10^{-13} and Maser clocks are typically stable to mid-to-low $Ex10^{-15}$ over one day.

Locata's link stability—achieved without the use of atomic clocks—is clearly capable of distributing Stratum 1 frequency and precise

time without substantially degrading the reference clock stability. This measured performance is significant, because a stable network is an essential prerequisite for precise time and frequency transfer. Moreover, for many traditional timing applications and developing digital and IoE applications, stability is more important than accuracy; just as for most advanced technology applications, frequency is more important than time of day.

Conclusions

The five USNO experiments suggest that the variations of the measured frequency synchronization between master and terminal slave LocataLites were not inevitably attributable to the distance between LocataLites, but rather governed by the number of nodes or cascade points in the LocataNet configuration, and LocataLite signal quality. Each signal cascade through an intermediate LocataLite introduced ~ 25 ps of jitter into the solution.

Additionally, it was noted that transmitting TimeLoc signals across an urban environment did not always allow for unobstructed line-of-sight or completely open-sky environments. For instance, some of the LocataNet configurations required the signal to travel through dense, leafy trees which appeared to slightly affect overall frequency stability. Additionally, one FAA configuration required the signal to travel indoors through a tinted window which ultimately affected received signal strength.

These USNO tests highlighted the capability of the LocataLite as a viable option for a stable 1PPS distribution setup within an urban environment in support of applications like cell tower synchronization in “GPS-challenged” environments. **All tested configurations demonstrated frequency synchronization of less than 200 picoseconds. This is significantly better than any other known**

wireless network synchronization methodology, including GPS.

Furthermore, if clear line-of-sight is available between a master and slave LocataLite, the 2-node precision has been shown to be on the order of 50ps, and has one-day stabilities to 1×10^{-15} .

These results, reinforced by those previously reported in University of New South Wales tests over a very large area, suggest that distance between nodes is not a significant factor, provided that sufficient signal quality is maintained. Thus, there are no theoretical or technical problems with scaling LocataNets to very large areas. In fact, this has already been demonstrated at the White Sands Missile Range where the USAF has now deployed a fully-operational Locata network that covers up to 2,500 square miles (6,500 square km),

about 80 times the size of Manhattan.

The USNO trials reported here have clearly demonstrated TimeLoc's relative picosecond-level synchronization of independent Locata networks. If this highly-stable network capability were not in place, precise time transfer would not be possible. The next step is to demonstrate how well a LocataNet can deliver absolute time transfer of the USNO's Master Clock time to any other network node across similar areas of Washington DC.

Acknowledgments

The authors would like to thank James Shepherd of the National Cathedral and Paul Worcester of the FAA for use of their respective buildings. The authors would also like to thank Locata personnel for the use of their

equipment and technical assistance in setting up the LocataNets under evaluation.

This article is based on a paper presented at ION GNSS+ 2015.

Disclaimer

Though particular vendor products are mentioned, neither official USNO endorsement nor recommendation of any product is herein implied.

EDWARD POWERS is the GNSS and Network Time Transfer Operations Division Chief at USNO. He also serves as an advisor to the USAF GPS Directorate supporting space atomic clock development, modernized GPS III navigation message design, GPS accuracy improvement studies, and GPS UE development.

ARNOLD COLINA is an electronics engineer in USNO's GNSS and Network Time Transfer division, tasked with providing accurate UTC reference through GPS and performing calibration tests on GNSS receivers.

Timing Versus Synchronization

"They say 'timing is everything' but nowadays it's probably more correct to say 'synchronization is everything'. There is a significant difference, yet many are surprised to learn they are not the same thing.

"Time dependent" applications rely on their clocks being close to the "real time", as defined by a consensus of super-accurate atomic clocks managed by national bodies like the USNO. Once agreed upon by the labs, this "real time" can be distributed to various "time dependent" networks as a reference time to drive their operations.

"Time synchronized" applications, on the other hand, employ a methodology in which a common network time can be transferred to each network node. In other words, often the real technology enabler is that all the clocks in a defined network are synchronized to each other, even if they all run to what is any arbitrarily defined time-base. The

"real time" doesn't matter as much as how closely the node times agree with each other. As Einstein famously taught us: "Everything is relative."

For example, accurate synchronization enables GPS positioning to work because a user's GPS receiver relies on time-of-arrival comparisons from four or more satellites transmitting their signals at the same instant. But — even in this GPS paradigm where atomic clocks are always touted to be the most fundamental of requirements — it is important to appreciate this: A GPS user's receiver does not care how, or to what "time," the satellites are made synchronous. The only things the user receiver needs to know is where the satellites are, and that the satellites are synchronized when they transmit their signal.

Unfortunately sustaining high-precision, reliable time synchronization of multiple network nodes is a mammoth engineering

task. Just ask the US Air Force! All clocks, no matter how accurate they are, eventually drift, so they cannot remain synchronized without comparison and adjustment.

Given the world's exploding, insatiable demand for more data transmitted via ever-faster wireless systems, synchronization will become even more important than it is today. More wireless users and more bandwidth per user means that nanosecond — or even picosecond — network synchronization is one of the great emerging engineering challenges of the 21st century. There are few resource on earth which are as scarce, or more precious today, than spectrum. So there is no question that better or cheaper ways to greatly improve network frequency and synchronization will translate directly into better use of the world's exceptionally valuable, extremely limited spectrum resource.