Overview of NIST Time Realization and Distribution Group

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Time Realization and Distribution Group

This new group was formed at NIST by Dr. Elizabeth Donley, the NIST Time and Frequency Division Chief, in August 2019. Three existing groups were combined into one group (time services, atomic standards/time scale, and cesium fountain clock development)

The group currently has 21 employees, including 17 U. S. government employees as well as several contractors and post doctoral researchers. Its members include:

- **Mr. Michael Lombardi**, Leader of Time Realization and Distribution Group
- **Dr. Jeff Sherman**, leads UTC(NIST) time scale and Two-Way Satellite Time Transfer program
- **Dr. Judah Levine**, NIST fellow, applies corrections to UTC(NIST) and leads Internet Time Service
- **Dr. Bijunath Patla**, leads GNSS calibrations and in charge of G2 calibrations
- **Dr. Vladislav Gerginov**, leads development of NIST primary standard cesium fountain clocks
- **Mr. Matt Deutch**, in charge of NIST Radio Stations WWVB and WWV
- **Mr. Dean Okayama**, in charge of NIST Radio Station WWVH
- **Mr. Andrew Novick**, quality manager for Time and Frequency Division

UTC(NIST) Time Scale

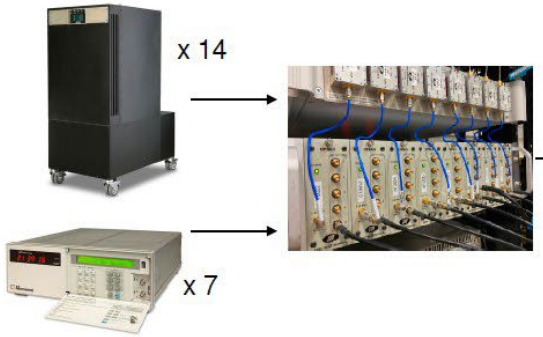
Jeff Sherman, Judah Levine, Biju Patla, Roger Brown, Ladan Arissian

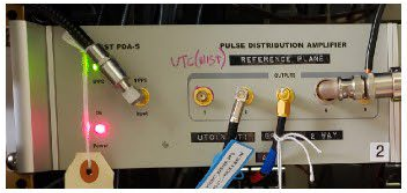
- Located in Boulder, Colorado
  - From 10 to 15 atomic clocks are typically included in the time scale
  - Approximately 2/3 hydrogen masers, 1/3 cesium clocks
- A weighted average of the clocks provides the U. S. national standard for frequency and time.
- A secondary UTC(NIST) time scale with five cesium clocks is located at our radio station site in Fort Collins, Colorado. We also have two cesium clocks at the NIST headquarters in Gaithersburg, Maryland.

Satellite comparisons for time realization

Signals sent to customers for time

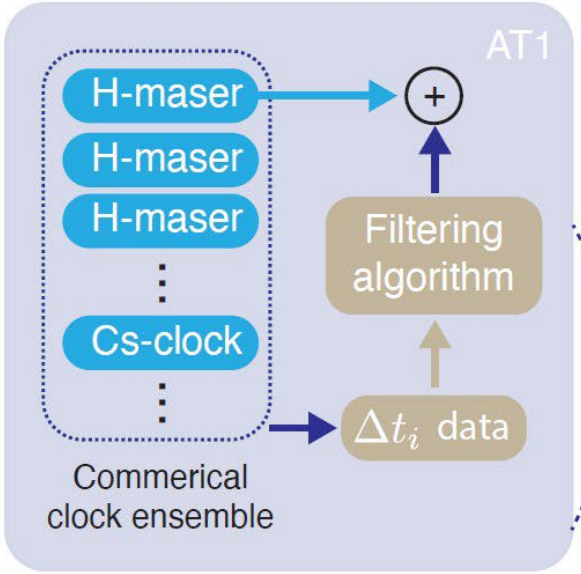
How is UTC(NIST) made?

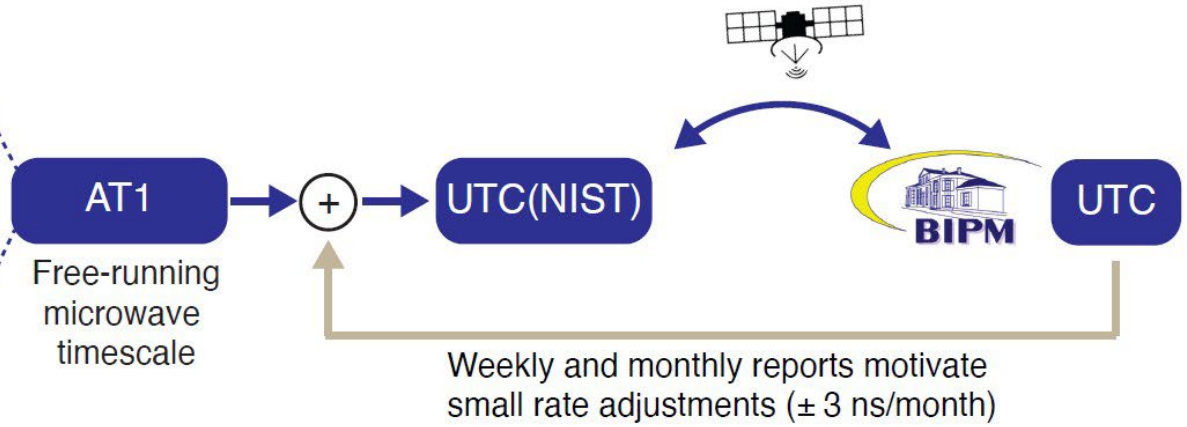




UTC(NIST)

TW satellite transfer,
GPS/GNSS common-view,
Internet Time Service, etc.





Two-way satellite time and frequency transfer (TWSTFT)

Jeff Sherman and Roger Brown

- Time transfer through geostationary communication satellites over microwave links (Ku band is commonly used).
  - ~ 2 ns timing uncertainty typical
- TWSTFT is the primary link for the contribution of UTC(NIST) to TAI, UTC, and UTCr.
- Due to industrial demand, a new TWSTFT service has been developed and should obtain its first customer later this year. The service is called “Time Over Satellite”.

TMAS/NIST Disciplined Clock Service

Michael Lombardi, Andrew Novick, Aidan Montare

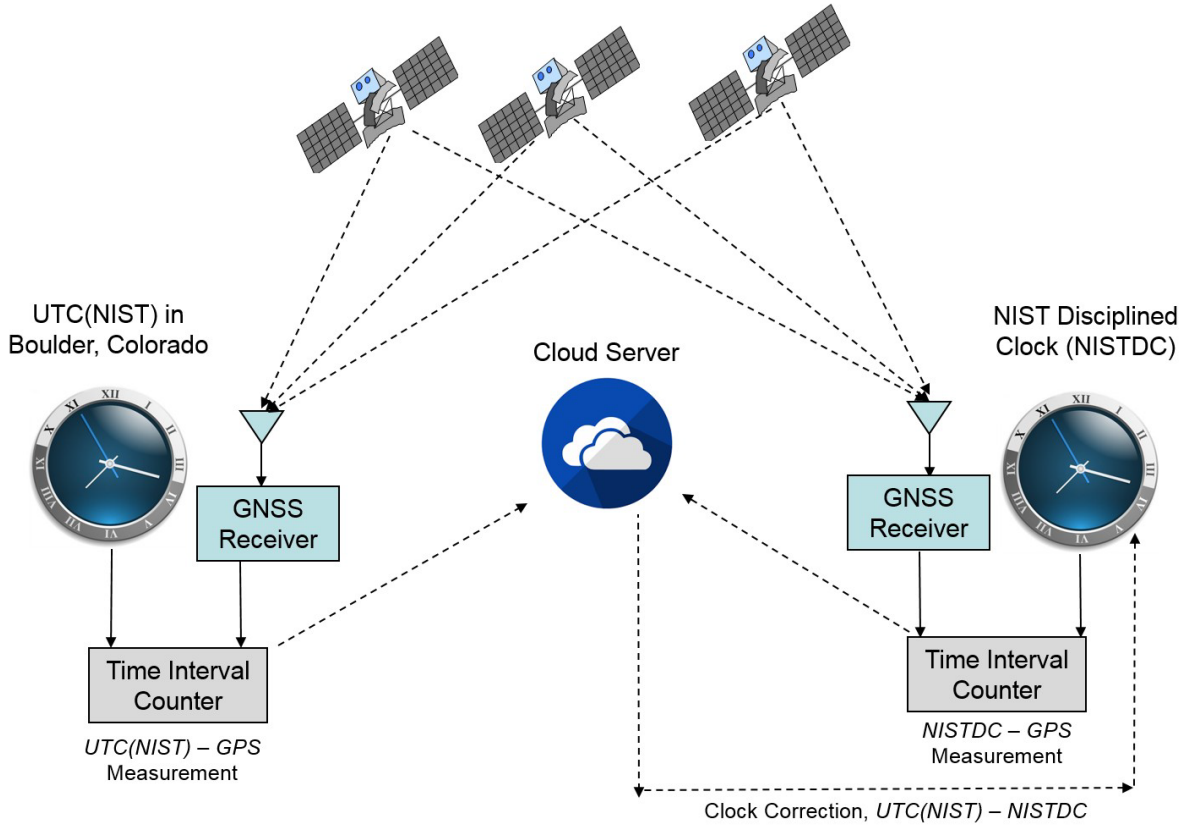
TMAS and NISTDC services

- Uses GPS Common View

Frequency to ~1×10^{14} at one day of averaging

Time to within ~10 ns of UTC(NIST) (k = 2)

Synchronizes major U. S. stock markets (NYSE, Nasdaq, MEMX)



Time Over Fiber

Judah Levine, Elizabeth Donley, Jeff Sherman

- NIST provides signals from the UTC(NIST) primary time scale, or from the secondary time scales, over network optical fiber links.
- Protocols supported include PTP (IEEE-1588) and White Rabbit.
- Customers lease their own fiber connection, and accuracy is dependent on the type and quality of the fiber link and the protocol selected.

Time by Low Frequency Radio: WWVB

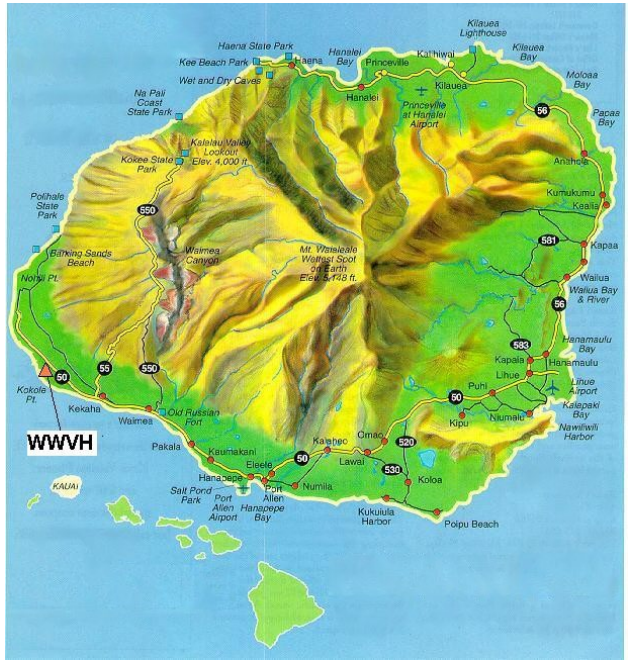
Matt Deutch, Glenn Nelson, Bill Yates, Jim Spicer

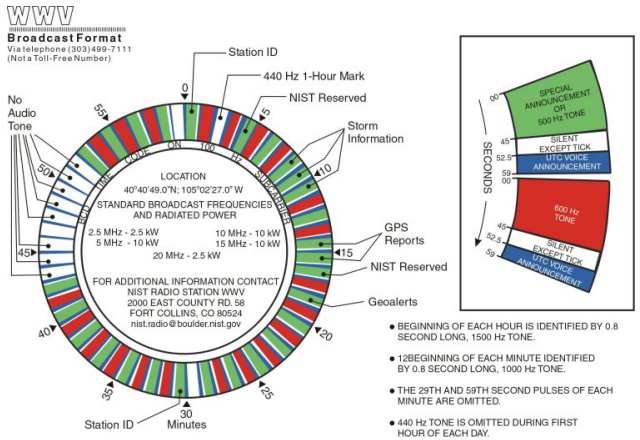
- WWVB continuously broadcasts a digital time code on a 60 kHz carrier from Fort Collins, Colorado that synchronizes an estimated 100 million clocks and watches daily.
- Typical accuracy is in milliseconds, but < 100 µs accuracy is possible with careful calibrations of propagation delays.
- Groundwave signals are stable, and prototype disciplined oscillators now under development are stable to near 1×10^{12} at one day of averaging.

Time by High Frequency (HF) Radio: WWV/WWVH

Matt Deutch, Glenn Nelson, Bill Yates, Jim Spicer, Dean Okayama, Dean Takamatsu, Chris Fujita, Adela Ochinang

- HF is the part of the radio spectrum from 3 to 30 MHz (often known as shortwave). WWV is the shortwave station operated by NIST from Fort Collins, Colorado. Its sister station, WWVH, is located on the island of Kauai in Hawaii.
- Both stations broadcast on 2.5, 5, 10, and 15 MHz, and WWV is also available on 20 MHz and 25 MHz, so 10 transmitters are continuously on the air.
- WWV and WWVH are best known for their audio announcements of UTC that occur once per minute. They are also used for simple frequency calibrations, as space weather beacons that assist with ionospheric studies of the HF spectrum.





Internet Time Service (ITS)

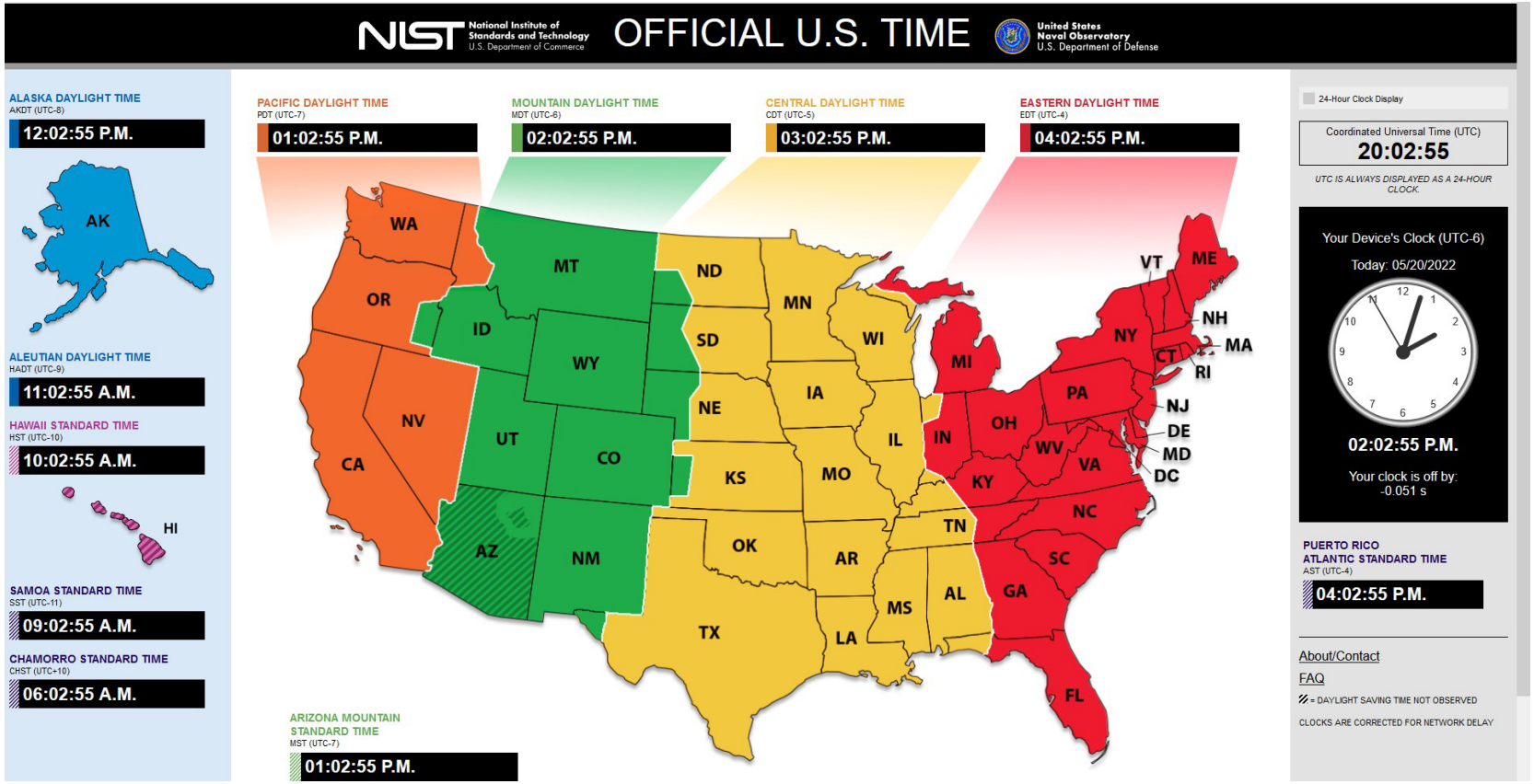
Judah Levine

- The Internet Time Service consists of 23 servers located at four different sites:
  - The NIST campus in Gaithersburg, Maryland (7 servers)
  - The NIST campus in Boulder, Colorado (7 servers)
  - NIST Radio Station WWV in Fort Collins, Colorado (7 servers)
  - JILA on the University of Colorado campus in Boulder (2 servers)
- The service receives about 100 billion timing requests per day.

Web Clock (time.gov)

Andrew Novick

- The United States national web clock, time.gov is sponsored in part by United States Naval Observatory (USNO). It displays the time-of-day for all U. S. time zones as well as UTC.
- A very popular web site, time.gov is not intended for serious measurements. However, it is referenced to the NIST Internet Time Service and continuously monitored for accuracy.



Time Signals Distributed by NIST

Service	Uncertainty	Customer Cost	Estimated Average Users Per Day
Two-way satellite T&F Transfer	2 ns	Used for international comparisons between NMIs with new service to being, possibly this year	12 (USNO, PTB, and other NMIs)
SIM Time Network	10 ns	Used for international comparisons between NMIs	26, if all sites are operational
Time Measurement & Analysis Service	10 ns	Requires paid monthly subscription	40
Time Over Fiber	50 ns	Requires paid monthly subscription	2
LF Radio, WWVB	100 µs	Free	100 000 000
Internet Time Service	1 ms	Free	50 000 000 000
HF Radio, WWV/WWVH	1 ms	Free	100 000
ACTS	5 ms	Free	500
Telephone Time of Day	50 ms	Free	1000

Primary Standards Development

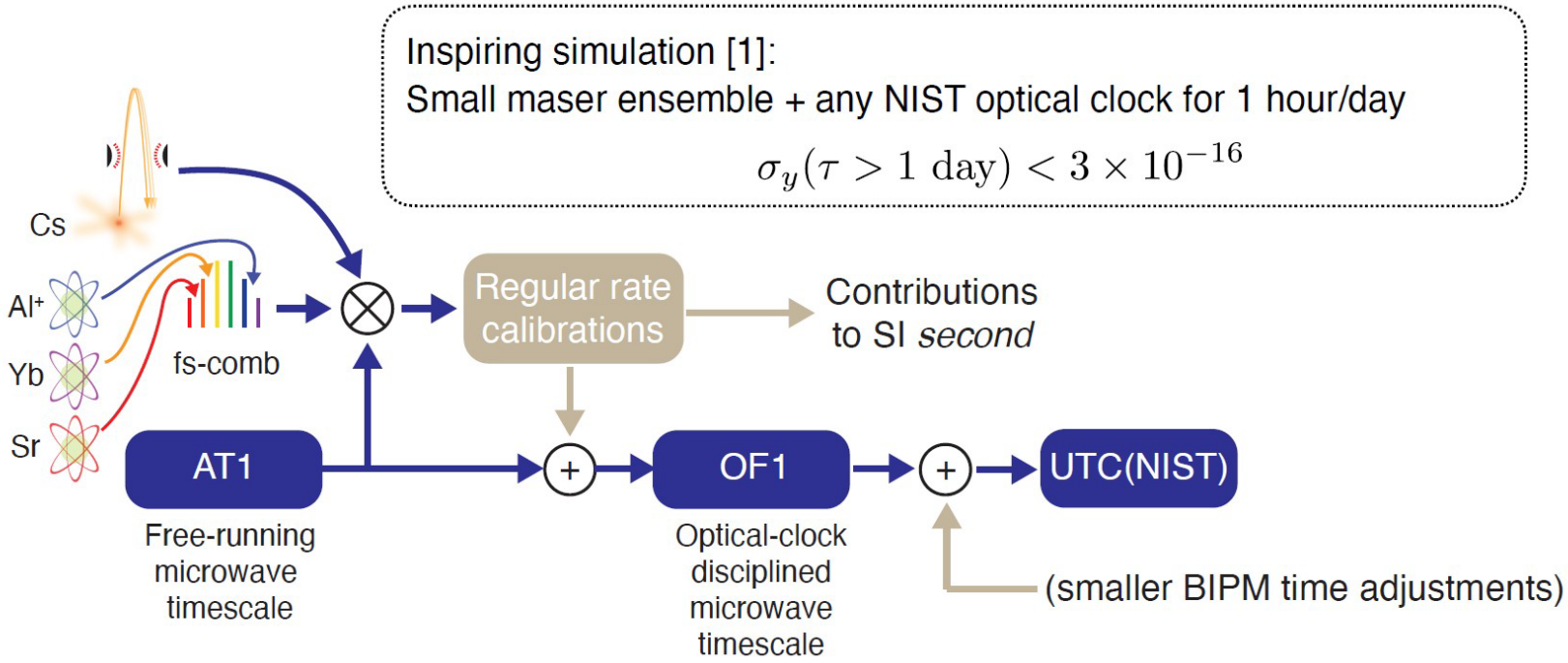
Vladi Gerginov, Greg Hoth, Tom Heavner

- NIST has not had a working primary frequency standard for several years. However, the former cesium fountain standard, NIST-F1, is currently being redesigned and rebuilt.
- A new cesium fountain standard, NIST-F3, is also under development.
- Much of this new development has taken place during the pandemic (our researchers have been in the lab throughout) and initial results are encouraging.

Optical clock development to support time scale

Roger Brown, Ladan Arissian, Tom Heavner, Jeff Sherman

- Rigorous efforts are underway to eventually integrate optical clock data into the UTC(NIST) time scale.
- The first optical observation of the SI second with a Ytterbium clock was reported in March 2021.
- Work has begun, in cooperation with the Ion Storage Group of NIST, to develop a Strontium clock that could perhaps regularly contribute to the time scale.



GNSS Independent Timing Efforts

EO 13905 directs NIST to:

"…make available a **GNSS-independent** source of UTC, to support the needs of critical infrastructure owners and operators, for the public and private sectors to access."

NATIONAL ARCHIVES

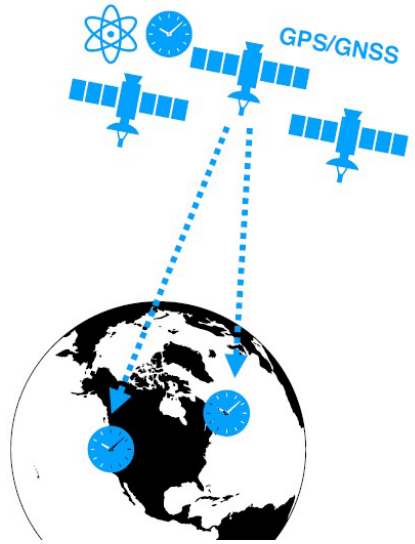
FEDERAL REGISTER

The Daily Journal of the United States Government

PD Presidential Document

Strengthening National Resilience Through Responsible Use of Positioning, Navigation, and Timing Services

A Presidential Document by the Executive Office of the President on 02/18/2020



NIST Response to Presidential EO

- Two technical notes were published by NIST in 2021, one evaluating U. S. dependencies on GPS, and one recommending some possible solutions.
- Time Over Fiber service was formed.
- Time Over Satellite service was formed.
- Research agreements were started with two LEO (low earth orbit) satellite providers and two ground-based signal providers to explore new ways to distribute UTC(NIST).
- Other agreements and plans are in progress.

Summary

- The Time Realization and Distribution group at NIST is dedicated to improving existing systems and finding better ways to realize the SI second and distribute time.
- The scope of the group is extensive. It covers everything from optical clock research and fundamental science, to common millisecond-level timing services that are freely available to the general public.