Time Distribution: Current Technologies and Future Visions

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Outline

- Time from Telecom
- WWVB
- TMAS
- eLORAN
- Iridium Satellite Signals
- RF Beacons

The Family of Global Navigation Systems: Global Source of UTC, but Each is Slightly Different

GPS	Galileo	GLONASS	Beidou/Compass
US	EU	Russia	China
(24+, Now 31)	(27, Now 8-10)	(24, Now 24-26)	(35, Now 5 GEO, 8 IGSO, MEO 6-7 out of 24)

Three Messages About GNSS

1. GNSS are extremely useful
    1. Constellations are growing
    2. Provide reliable, extremely accurate real-time UTC time and frequency for mostly free
    3. Excellent navigation
    4. A global > $100B industry

2. GNSS signals are dangerously vulnerable to both accidental and intentional interference

3. Time from GNSS can be accurate to UTC below 100 ns. The local oscillator (TCXO, OCXO, Rb) will largely determine reliability

GNSS Systems: General Properties

- Position, Navigation, Timing (PNT)
- Four + synchronized timing signals from known locations in space required for navigation
- Two + frequencies measure ionosphere
- Control, Space, User Segments
- Open and Restricted Services
- All signals are weak and clustered in the spectrum
  - Allows interoperability
  - But also makes it is relatively easy to jam GNSS and spoof

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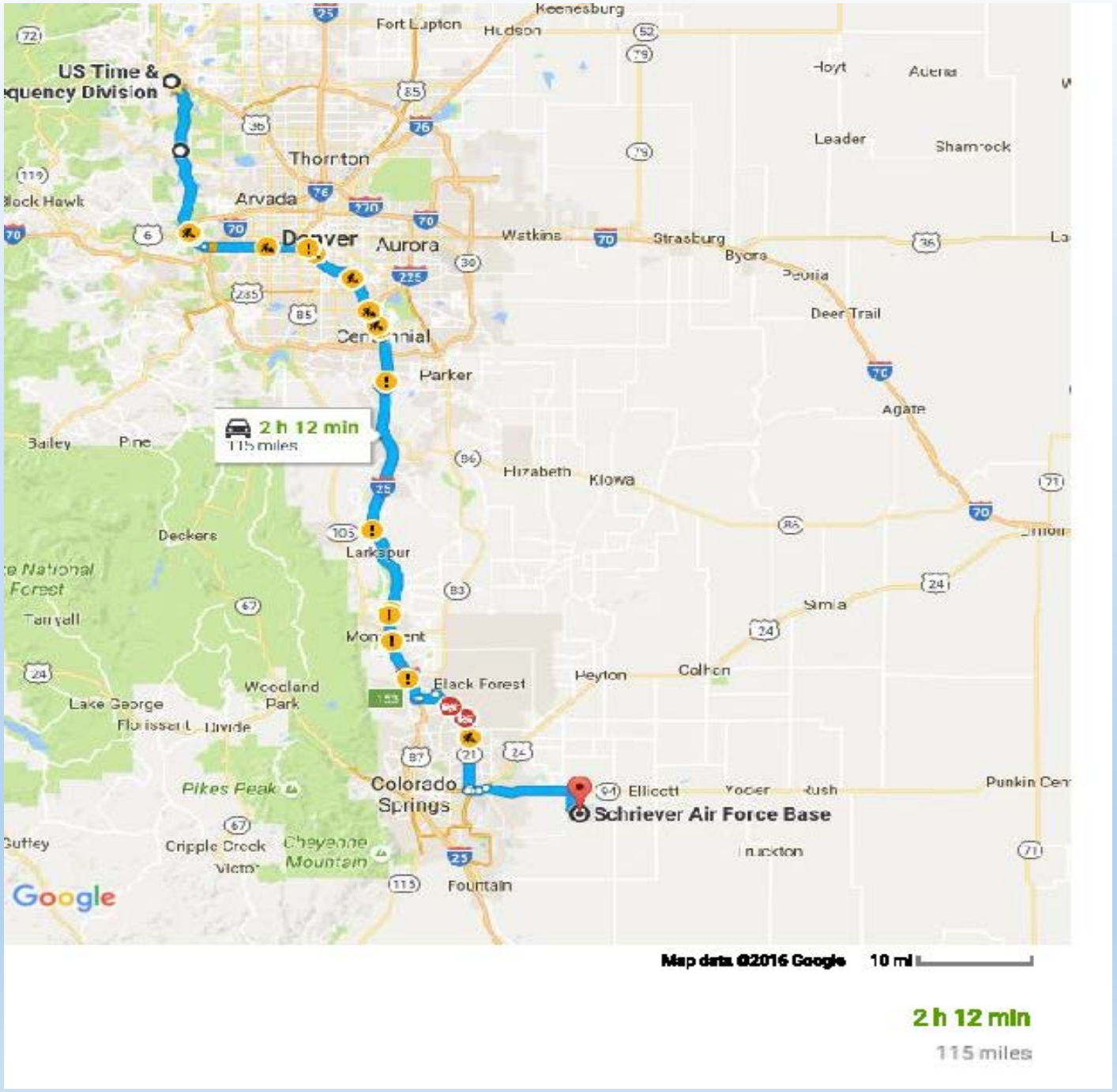
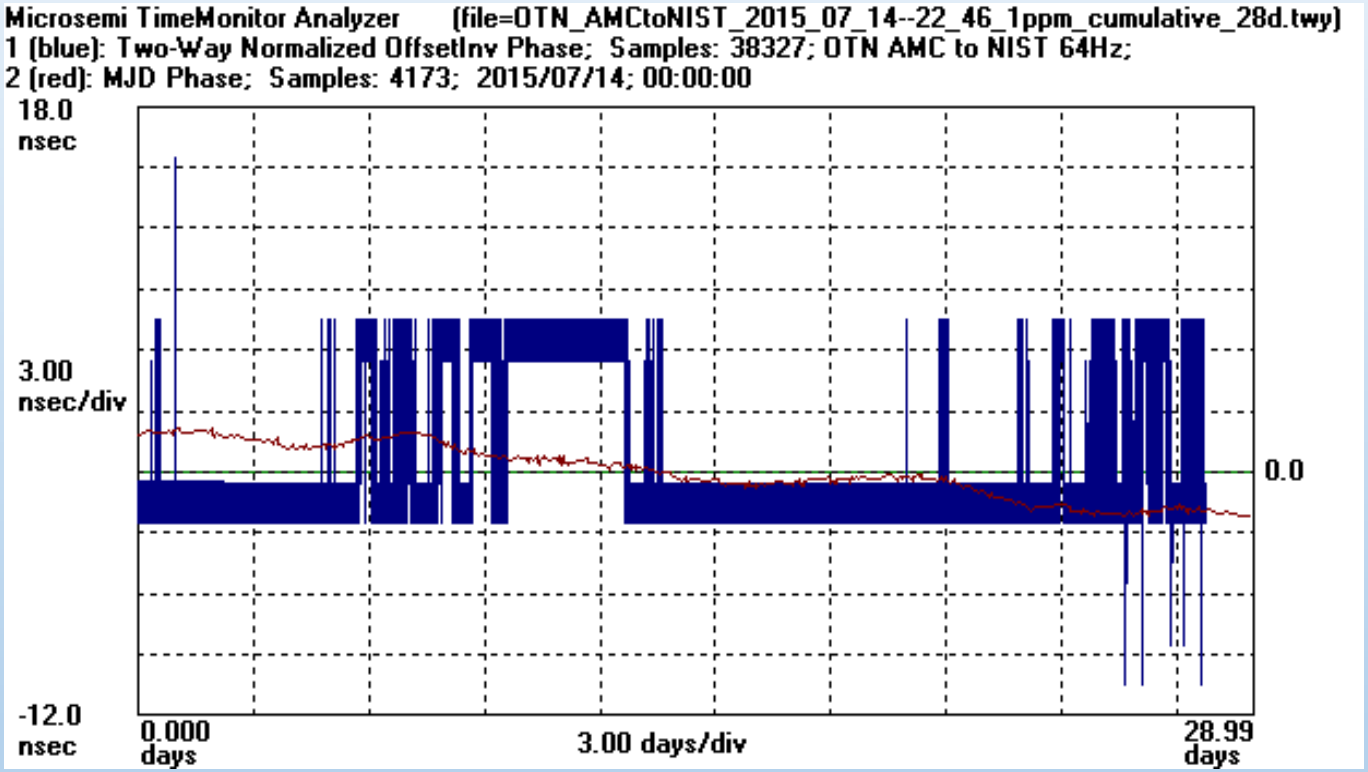
Experiment from NIST, Boulder to USNO at Schriever AFB using CenturyLink



PTP fiber vs. GPS Carrier Phase

PTP (blue) and GPS carrier-phase (red) measurements both comparing UTC(NIST) and UTC (USNO)



The two measurements generally match though the timestamp resolution of the PTP equipment does not have the precision to show the sub-nanosecond movement

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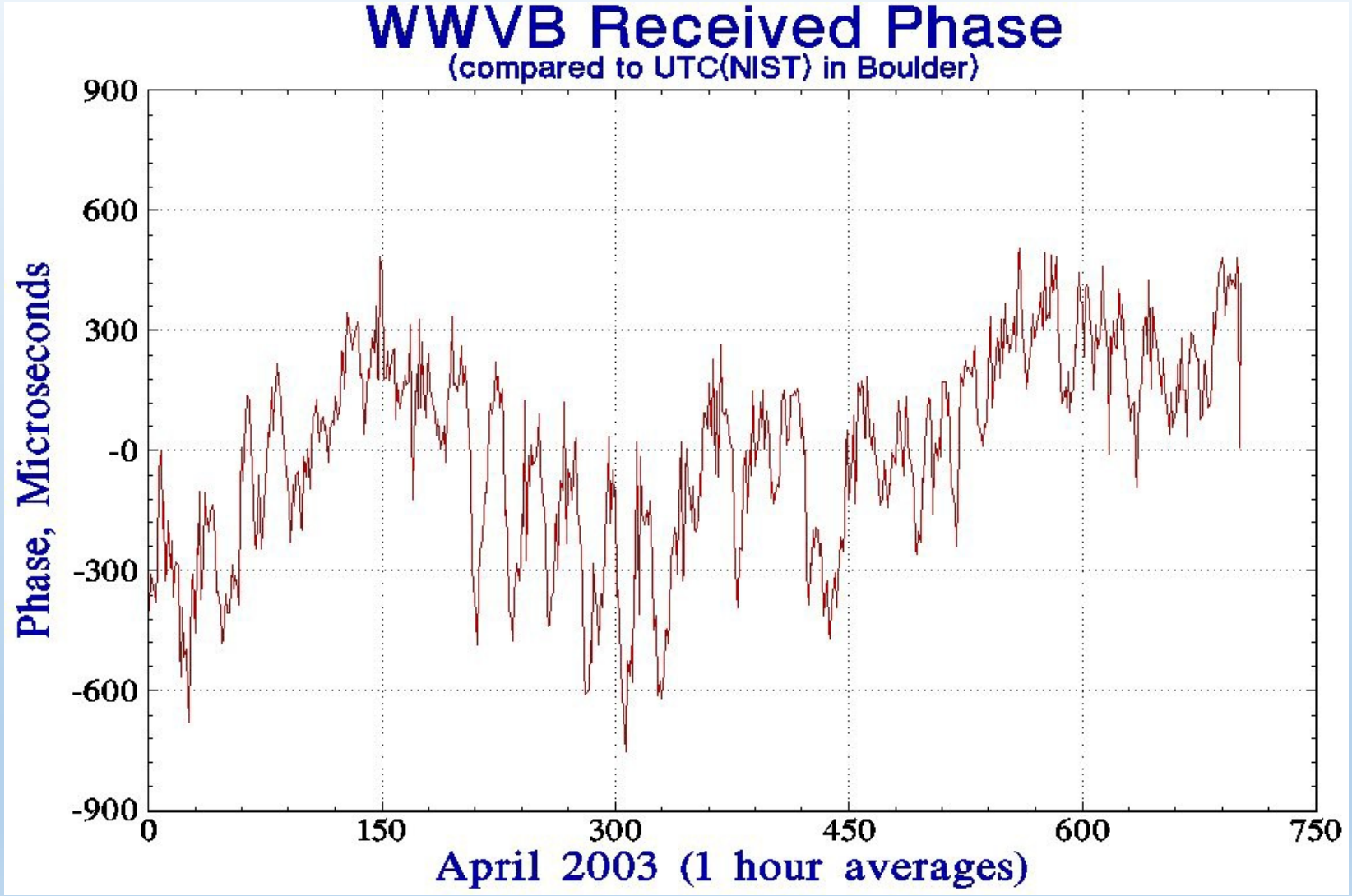
Differential WWVB

- Receive WWVB at two or more locations over 10’s of km
- Calibrate the differential arrival time between locations using, e.g. GPS
- The differential arrival time will remain the same within about 1 microsecond
- Allows *Time Transfer* between locations

Differential WWVB

- WWVB is a 60 KHz signal from Ft. Collins, Colorado, with enough power to cover the CONUS
- Directly receiving UTC from WWVB is difficult below about 1 ms due to problems determining the reflections along the path, and difficuklties detecting the on-time point
- Using WWVB differentially when calibrated, such as with GPS can be at the microsecond level over 80 km or so
- Diurnal variations at sunrise and sunset, which typically have an amplitude of 500 ns or less over the 80 km path between Boulder and Fort Collins
- The peak-to-peak variation for the entire month of April 2003 is about 1.2 µs.


WWVB Received Phase
(compared to UTC(NIST) in Boulder)
900
600
300
-0
-300
-600
-900
Phase, Microseconds
0
150
300
450
600
750
April 2003 (1 hour averages)

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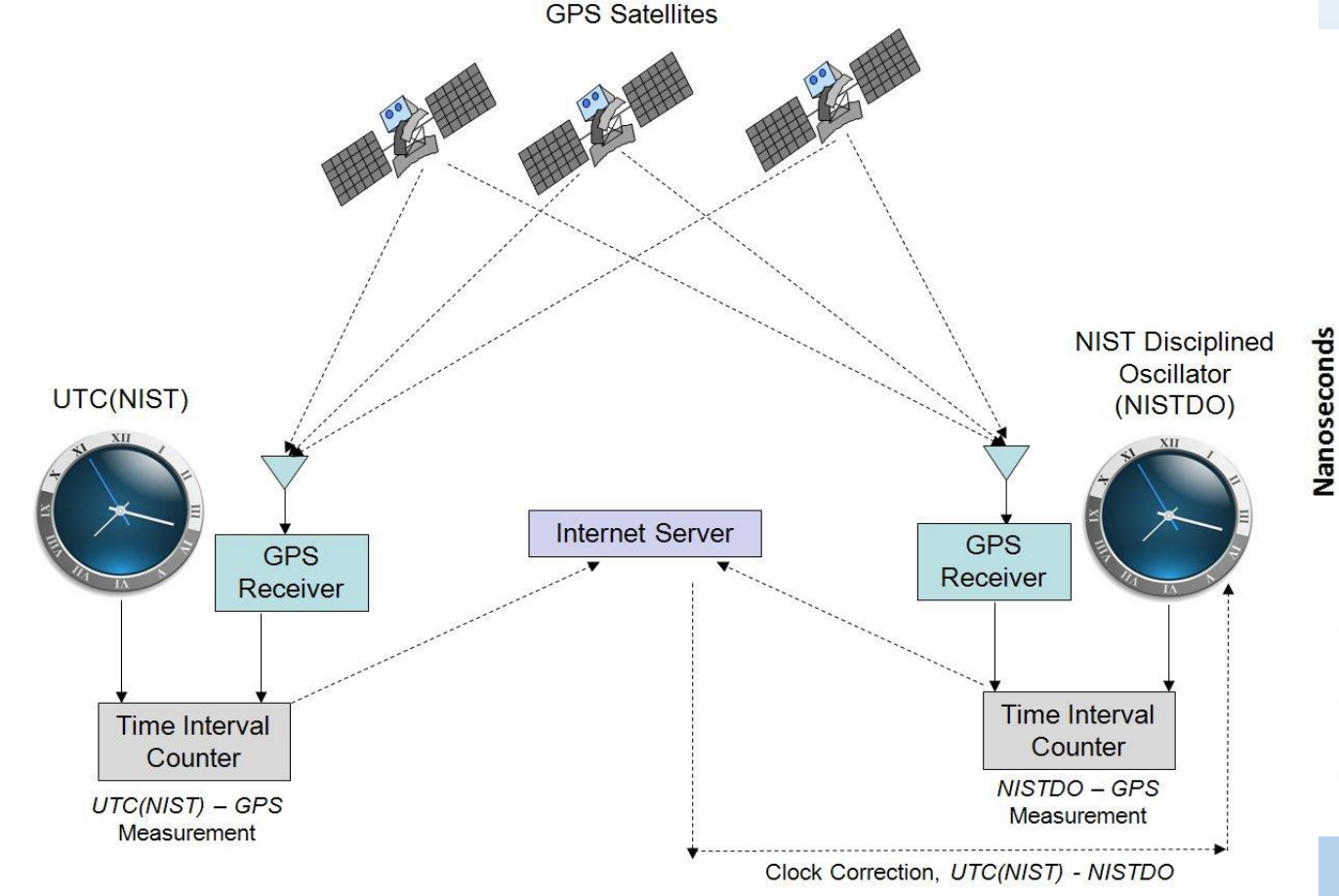
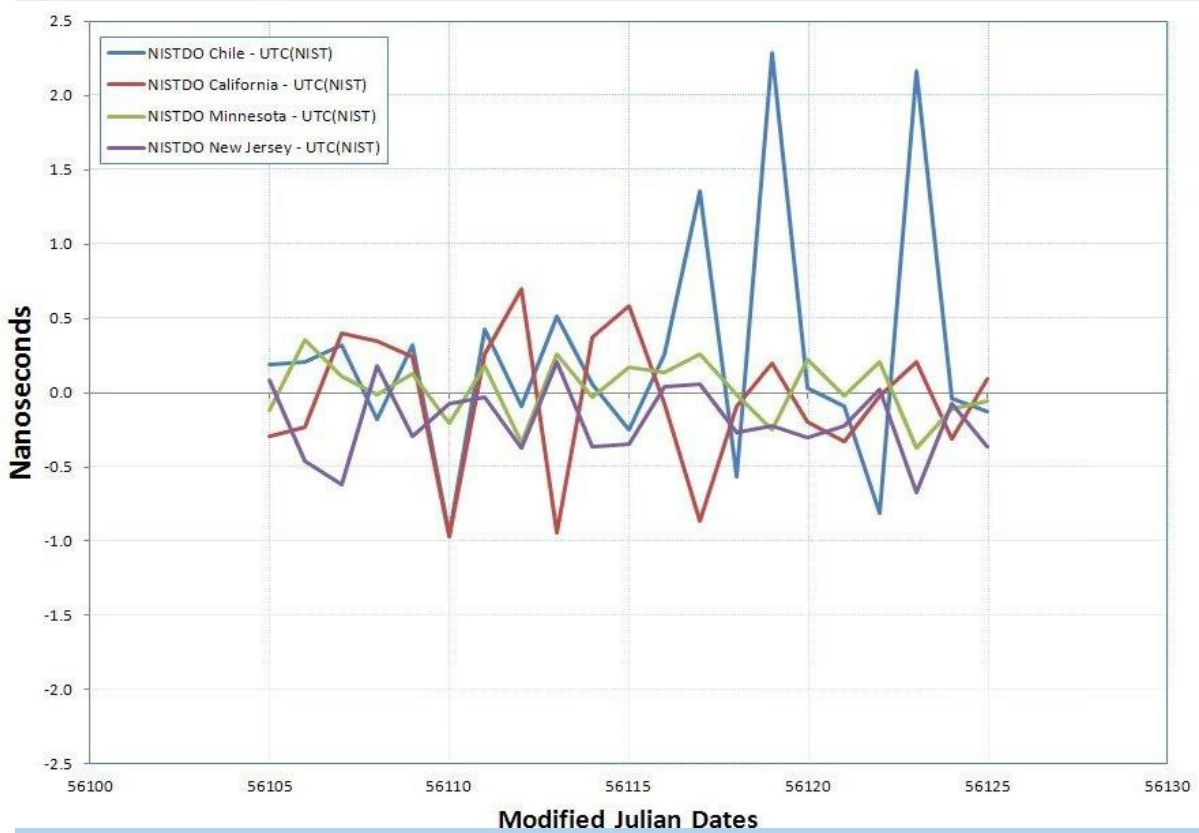
NIST Time Measurement and Analysis Service (TMAS) With Disciplined Oscillator (DO)





For details about the NISTDO, Contact Michael Lombardi: michael.lombardi@nist.gov

Specifications for NIST TMAS

Measurement Input	A 1 pulse per second (pps) signal from the laboratory's primary time standard.
Measurement Uncertainty (frequency)	$<5 \times 10^{-14}$ (24 hour averaging time, $k = 2$)
Measurement Uncertainty (time)	<15 nanoseconds ($k = 2$)
Reporting	All results are made available in near real time (maximum 10 minute delay), viewable with any Java-enabled web browser.

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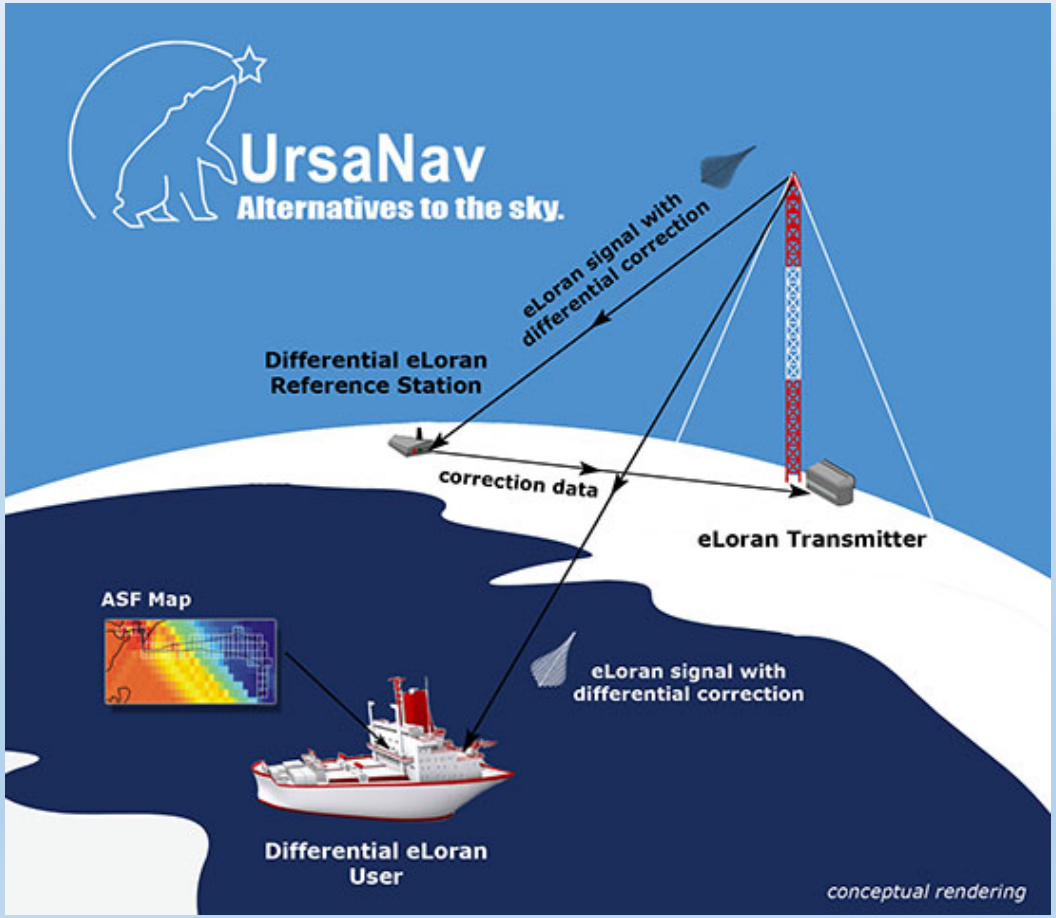
eLORAN

- Based on the LORAN system: 100 KHz signals from 19 US transmitters, turned off in 2010, now being proposed as a GPS backup
- For accuracy against UTC requires path calibration. The proposal includes reference stations. For 100 ns accuracy, a reference station is needed within about 50 km
- Bill passed the House 9/28/2016 proposing the Coast Guard develop eLORAN “subject to appropriations”. Senate and president remain.

eLORAN System Design



http://gpsworld.com/innovation-enhanced-loran/

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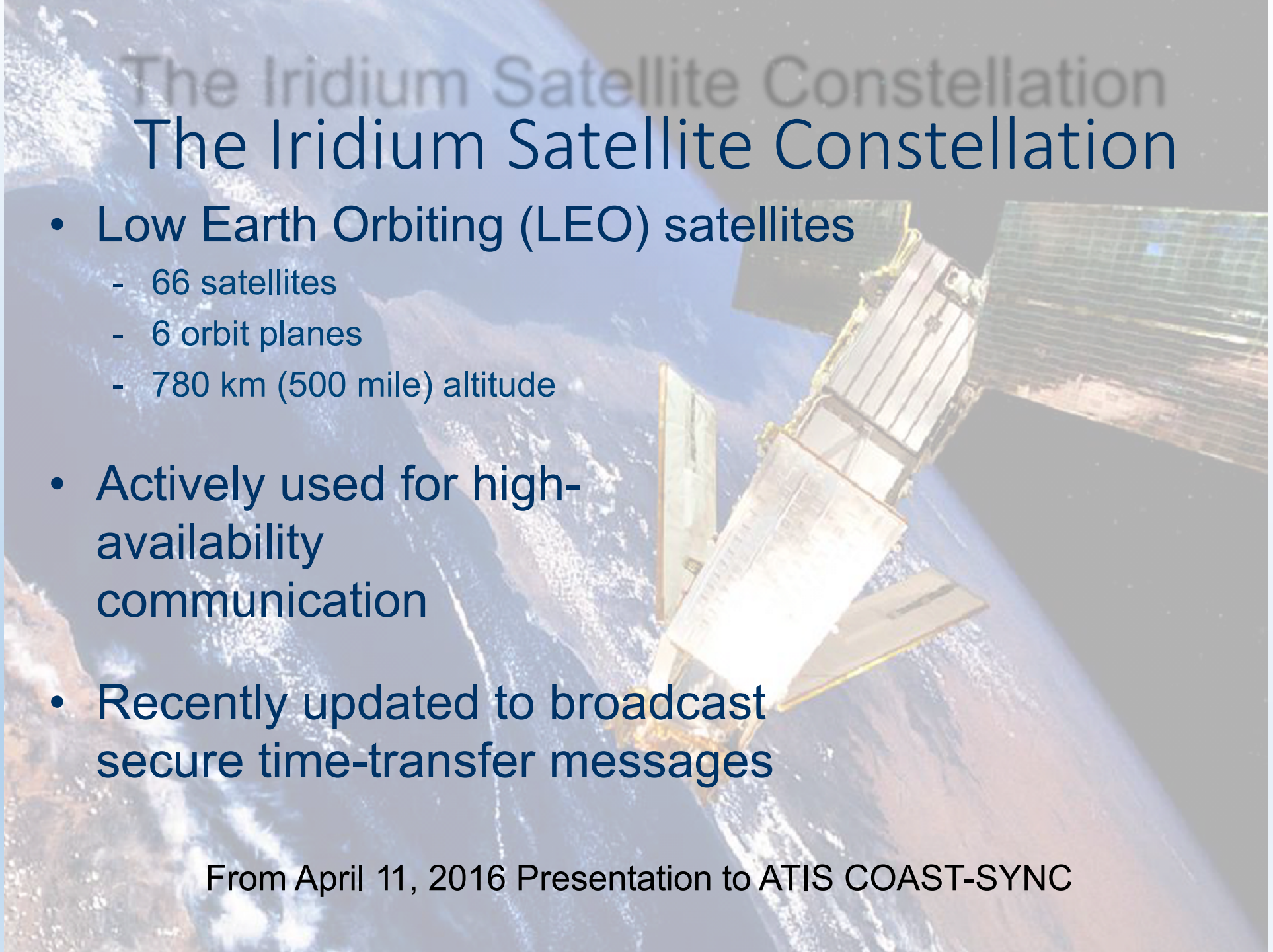
The Iridium Satellite Constellation



- Low Earth Orbiting (LEO) satellites
  - 66 satellites
  - 6 orbit planes
  - 780 km (500 mile) altitude
- Actively used for high-availability communication
- Recently updated to broadcast secure time-transfer messages

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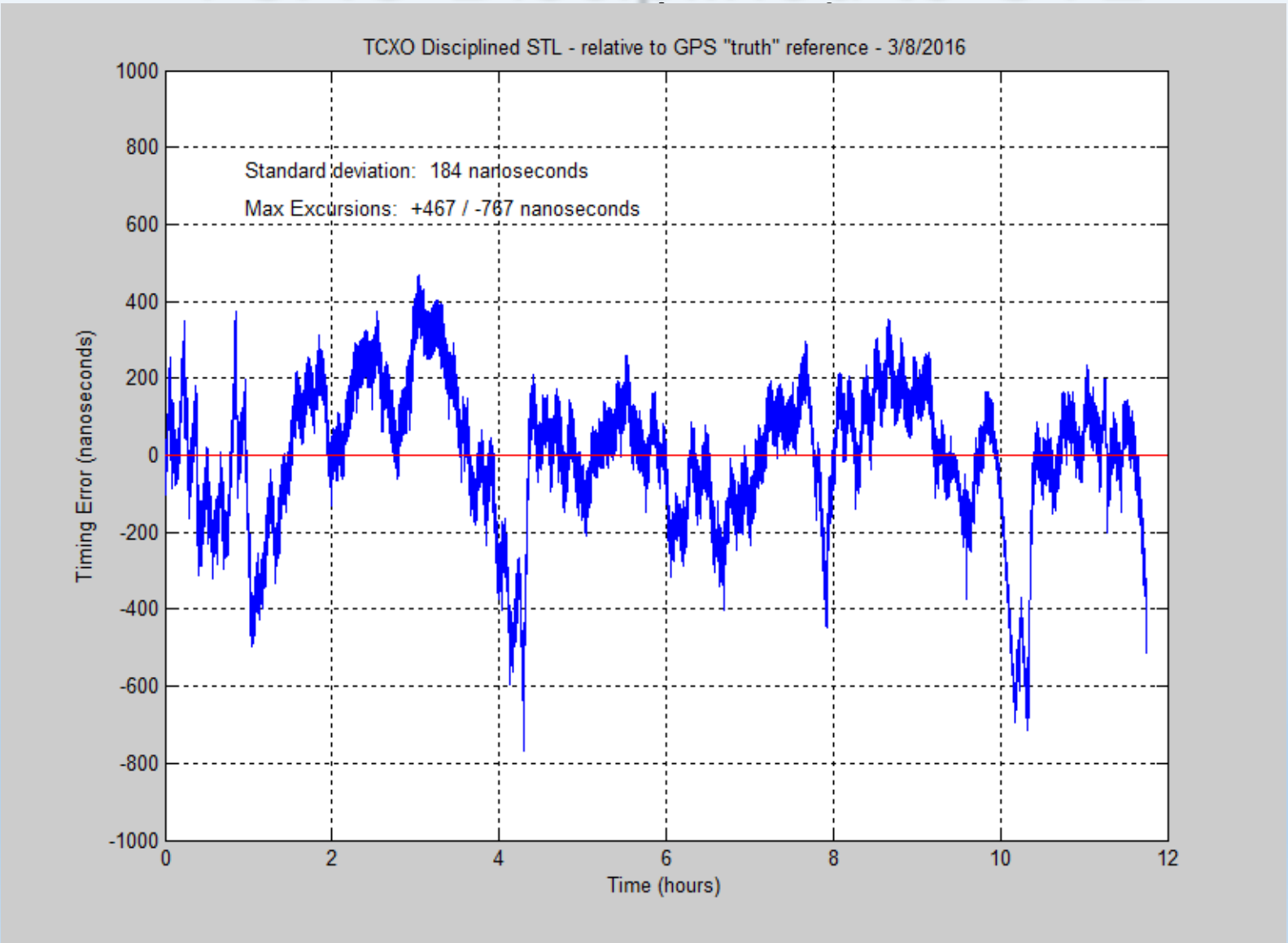
TCXO Disciplined to STL



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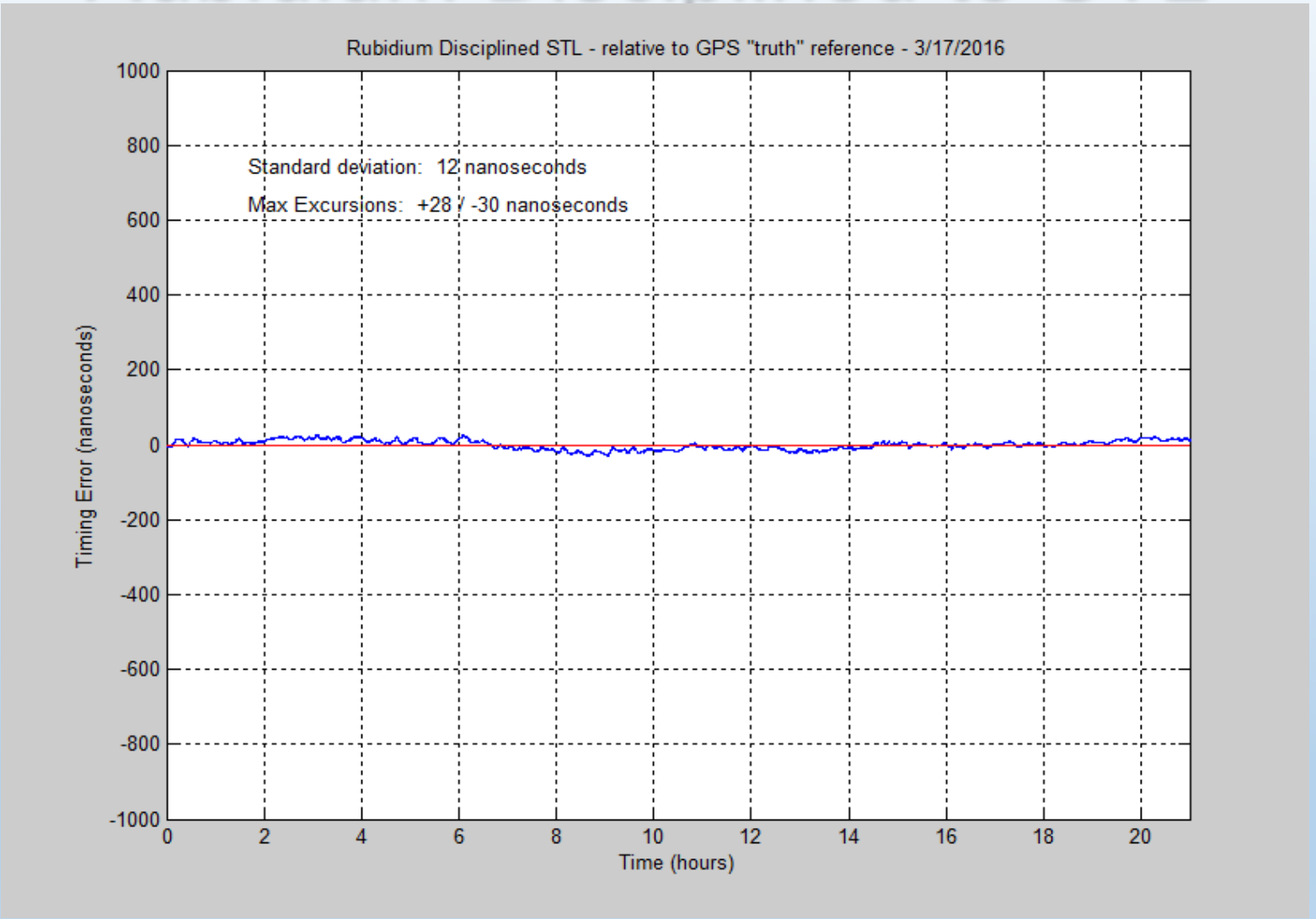
Rubidium Disciplined to STL



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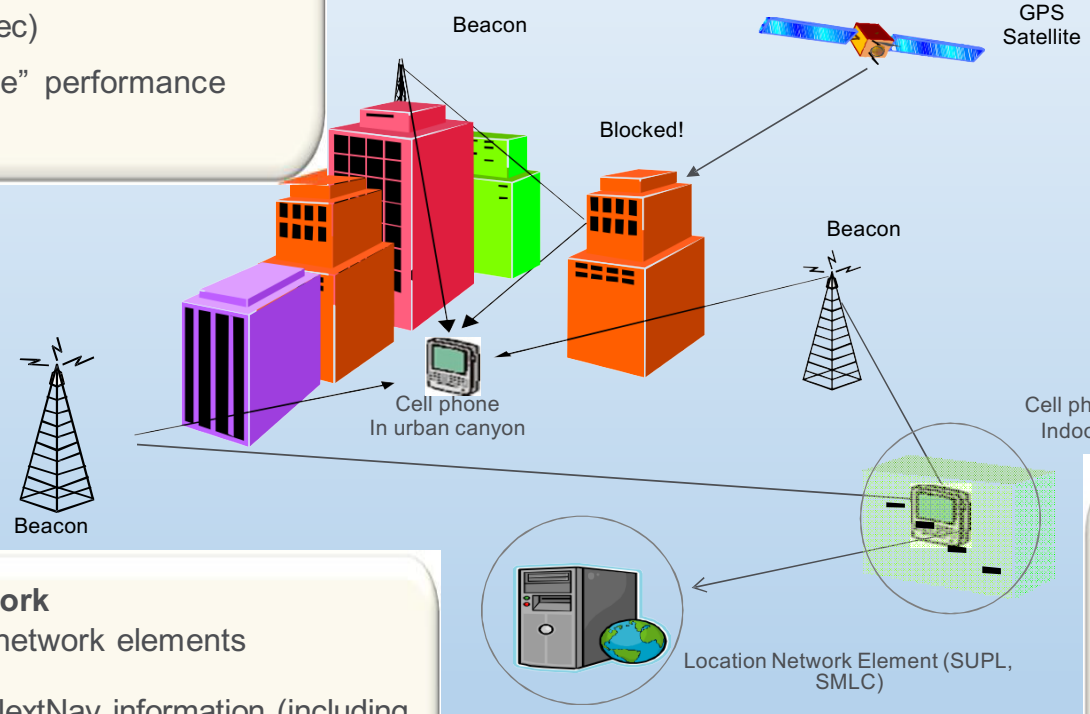
Network Architecture: NextNav Terrestrial Beacon Network

Performance Advantage

- Accurate location in urban and indoor environments
- Precise vertical position (1-3m)
- Fast time to first fix (1-6 sec)
- Dependable “carrier-grade” performance



Broadcast Beacons

- Low-power, highly synchronized
- Encrypted signal
- Broad coverage from minimal sites
- No backhaul, small form factor
- Operate on licensed spectrum

Core Network

- Utilizes existing cellular network elements
- Modifications to support NextNav information (including vertical)

Receivers

- Compatible with GPS baseband
- Minimal handset integration cost
- On-device computation of location
- Reduced power consumption
- Utilizes existing cellular network elements

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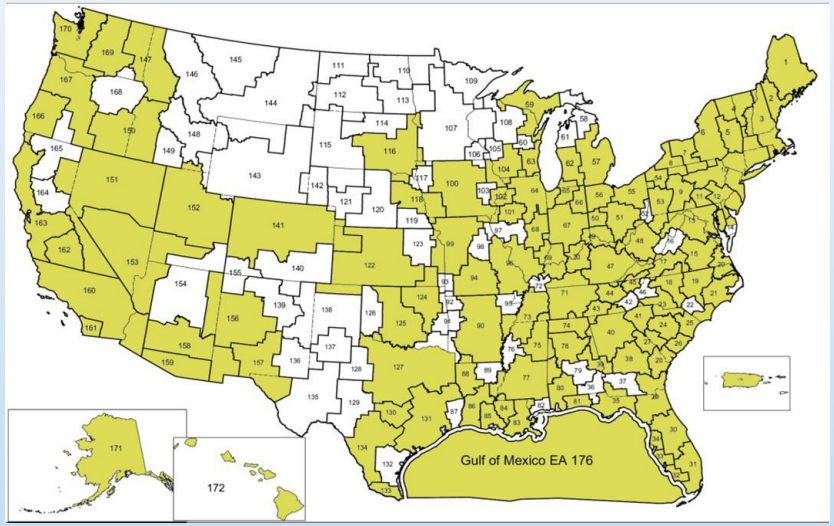
NextNav is Building a Nationwide Service Capability

NextNav M-LMS B&C Block Licenses



- Initial deployment in top 47 CMAs, with a fully-deployed service capability in San Francisco
- Spectrum footprint covers over 93% of U.S. population (98% of urban POPS), authorized for commercial operation in June 2013

From ATIS presentation, March 2015

End of talk
Thank you for your attention.
Questions?