OAK RIDGE National Laboratory

Recent Developments in Precise Distributed Time

Terry Jones, Oak Ridge National Laboratory

Oct 19, 2022

2022 Fall NASPI Meeting

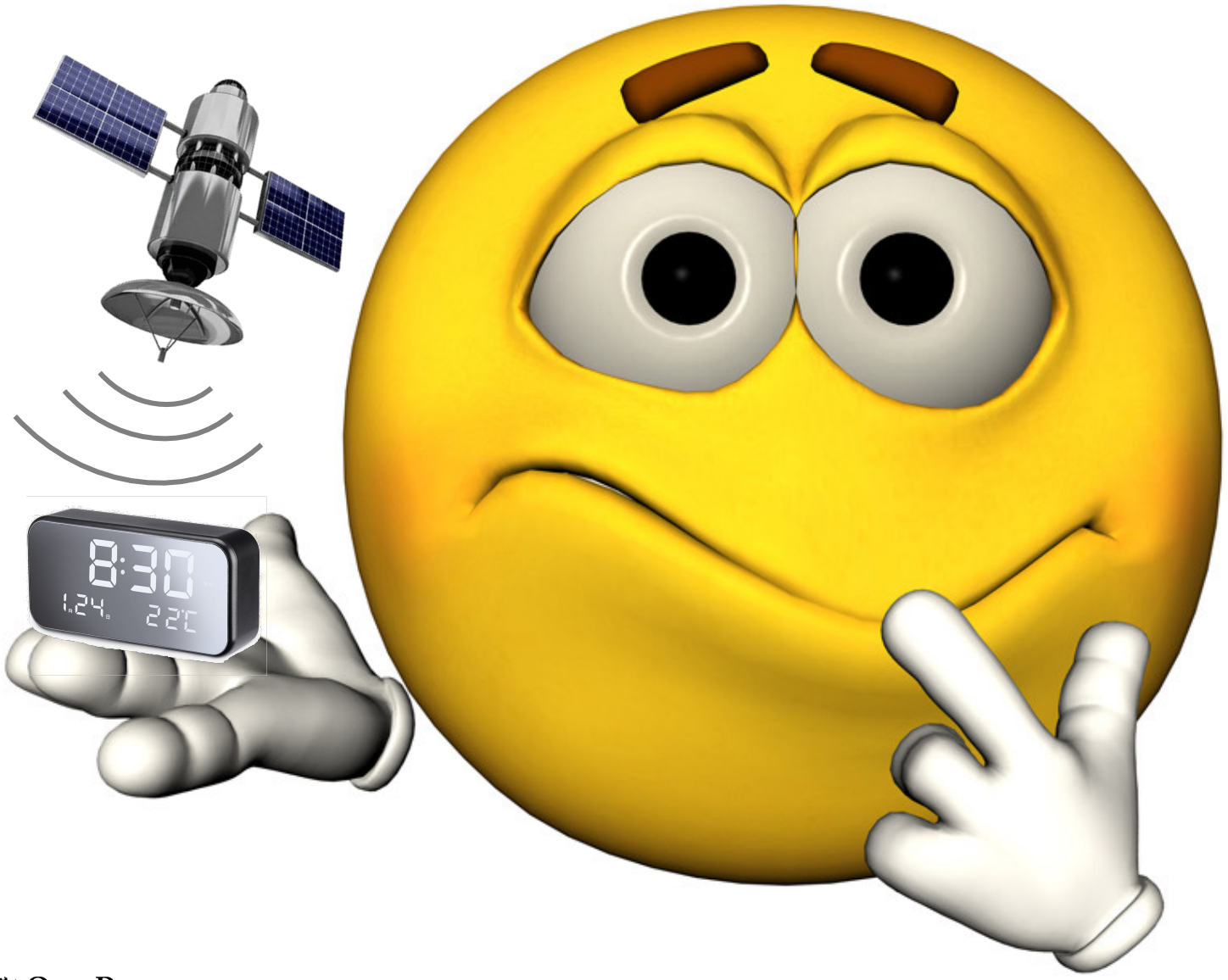
ORNL is managed by UT-Battelle, LLC for the US Department of Energy

U.S. DEPARTMENT OF ENERGY

Outline

- What?
  - Black Swans and a national history of reactive infrastructure improvements
  - Black Hats and the GNSS/GPS problem
  - A Green Tomorrow and changes on the way
- So What?
  - Impacts of disruptions
  - Potential solutions
  - Pay me now or pay me later
- Now What?
  - What's New and Relevant?

Q: Why can't we just be happy with GPS?



A: Black Swans,
Black Hats, and
a Green Tomorrow

Black Swans, Reactive and Proactive Responses

Black Swan

[1]Source: https://en.wikipedia.org/wiki/Black_swan

New London TX School Explosion

- Natural gas explosion levels elementary school (March, 1937)
- More than 300 students and teachers died

Outcome

- Rules for odorized gas

[1]Source: https://en.wikipedia.org/wiki/New_London_School_explosion

Exxon Valdez Oil Spill

- Exxon tanker crashes off Alaskan coast (March, 1989)
- Affected 1300 miles of coastline, 200 miles heavily

Outcome

- Rules for Captain and crew rest
- Rules for keeping collision avoidance radar operational

[1]Source: https://en.wikipedid.org/wiki/Exxon_Valdez_oil_spill

Cerro Grande Fire

- Los Alamos, NM *controlled burn goes awry* (May, 2000)
- 400 homes lost in Los Alamos, NM

Outcome

- Rules for when controlled burns can be scheduled (not during windy Spring)

[1]Source: https://en.wikipedia.org/wiki/Cerro_Grande_Fire

Securing Against Black Hats and Bad Actors…

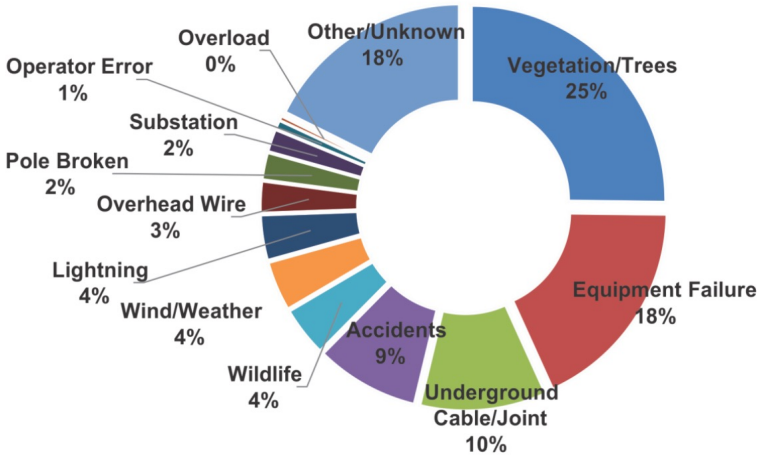
- Redundant & Resilient
  - Multiple reference paths
  - Best Master Clock across multiple Master Nodes
- Secure
  - Jamming (e.g., terrestrial redundancy)
  - Spoofing (e.g., terrestrial, quantum, MACsec)
  - Cyber (e.g., quantum, MACsec)
  - Physical (e.g., badged access)
- Scalable
  - Hierarchical design
- Precise & Traceable
  - IEEE standards-based
  - Traceability/verifiable with NIST

The Need: Insulate the power grid's synchronized timing requirements from bad-actors intent on disrupting GPS

Transitioning To a Green Tomorrow

Timing is already important for…

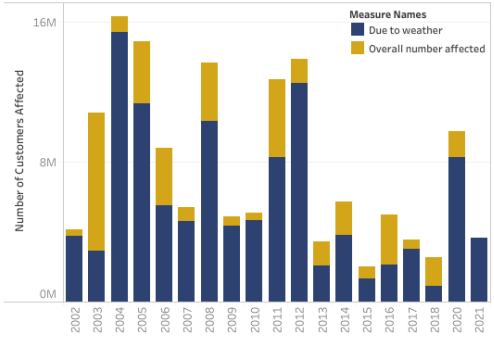
Fault location, isolation, and service restoration (FLISR) – A key part of improving power system reliability



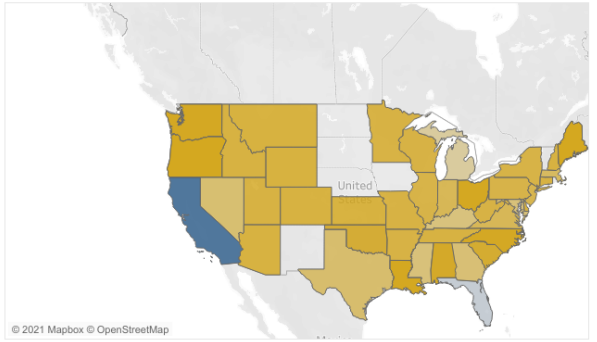
National Power Outages (2003–2021)

Number of Outages	Customers Affected	Hours Lost	Average hours down
1,519	146,246,051	62,328	41.03
Total number of outages	Customers affected total	Total Hours lost	Average time without power
594	108,912,036	33,264	
Number of incidents due to weather	Customers affected by weather incidents	Hours lost due to weather	

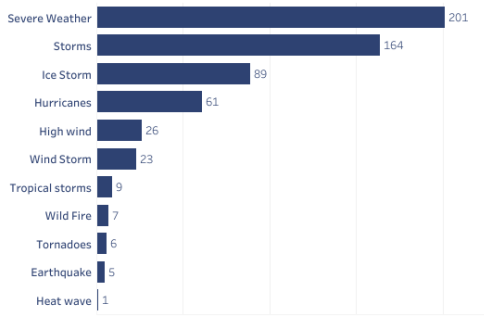
Weather affected customers



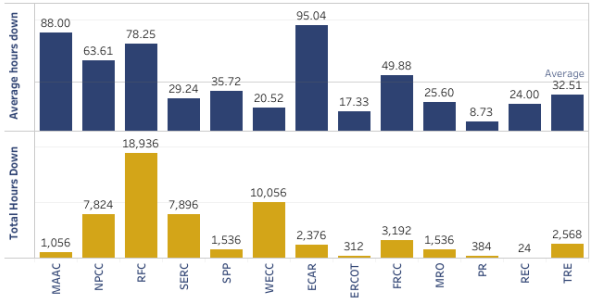
Affected customer location



Count of Event type



Nerc Regions



- "Fault Location, Isolation, and Service Restoration Technologies Reduce Outage Impact and Duration - Smart Grid Investment Grant Program," Tech. Rep., Electricity Delivery & Energy Reliability, U.S. Department of Energy, Dec 2014.
- Visualization of data from the US DOE-managed US National Power Outage dataset: https://www.jaywait.com/work-1/project-two-mdjty

The Cost of a Green Tomorrow (part 2)

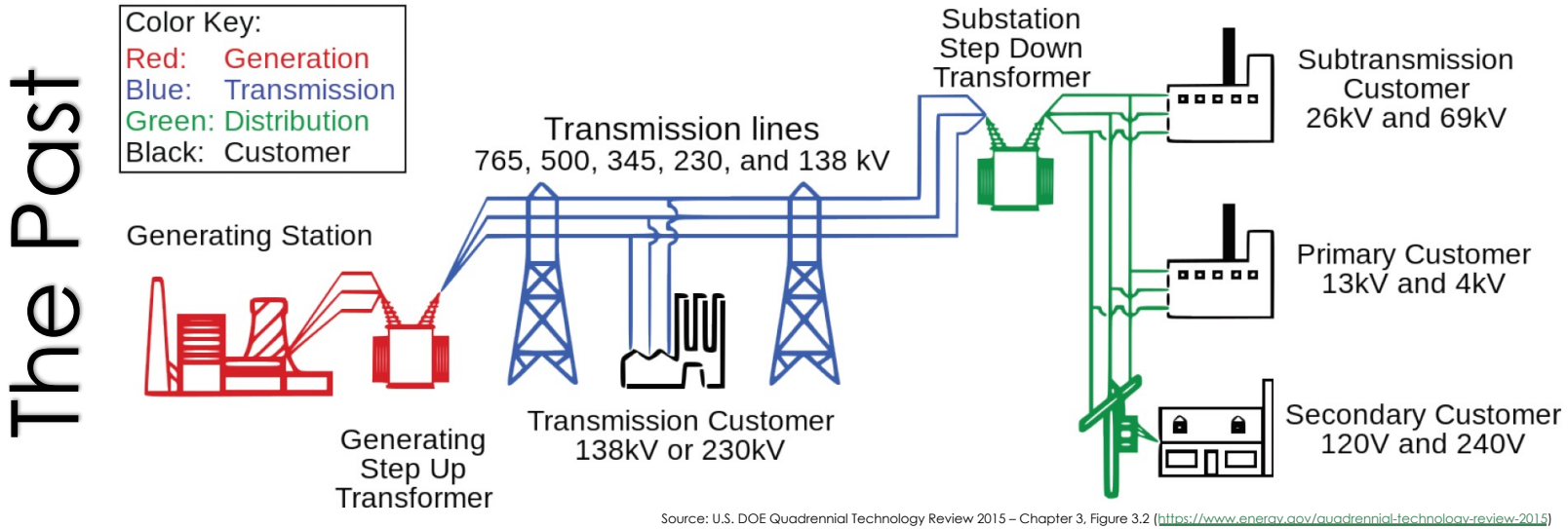
Timing's importance is growing…

Our transition to clean energy, including rapid assimilation of renewables and Distributed Energy Resources, increases our need for ***Situational Awareness***

The Grid is Becoming a Wide-Area Network

The Future

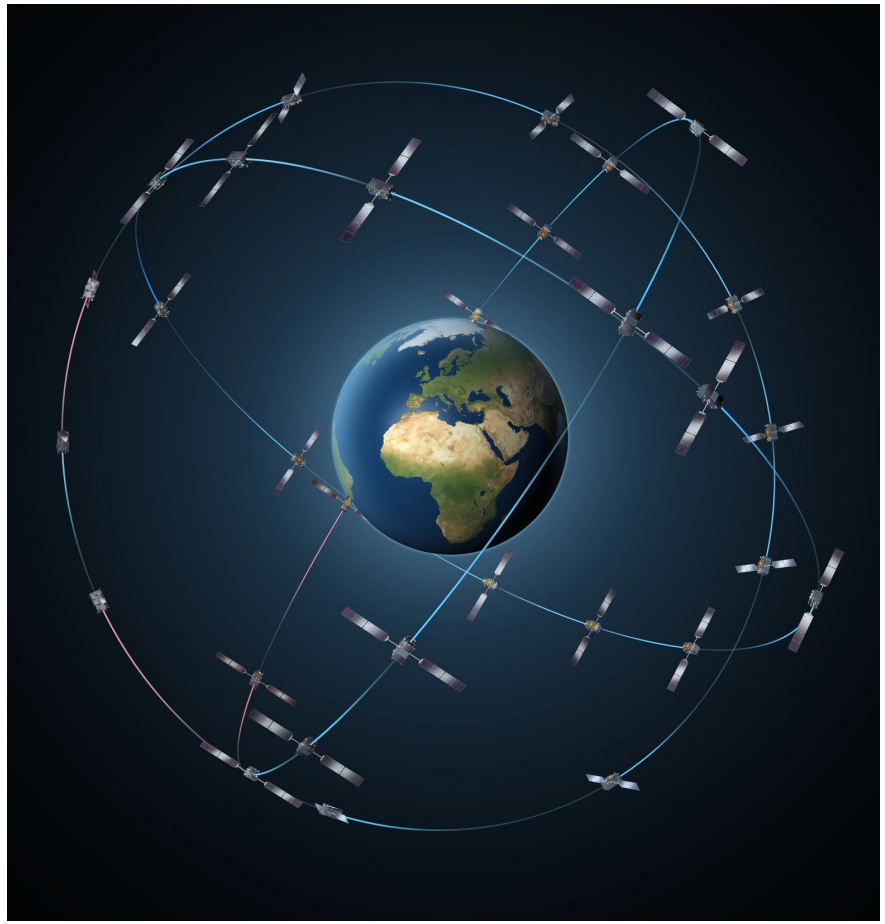
The Past



Source: U.S. DOE Quadrennial Technology Review 2015 – Chapter 3, Figure 3.2 (https://www.energy.gov/quadrennial-technology-review-2015)

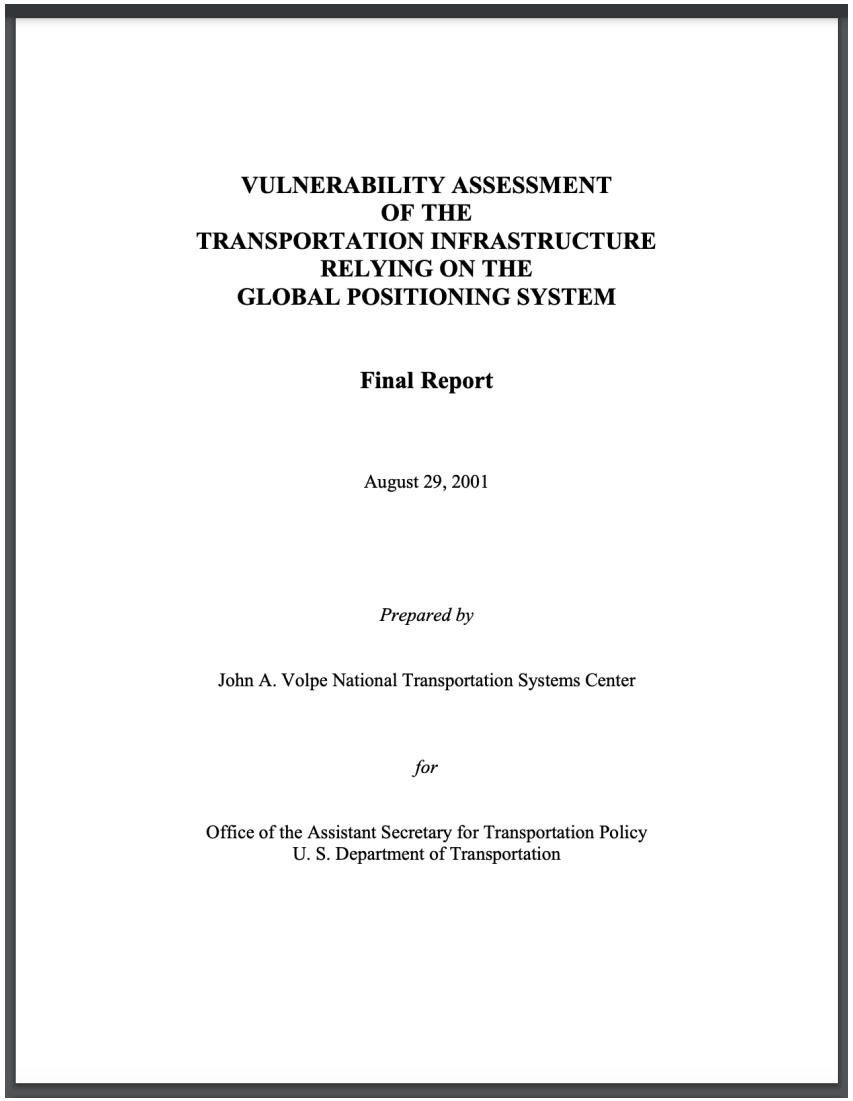
A Dynamic Power Grid Requires Time-Awareness And Today, That Time-Awareness Comes Via GPS

- PMU derived situational awareness is achieved through **time-synchronization**
  - Standards call for 1000ns uncertainty from UTC
- Accomplished today via low-cost GPS-based solutions



Concerns about Vulnerabilities of GPS

- The ubiquitous power grid application currently depends on civilian GPS technology
- The power grid is critical infrastructure and must be able to withstand sophisticated, and potentially state-sponsored, multi-actor attacks



VULNERABILITY ASSESSMENT
OF THE
TRANSPORTATION INFRASTRUCTURE
RELYING ON THE
GLOBAL POSITIONING SYSTEM

Final Report

August 29, 2001

Prepared by

John A. Volpe National Transportation Systems Center

for

Office of the Assistant Secretary for Transportation Policy
U. S. Department of Transportation

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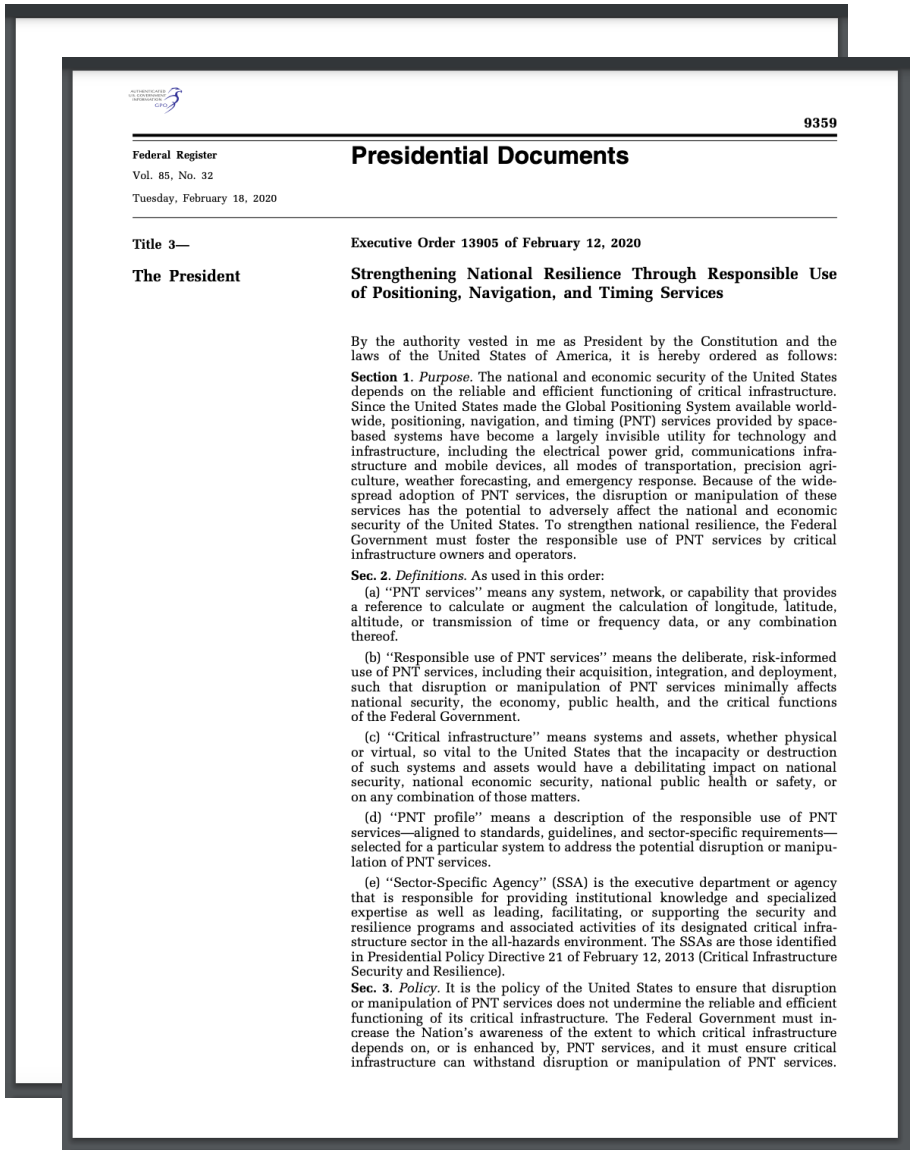

9359

Federal Register
Vol. 85, No. 32
Tuesday, February 18, 2020

Presidential Documents

Title 3—
The President

Executive Order 13905 of February 12, 2020

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

By the authority vested in me as President by the Constitution and the laws of the United States of America, it is hereby ordered as follows:

Section 1. *Purpose*. The national and economic security of the United States depends on the reliable and efficient functioning of critical infrastructure. Since the United States made the Global Positioning System available worldwide, positioning, navigation, and timing (PNT) services provided by space-based systems have become a largely invisible utility for technology and infrastructure, including the electrical power grid, communications infrastructure and mobile devices, all modes of transportation, precision agriculture, weather forecasting, and emergency response. Because of the widespread adoption of PNT services, the disruption or manipulation of these services has the potential to adversely affect the national and economic security of the United States. To strengthen national resilience, the Federal Government must foster the responsible use of PNT services by critical infrastructure owners and operators.

Sec. 2. *Definitions*. As used in this order:

(a) ''PNT services'' means any system, network, or capability that provides a reference to calculate or augment the calculation of longitude, latitude, altitude, or transmission of time or frequency data, or any combination thereof.

(b) ''Responsible use of PNT services'' means the deliberate, risk-informed use of PNT services, including their acquisition, integration, and deployment, such that disruption or manipulation of PNT services minimally affects national security, the economy, public health, and the critical functions of the Federal Government.

(c) ''Critical infrastructure'' means systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact on national security, national economic security, national public health or safety, or on any combination of those matters.

(d) ''PNT profile'' means a description of the responsible use of PNT services—aligned to standards, guidelines, and sector-specific requirements—selected for a particular system to address the potential disruption or manipulation of PNT services.

(e) ''Sector-Specific Agency'' (SSA) is the executive department or agency that is responsible for providing institutional knowledge and specialized expertise as well as leading, facilitating, or supporting the security and resilience programs and associated activities of its designated critical infrastructure sector in the all-hazards environment. The SSAs are those identified in Presidential Policy Directive 21 of February 12, 2013 (Critical Infrastructure Security and Resilience).

Sec. 3. *Policy*. It is the policy of the United States to ensure that disruption or manipulation of PNT services does not undermine the reliable and efficient functioning of its critical infrastructure. The Federal Government must increase the Nation's awareness of the extent to which critical infrastructure depends on, or is enhanced by, PNT services, and it must ensure critical infrastructure can withstand disruption or manipulation of PNT services.

Concerns about Vulnerabilities of GPS

- The ubiquitous power grid application currently depends on civilian GPS technology
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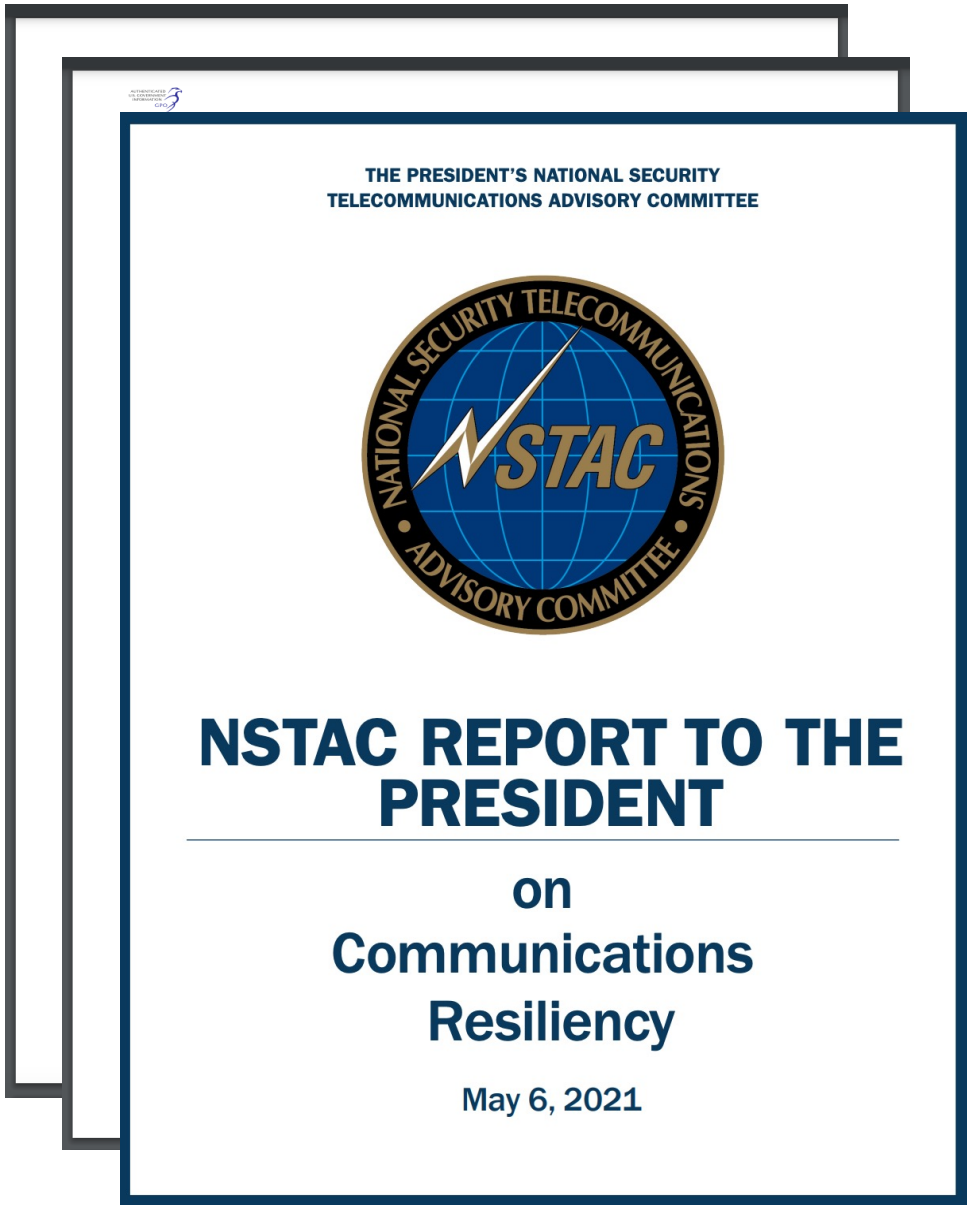

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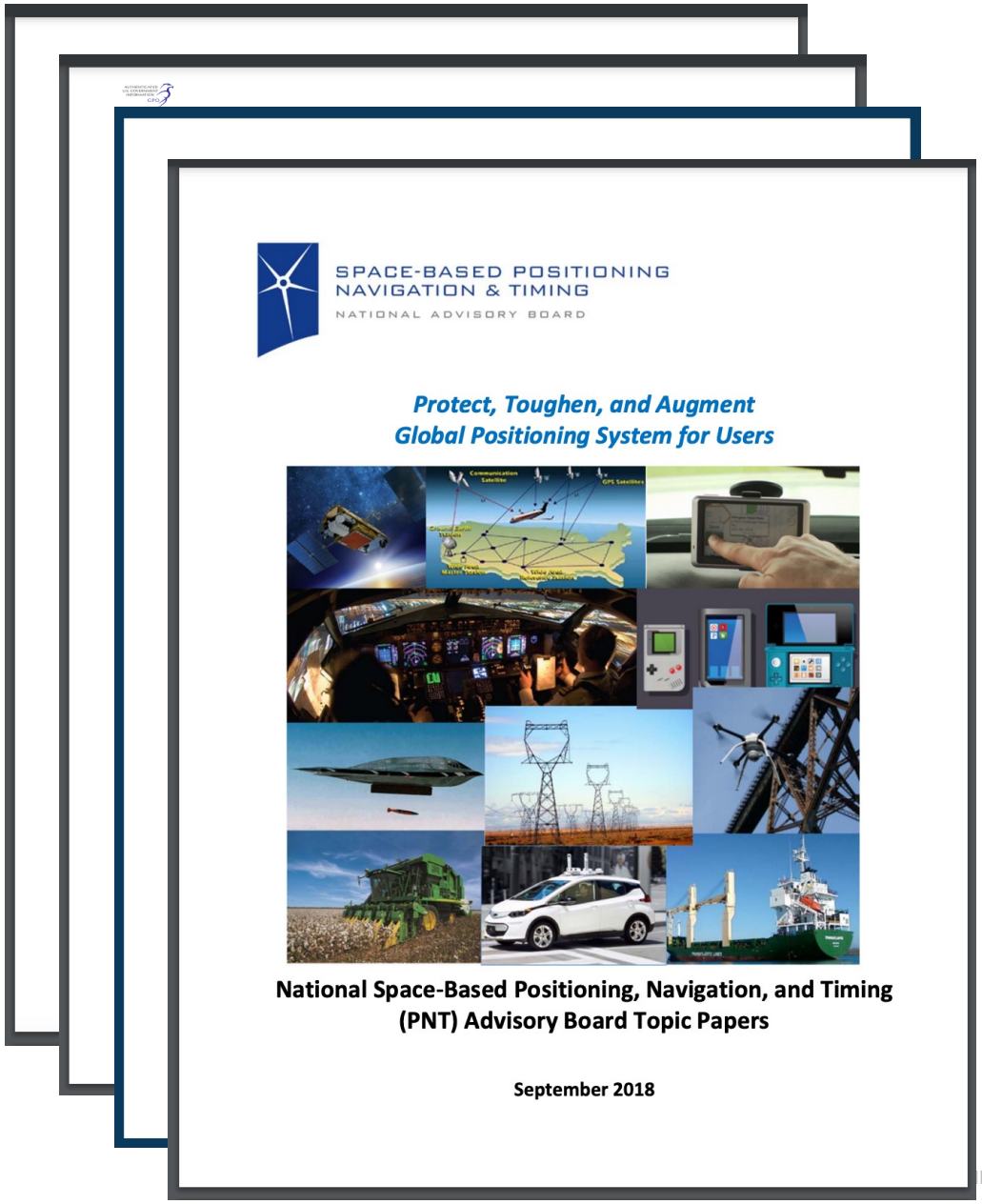

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May 7, 2021

The Honorable Adam Smith
Chair
Committee on Armed Services
United States House of Representatives
Washington, D.C. 20515

The Honorable Eddie Bernice Johnson
Chair
Committee on Science, Space and Technology
United States House of Representatives
Washington, D.C. 20515

The Honorable Mike Rogers
Ranking Member
Committee on Armed Services
United States House of Representatives
Washington, D.C. 20515

The Honorable Frank Lucas
Ranking Member
Committee on Science, Space and Technology
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The Honorable Peter DeFazio
Chair
Committee on Transportation and Infrastructure
United States House of Representatives
Washington, D.C. 20515

The Honorable Bennie Thompson
Chairman
Committee on Homeland Security
United States House of Representatives
Washington, D.C. 20515

The Honorable Sam Graves
Ranking Member
Committee on Transportation and Infrastructure
United States House of Representatives
Washington, D.C. 20515

The Honorable John Katko
Ranking Member
Committee on Homeland Security
United States House of Representatives
Washington, D.C. 20515

Re: Urgent Need for Alternative Positioning, Navigation, and Timing Systems Funding

Dear Members of Congress:

The Alliance for Telecommunications Industry Solutions (ATIS), on behalf of its SYNC Committee (SYNC), is writing to explain the urgent need for funding the deployment and adoption of Alternative Positioning, Navigation, and Timing (PNT) Systems in U.S. critical infrastructure, including the U.S. telecom industry.

ATIS is a leading developer of standards and other technical deliverables for Information and Communications Technology (ICT) and Services companies. ATIS develops standards on a broad range of important issues, including 5G and the Internet of Things (IoT). Industry subject matter experts work collaboratively in ATIS' open industry committees, such as SYNC. ATIS SYNC develops and

Impact of timing disruptions

- Best Case:
  - Blocking of protection function due to erroneous or loss of synchronization
- Worst Case:
  - Mal-operation of protection system including unnecessary switching of transmission circuits, cascading failures, and/ or damage to assets
  - Consequences beyond the power grid are even more grievous: a 30-day GPS outage: **> $1B / day loss** to US economy (50% in telecom) [1]

[1] A. O'Connor et al., "Economic benefits of the global positioning system (GPS)," RTI International, 306 p., June 2019

Recent Helpful Advances

- New IEEE activity
  - IEEE 1588-2019: Precision Time Protocol
  - IEEE 1952: Resiliency of Positioning, Navigation & Timing
- New services offered from NIST
- Key timing gear is improving
- New ways to receive reference UTC

Most Advances will require investments

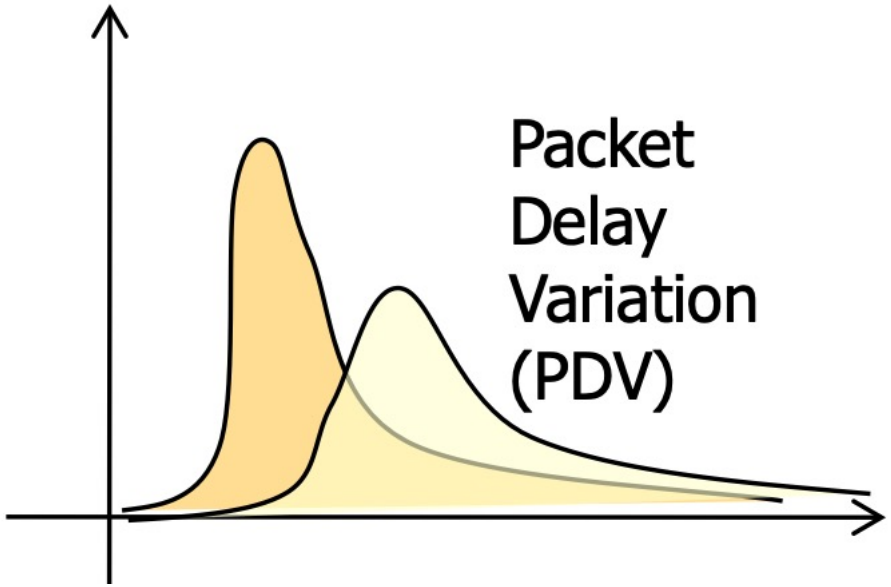
Note that advances are positive and negative

- PTP 1588-2019 (end of 2020)
- Improved Oscillators
- Additional NIST Services
- New reference sources
- Better antennas (16 lobe)

- Low-cost Chinese GPS jammers
- Software defined radio spoof kits
- Power grid attacks part of warfare

IEEE 1588 releases revised spec in November 2020

- New specification has added adaptability for Power Grid
- As always, a 1588 Implementation will depend on
  - The quality of the oscillator at the slave,
  - the packet delay variation of the network,
  - the number of timing packets per second

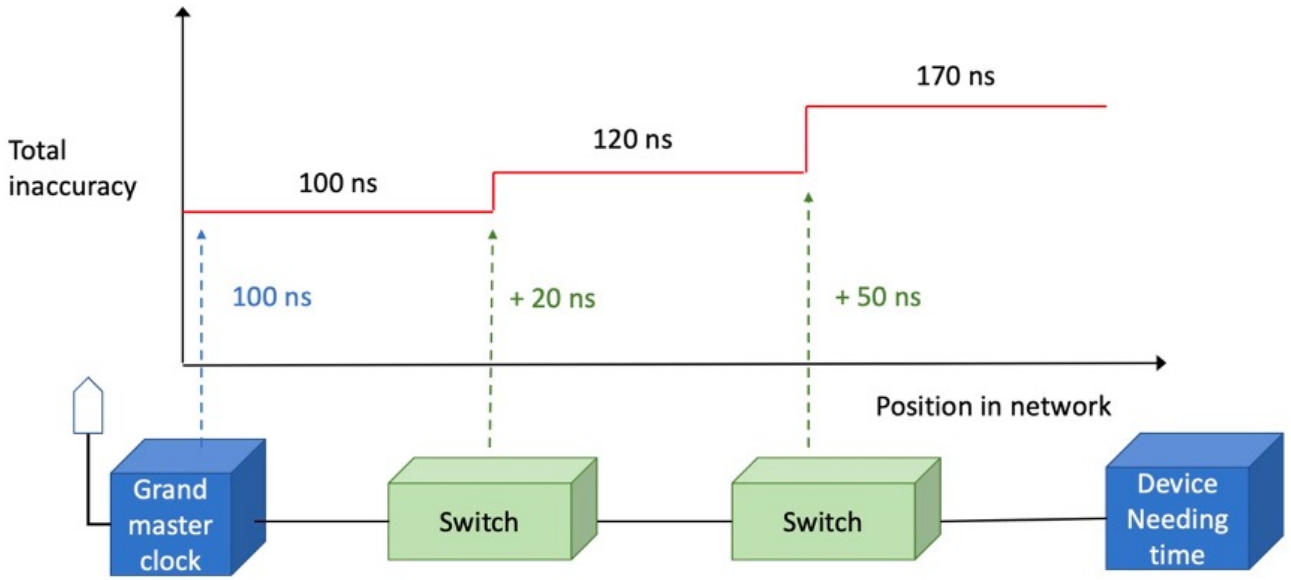


IEEE 1588 adopts more easily to Power Grid via Profiles

- "Profiles" customize 1588 to describe how systems and applications behave, clock synchronization protocols can support complex usage models and enable highly effective solutions for complex environments.
- IEEE-1588 defines profile as "The set of allowed Precision Time Protocol (PTP) features applicable to a device"
- "The purpose of a PTP profile is to allow organizations to specify specific selections of attribute values and optional features of PTP that, when using the same transport protocol, inter-work and achieve a performance that meets the requirements of a particular application."
- A PTP profile should define
  - Best master clock algorithm options
  - Configuration management options
  - Path delay mechanisms (peer delay or delay request-response)
  - The range and default values of all PTP configurable attributes and data set members
  - The transport mechanisms required, permitted, or prohibited
  - The node types required, permitted, or prohibited
  - The options required, permitted, or prohibited

IEEE 1588 also increases adaptability via new TLVs

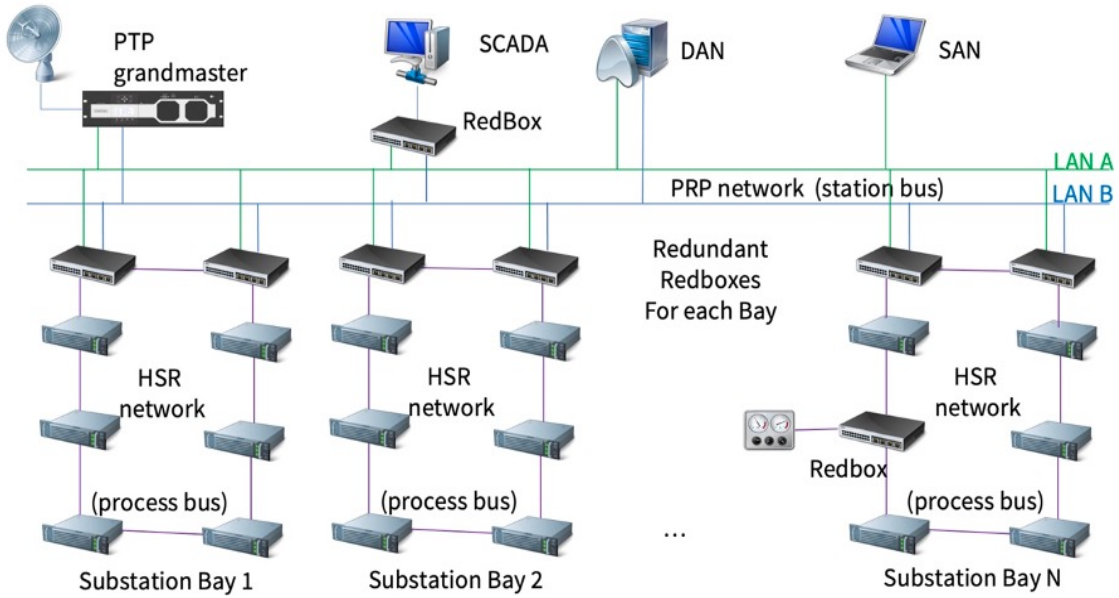
- 1588 Defines message extensions. Message extensions are called TLVs, after the fields in the extension for type, length, and value.
- New ENHANCED_ACCURACY_METRICS TLV
- Enables more detail on the accumulated inaccuracy.



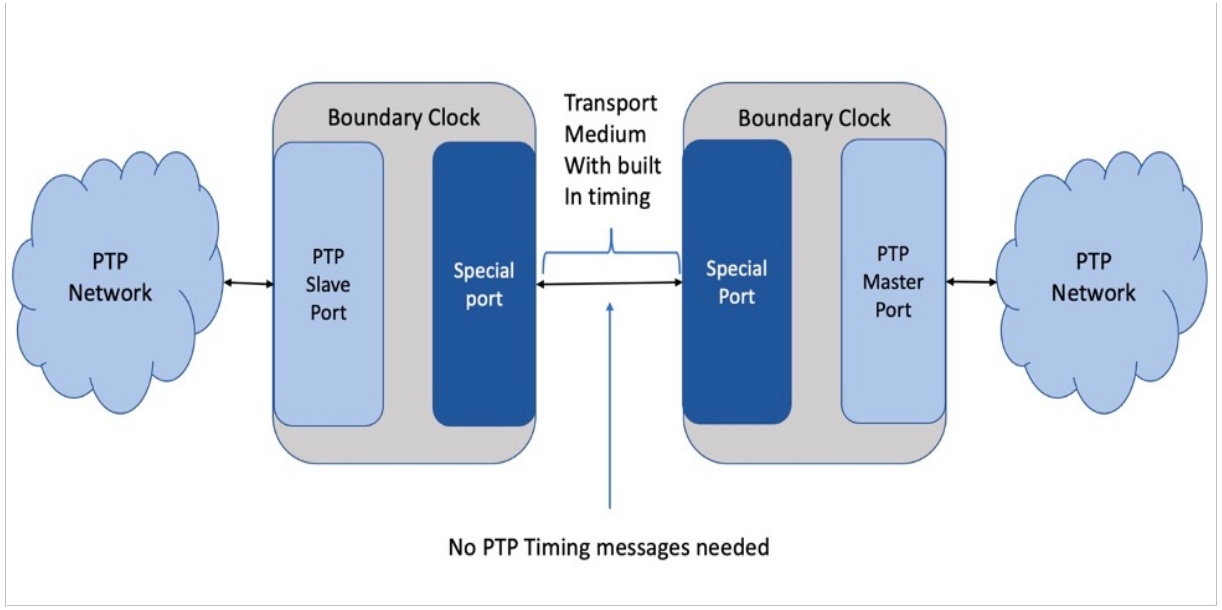
The PTP accuracy TLV (message extension) is loaded by the Grandmaster clock and updated by each switch and router through which the message passes. End devices can review the accumulated inaccuracy value to determine whether they are receiving time with sufficient accuracy.

Source: Terry Jones, Doug Arnold, Frank Tuffner, Rodney Cummings, and Kang Lee. "Recent Advances in Precision Clock Synchronization Protocols for Power Grid Control Systems." Energies 14, no. 17 (2021): 5303. https://doi.org/10.3390/en14175303

IEEE 1588 support for non-homogeneous networks



A redundant substation network in which the station bus is implemented with the PRP, and each bay of the process bus is implemented with HSR.

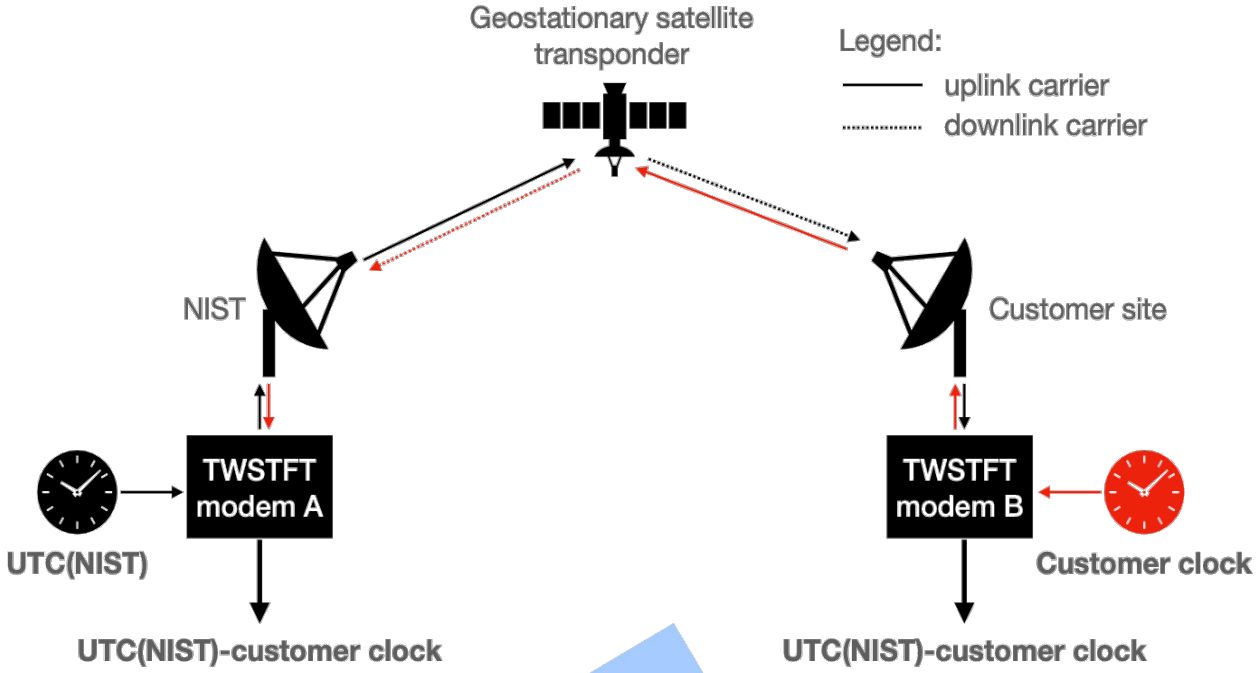


The PTP is transferred across a transport media that has a built-in timing mechanism by using special ports on boundary clocks.

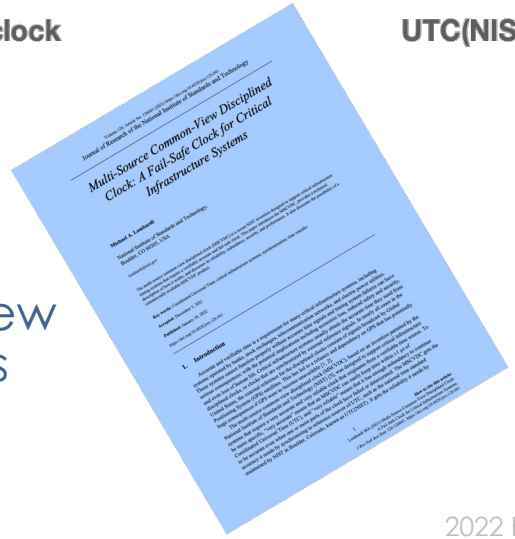
Source: Terry Jones, Doug Arnold, Frank Tuffner, Rodney Cummings, and Kang Lee. "Recent Advances in Precision Clock Synchronization Protocols for Power Grid Control Systems." Energies 14, no. 17 (2021): 5303. https://doi.org/10.3390/en14175303

New NIST Service provides UTC reference

- NIST preparing to offer UTC(NIST) via **two-way satellite time/frequency transfer (TWSTFT)**
  - Link stability ~ 1 ns
    Inaccuracy ≤ 15 ns, depending on method of initial calibration
- **"Service" profile:**
  - Available late CY 2022 or 2023, demand-dependent Dedicated Earth station, satellite bandwidth
- **Fees:**
  - NIST services must recover all costs
    Anticipate $4k to $6k/site/mo.



Also new Common View technologies



[1]Source: Sherman, Jeffrey A. <jeff.sherman@nist.gov>

Other new precise time developments

- Improved cesium oscillators!
  - Much Longer durations for holding 100 ns level accuracy
- National Association of Broadcasters moving to ATSC 3.0
  - Implications for UTC source

- IEEE 1952 to provide helpful characterizations of PNT equipment
  - More description in next talk!

Summary

- US power grid is moving toward a wide-area network; requires precise, secure, and resilient time synchronization
- GPS is an amazing capability for domestic and global PNT needs, but inherent limitations lead to grid vulnerabilities
- Recent developments make GPS alternatives viable
- These developments include:
  - IEEE 1588 advances
  - New UTC reference possibilities including new NIST services
  - Advances in holdover oscillators and antennas

Questions & Comments Welcome: trj@ornl.gov