National Distribution

How labs may distribute time and frequency information

OUTLINE

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7. One Way Radio
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Time Transfer - Concepts

- Comparing or sending information from a time and/or frequency reference to a remote receiver.
- A comparison begins with a good reference (i.e. atomic oscillator, on-time pulse) from an official or trusted source.
- The transfer medium (path) is the main factor for how well the reference can be realized.

Time and Frequency is well suited for remote calibrations

- Usually time and frequency transfer is done wirelessly (with transmitted signals).
- Broadcast frequency itself can be used as a reference, as well as carry information.
- Receiver can be at very remote locations.
- Do not need to turn off/ship oscillator .

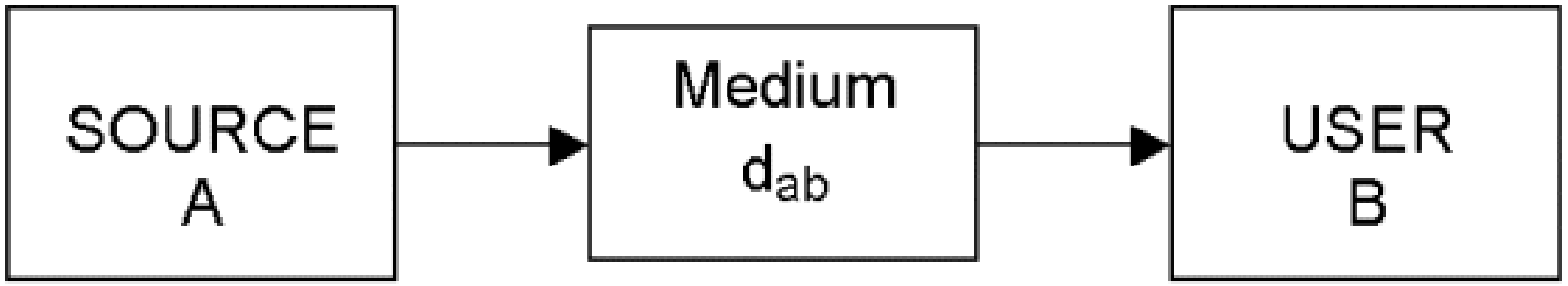
The Receiver

- Can serve as a frequency standard by disciplining a local oscillator (usually 5 or 10 MHz) so that it remains in phase with the received carrier or code, using a phase locked loop (PLL).

- Can serve as a time interval and a synchronization standard by outputting the OTM as a 1 pulse per second (pps) signal.

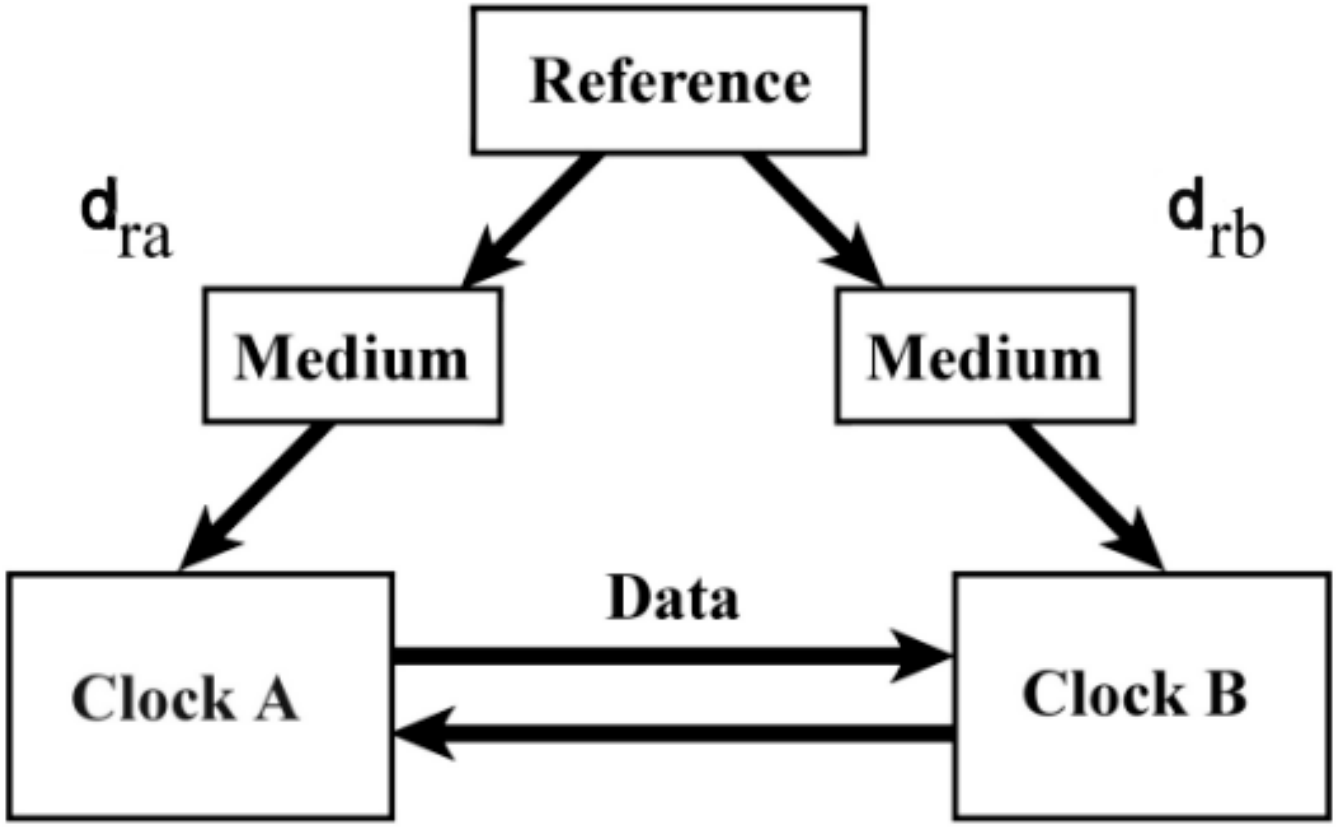
- Can serve as a time-of-day standard by decoding and displaying the time.

One Way T&F Transfer



- The key issue of time and frequency transfer is path delay.
- For time, the uncertainty of the signal is always limited by the knowledge of the path delay.
- For frequency, only the variation in the path delay matters.

Common-View Time Transfer



Time Transfer – NIST Perspective (it's not the only way)

- Many examples, mostly from how NIST distributes time/frequency
- But it's not the only way to do things

Free Time Services – Telephone time-of-day

Requirements:

- Telephone Line(s) (rotary)
- Announcement method

- Can be used to set clocks or calibrate timers/stopwatches.
- Uncertainty can be < 30 ms with appropriate technique.

- Land lines typically have stable delays
- Cellular phones and VoIP add delay/variation

Free Time Services – Time via Modem

- Outmoded service, but still in operation
- Requires timing hardware, multiple-line rotary

- Uses loop-back method

Loop-Back Method

- A data exchange to estimate the path delay.

- The receiver sends received time code back to transmitter.
- Transmitter compares this code to the current time, resulting in the round-trip path delay.
- Transmitter then sends out a new time code, advanced by ½ the path delay.

Issues:

- Assumes reciprocal path delay
- ‘Measurement’ is not of the final time code sent.

Free Time Services – Web Clocks

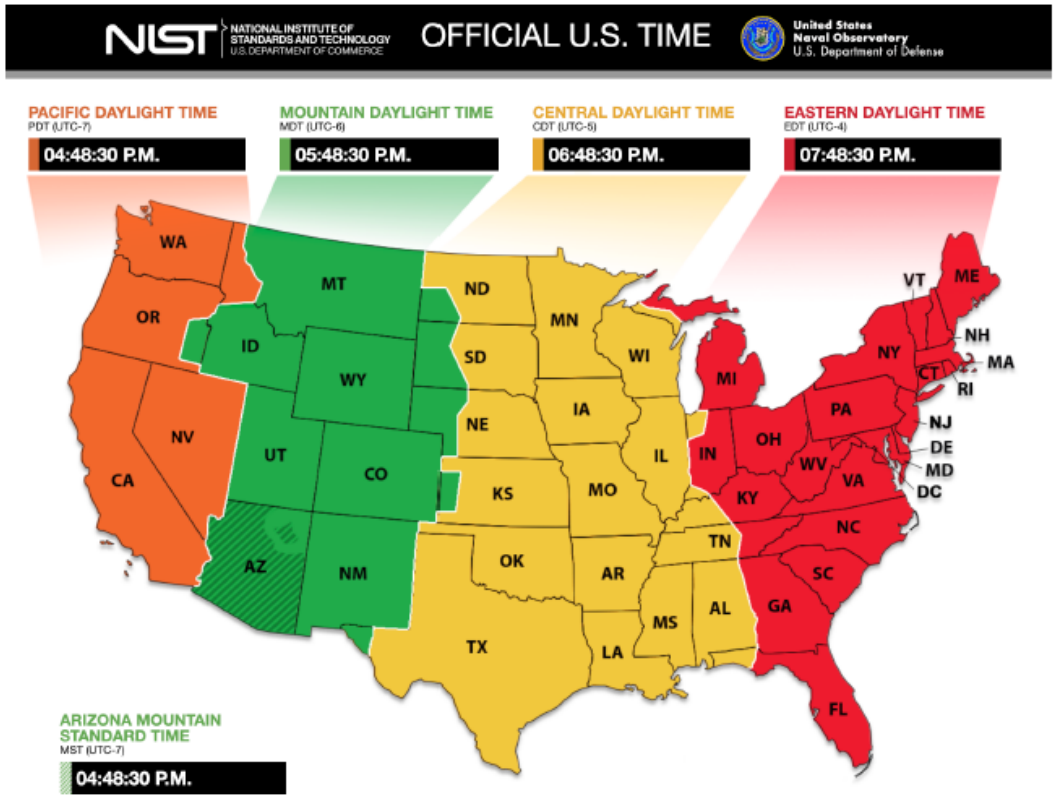
- Client makes HTTP(S) request to web server.
- Web server kept on time, delivers a timestamp, which is delayed on the return path.
- Client measures the round-trip path delay, estimates the return path (based on ½ the round-trip delay).
- Software running in browser shows a “running” clock, most likely using local oscillator on machine.

time.gov is visited more than nist.gov

Source: analytics.usa.gov (sampled June 7, 2023)
Visit statistics of Department of Commerce domains

We count every "client resynchronization" event (every 10 mins): typical **14 million/day**

→ Many users are leaving window open for long periods



Top Domains

Now | 7 Days | 30 Days

Visits over the last month to domains, including traffic to all pages within that domain. Download the full dataset.

forecast.weather.gov	37,881,689
weather.gov	18,577,391
radar.weather.gov	7,567,865
nhc.noaa.gov	7,101,841
cbp.gov	5,303,526
census.gov	3,586,597
noaa.gov	3,121,688
aviationweather.gov	3,068,174
spc.noaa.gov	2,709,180
water.weather.gov	2,631,137
uspto.gov	2,441,606
ndbc.noaa.gov	1,725,848
time.gov	1,723,618
mobile.weather.gov	1,573,108
nvd.nist.gov	1,495,066
oceanservice.noaa.gov	1,431,517
trade.gov	1,360,164
nist.gov	1,155,025
my.uspto.gov	1,088,131
help.cbp.gov	1,030,157

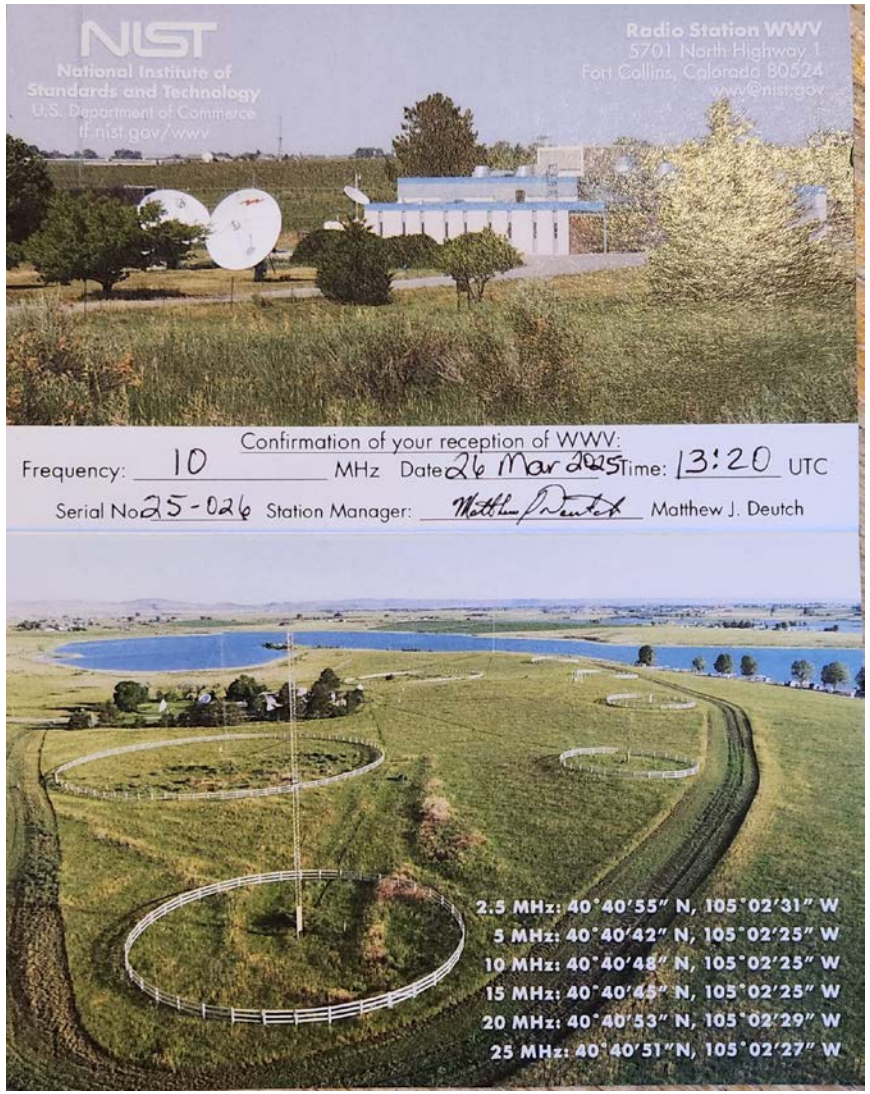
Free Time Services – NTP

To be discussed later

A variation on loop-back method (receiver does the computation)

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

WWV
Fort Collins
Colorado



Similar:
- LOL
- CHU
- BPM

WWVH, Kauai, Hawaii

Standard frequencies, audio announcements, equipment calibration, propagation studies. Performance parts in 10^9 for frequency, ms for timing.

Time by Low Frequency Radio: WWVB (groundwave)

WWVB continuously broadcasts a digital time code from Fort Collins, CO that synchronizes many millions of clocks and watches daily.

100 microsecond uncertainty achievable with careful calibrations for propagation delays.

Similar broadcasts: JJY, MSF, DCF77

WWVB 60 kHz, Fort Collins, Colorado

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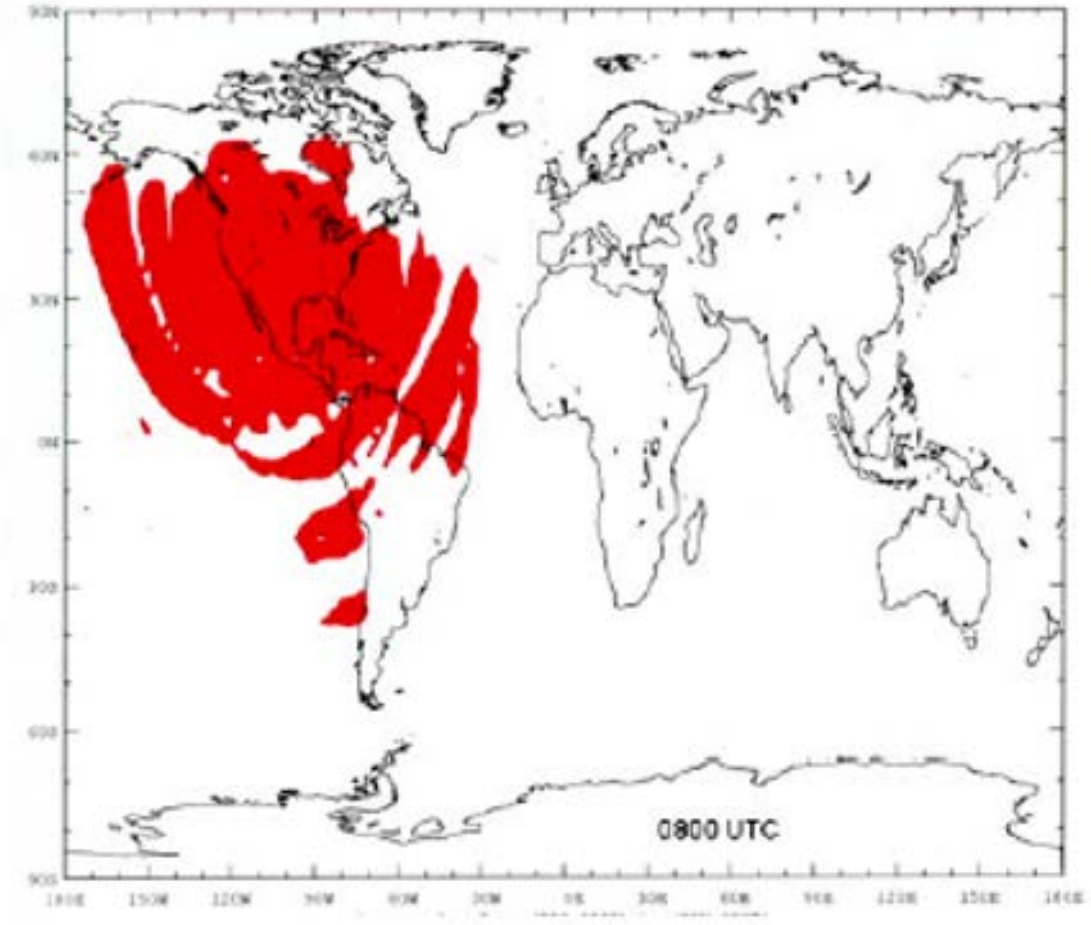


WWVB 60 kHz, Fort Collins, Colorado

Line-of-sight Signals (UHF)

- UHF (ultra high frequency) is defined as the spectrum from 300 to 3000 MHz.
- Signals transmitted from the ground in the VHF and UHF spectrums tend to be line-of-sight. They are used for local transmissions where there is an unobstructed path between the transmitter and the receiver.
- The National Association of Broadcasters (NAB) has developed a Broadcast Positioning System (BPS) that uses ATSC 3.0 broadcasts to transmit precise high-definition television signals (HDTV), which are in the UHF band.
- Can be used in common-view
- This technology is designed to augment or replace GPS, offering a more resilient and secure alternative for critical infrastructure, especially during GPS disruptions.

Time via Satellite

- Potentially the best signals used as broadcast standards. Since the signals originate high above Earth, there is an unobstructed path between the transmitter and receiver.
- Coverage area can be worldwide (excluding poles) with about five or six geostationary satellites, or an orbiting constellation of satellites.
- Receivers can provide on-time pulse and standard frequencies.
- Position of satellite and receiver necessary to estimate delay.

Two-way satellite time and frequency transfer (TWSTFT)

Point-to-point sync through communications relay satellites

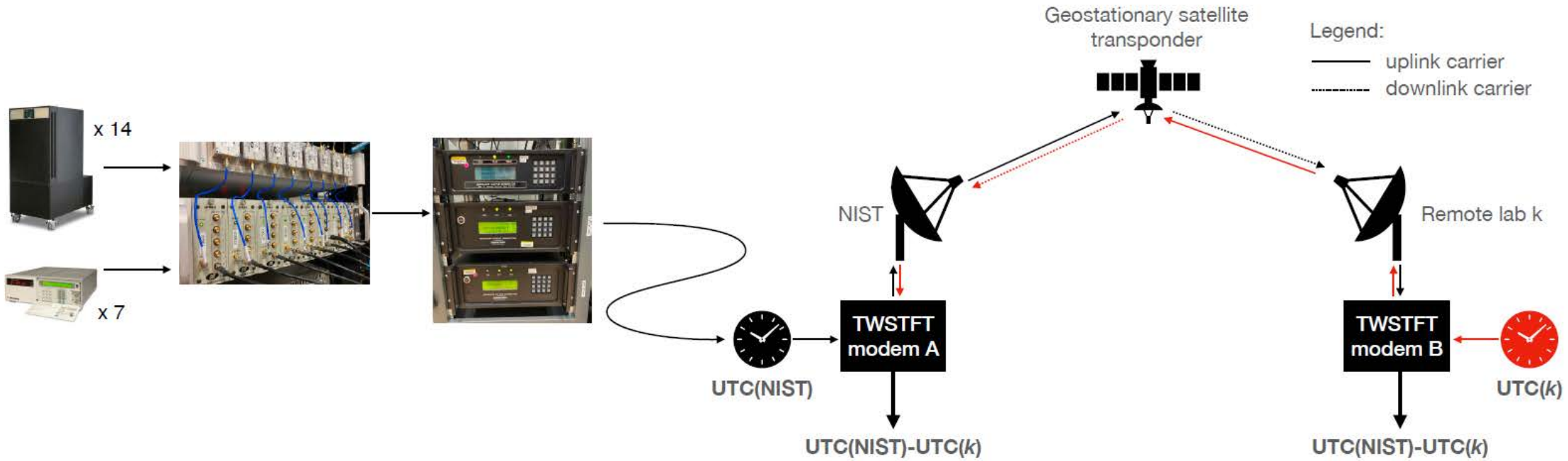
~ 2 ns timing uncertainty typical

Equipment commercially available but requires investment in a ground station and satellite time. High expense, but bandwidth can be shared.

Calibration is an issue.

National Distribution

Two-way satellite transfer (TWSTFT) of UTC(NIST)



ATS-6502 modem
(Microsemi/Microchip; USA)

SATRE modem
(TimeTech; Germany)

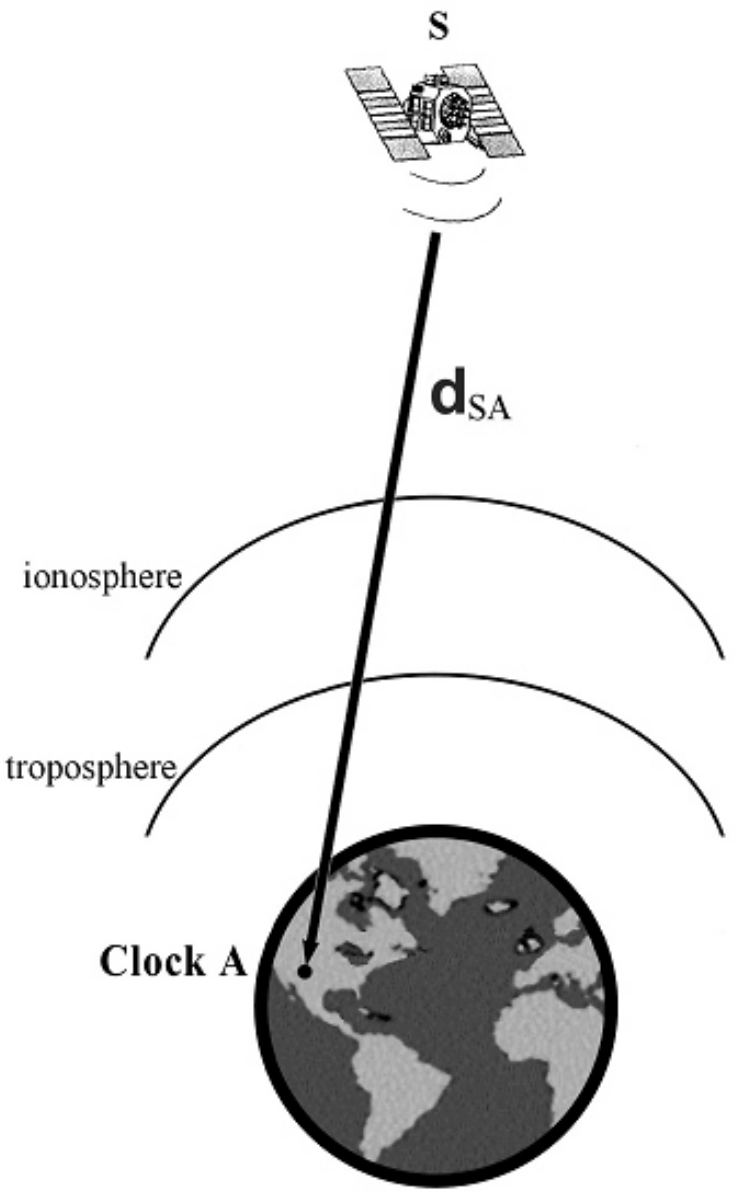
One-Way Satellite Time Transfer

Small path delay changes occur as signal passes through ionosphere and troposphere, but these are measured in nanoseconds.

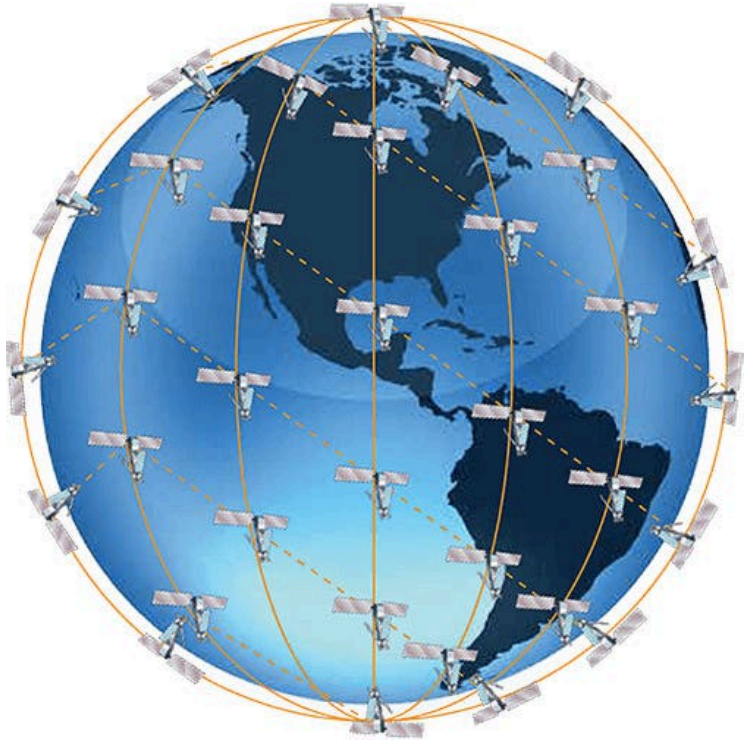
Time uncertainty can be less than 100 μs. (geostationary) or less than 1 μs (constellation).

Time uncertainty using a satellite constellation can be much less than 100 ns if the receiver, cable and antenna delays are calibrated.

Frequency uncertainty can be < 1 x 10^{-12} after 1 day of averaging.



Low Earth Orbit (LEO) Satellite Timing

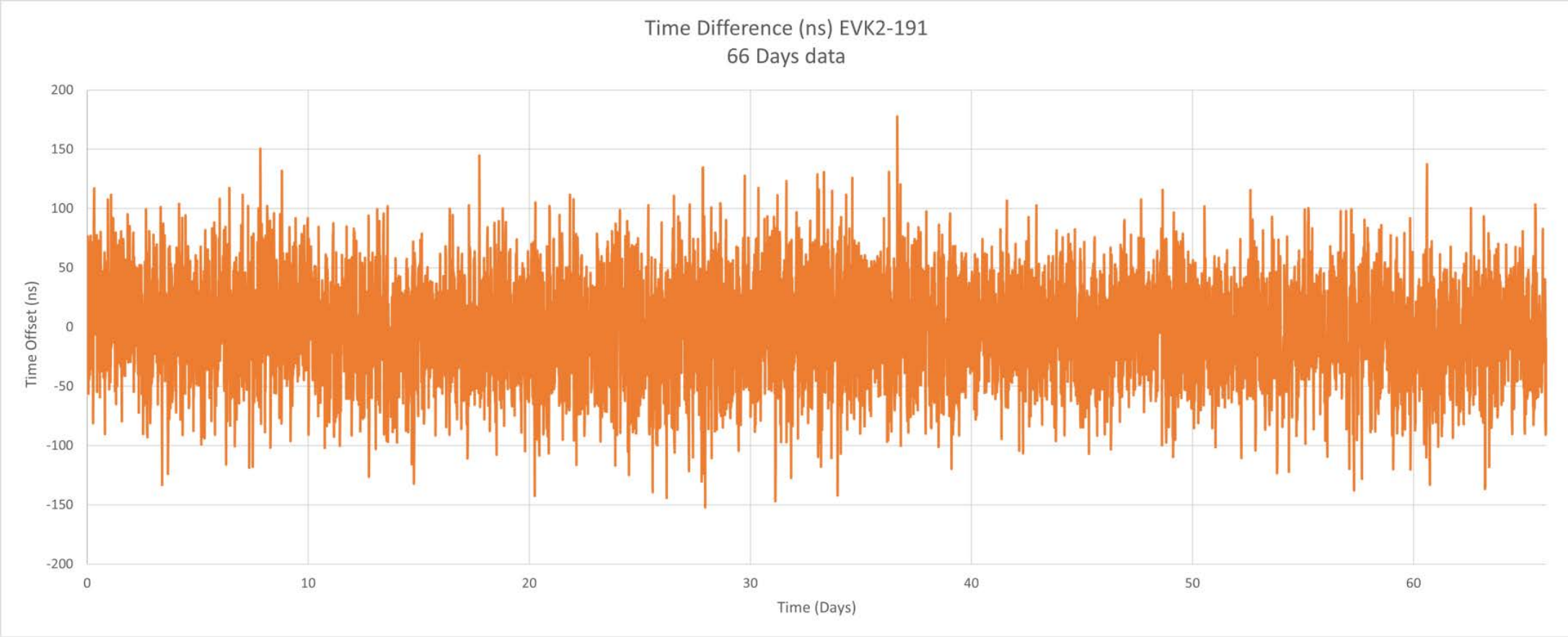


Constellation of 66 satellites, 485 mile altitude, indoor reception

Satellite Time and Location (STL) from Iridium constellation

- Proprietary, encrypted - Spoof-proof, but not free.
- Higher power than GNSS (by 30 dB), but Less satellites in view at a time.
- Worse performance, but independent.

STL data with OCXO receiver



(Skipping comm0n-view GNSS)

Time over Optical Fiber

- Time distribution over optical fiber can utilize PTP, White Rabbit, or other protocols over long-distances.
- Can provide a level of security that wireless signals cannot
- Immune from RF interference, free from reliance on satellite signals.
- Challenges with wide adoption are logistical and financial, but not technical.
- Performance < 100 ns possible, but network changes may cause steps

A Few Time and Frequency Signals/Calibrations by NIST

NIST serves the private and public sectors through the continuous distribution of UTC(NIST).

Service	Best Case Uncertainty	Customer Cost	
Two-way satellite T&F Transfer	2 ns	~$100k per year plus ground station	
Time Measurement & Analysis Service	10 ns	$1300 to $1990 per month	
Time Over Fiber	50 ns	>$5000/month, depending on route	
Frequency Measurement and Analysis	2×10^{-13} at 1 day	TMAS ($1300) + FMAS add-on ($345/month)	
WWVB	100us	Free	
Internet Time Service (ITS)	10-50 ms	Free	
www.time.gov	100 ms	Free	