Report on GPS activities
2018

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Timing Subcommittee of the 58th CGSIC Meeting – Miami, FL
OUTLINE

GPS Time Transfer for Coordinated Universal Time (UTC)

Time Dissemination and Services via GPS

Science: comparing clocks and supporting ACES

A resilient timing infrastructure
Coordinated Universal Time (UTC) is the official world time scale.

UTC is computed by the International Bureau of Weights and Measures (BIPM) in France.

- UTC(NIST) is the local realization of UTC. The UTC(NIST) time scale consists of an ensemble of hydrogen masers and cesium clocks.

- NIST maintains and operates UTC(NIST) and the U. S. Primary Frequency Standards, cesium fountain devices F1 and F2.

- The time transfer links between NIST and BIPM are based on
  - Two-Way Satellite Time and Frequency Transfer (TWSTFT) measurements utilizing geostationary satellites.
  - GPS common-view measurements.
Two-Way Satellite Time and Frequency Transfer
USNO shares with NIST the responsibility of maintaining accurate realizations of UTC in the US

GPS: common-view

TWSTFT: Indirect satellite link going through PTB

SUV: TWSTFT mobile station owned by USNO, periodically driven to NIST in Boulder, CO

GPS with SUV cal: common-view calibration
BIPM issued updated Calibration Guidelines for all laboratories contributing to UTC

G1 = Group 1 Laboratory
G2 = Group 2 Laboratory
RMO = Regional Metrology Organization

- **NIST** (Boulder, CO, USA)
- CNM (Queretaro, MEXICO)
- CNMP (PANAMA)
- INTI (Buenos Aires, ARGENTINA)
- INXE (Rio de Janeiro, BRAZIL)
- NRC (Ottawa, CANADA)
- ONRJ (Rio de Janeiro, BRAZIL)
- INM (Bogota, COLOMBIA)
- INCP (Lima, PERU)

- **USNO** (Washington, DC, USA)
- APL (Laurel, MD, USA)
- IGNA (Buenos Aires, ARGENTINA)
- NRL (Washington, DC, USA)
- ONBA (Buenos Aires, ARGENTINA)
NIST provides common-view GPS measurement systems to its remote customers, allowing them to compare their clocks to UTC(NIST) by using the GPS.

The common-view data is processed in real-time and shows the time or frequency difference between UTC(NIST) and the customer’s clock.

**FMAS**: reports frequency uncertainty to the customer  
**TMAS**: reports time uncertainty to the customer  
**NISTDO**: locks the customer’s clock (rubidium or cesium) to the UTC(NIST)

Customers can then show traceability to the International System (SI) of units through NIST.
DISSEMINATION

GPS Common-view

TMAS and FMAS

NISTDO uncertainty

\[ \sim 5 \times 10^{-14} \text{ at } \tau = 1 \text{ day for frequency} \]

\[ \sim 10 \text{ ns for time,} \]

(k = 2)
Map of Common-View GPS Systems Maintained by NIST
(78 total systems deployed, 53 at customer sites and 25 in SIM Time Network)
DISSEMINATION

NIST remote time and frequency dissemination
Customers by sector

- Electronics and Instrument Manufacturers: 26%
- Financial Markets / Stock Exchanges: 21%
- U. S. Military: 13%
- Defense Contractors: 13%
- Aerospace: 9%
- U. S. Government: 8%
- Private Calibration Laboratories: 8%
- Nuclear Energy: 2%

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International GNSS Service (IGS) Tracking Network

Receiver NIST is an active station [https://igscb.jpl.nasa.gov/network/site/nist.html](https://igscb.jpl.nasa.gov/network/site/nist.html)

NIST data archives:

- One-way GPS data vs UTC(NIST) [http://www.nist.gov/pml/div688/grp40gpsarchive.cfm](http://www.nist.gov/pml/div688/grp40gpsarchive.cfm)
- Common-view UTC(USNO)-UTC(NIST) [http://www.nist.gov/pml/div688/grp50nistusno.cfm](http://www.nist.gov/pml/div688/grp50nistusno.cfm)
The acknowledgment of vulnerabilities in the GPS signals has spurred a lot of activities on both the user side (power grid, telecom and finance) and the provider side (GPS receivers manufacturers and timing providers).
GNSS Stationary Timing Receiver Resilience Workshop

To the **US Government**:

1. Establish Assured PNT Program for America’s CI
2. Monitor spectrum (see EU Strike3), publish reports and recommendations
3. Promote development & use of PNT maturity model by industries/sectors
4. Enforce against violations of the spectrum: jamming and spoofing

To **Standards Organizations**:

1. Define resilience (metrics and language) and how to test for it
2. Define standard way of detecting threats, validating receivers resilience
3. Promote the development of a procurement language relating to resilience

To **User Industries**:

1. Adopt an Organizational Maturity Model: identify system’s dependence on GNSS and create case studies to illustrate needs.
2. Adopt a common procurement language
3. Monitor for problems and impacts and report, leveraging user base in collaboration with Government to support spectrum protection
4. Use alternative timing sources

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TIMING INFRASTRUCTURE

**Assured Access to Accurate Time Workshop**

- Provide a common venue for US Government, users and time providers
- Define attributes and metrics for assured and accurate time

**FRAMING THE PROBLEM**

Now:
- Fragile (single source)
- Limited use of alternative timing source
- Lacking Competence

Access to Assured and Accurate Time (at least 3 independent sources):
- Robust (system diversity)
- Time Source diversity
- Modernized GPS SVs, NAV Message
- GPS multi-constellation
- NTP
- Timing via long-wavelength transmitters
- Timing via fiber
- Other timing sources (including redundant clocks)

**ROBUST COMPETENT PROCESSOR**

NIST
The MITRE Corporation

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FRAMING THE PROBLEM

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Assured Access to Accurate Time Workshop

Accuracy
- determined by calibration to a known standard
- traditional statistical estimator may not be appropriate

Stability
- Statistical noise
- Long-term drifts (how often to calibrate)

Traceability

Assuredness
- Reliability
- Signal integrity
- Confidence (flag or statistical)

Availability
- “No signal is better than wrong signal”
- Geographical
- For both time delivered to user and to competent processor

Continuity
- Temporal availability (probability of delivery of assured signal over time)
- Holdover

Processor’s health
- Exceeds RAIM

Number of timing inputs
- >3 for diagnostic

Degrees of diversity of inputs
- All UTC, different deliveries

Use of corollary information
- Well-surveyed antenna
- Frequent checks on frames
- Doppler information
- Etc.

Graceful degradation
- Quantify the degradation as one or more inputs are compromised

Time to first time/recovery
Next steps:
• Continue as working group
• Quantify the attributes to derive metrics and performance bands
• Define reference architectures to be characterized
• Develop testing procedures and protocols

Assured Access to Accurate Time Workshop II
January 28th, 2019
Co-located with PTTI
Reston, VA
Atomic Clock Ensemble in Space (ACES) mission support

Accurate position of the International Space Station (ISS) to allow for the best frequency transfer between ground stations and ISS.

Test of Local Position Invariance principle

Using long-term (14 years) comparison of remote clocks (H masers and Cs fountains), via UTC. x5 better than previous effort in 2007.

The next improvement will use optical clocks

ARTICLES
https://doi.org/10.1038/s41567-018-0158-2

A null test of general relativity based on a long-term comparison of atomic transition frequencies

Neil Ashby, Thomas E. Parker, and Bijunath R. Patla.

The Timing Subcommittee of the 58th CGSIC Meeting – Miami, FL
Atomic Standards
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THANK YOU!

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