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Oak Ridge National Laboratory

Strategy for Resilient Synchronization of Smart Grids

WSTS 2024
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YOUR TAX DOLLARS AT WORK!

U.S. DEPARTMENT OF ENERGY | OFFICE OF ELECTRICITY

CAST is a program at Oak Ridge National Laboratory sponsored by the US Department of Energy, Office of Electricity

CAST — Center for Alternative Synchronization and Timing —

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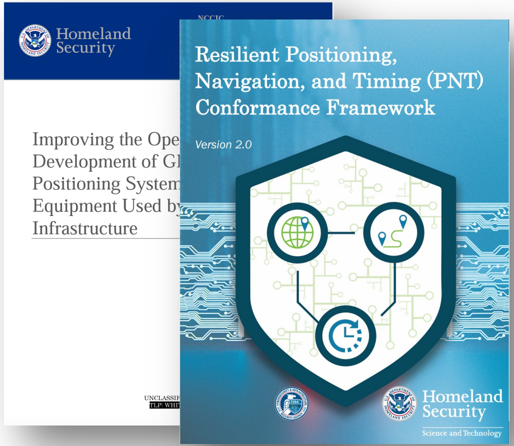
Alternative PNT is a National Security Imperative

Executive order 13905: Strengthening National Resilience Through Responsible Use of Positioning, Navigation, and Timing Services

Critical infrastructure is fundamentally dependent on PNT

- Power grid
- Finance
- IoT sensors
- Internet
- Communications



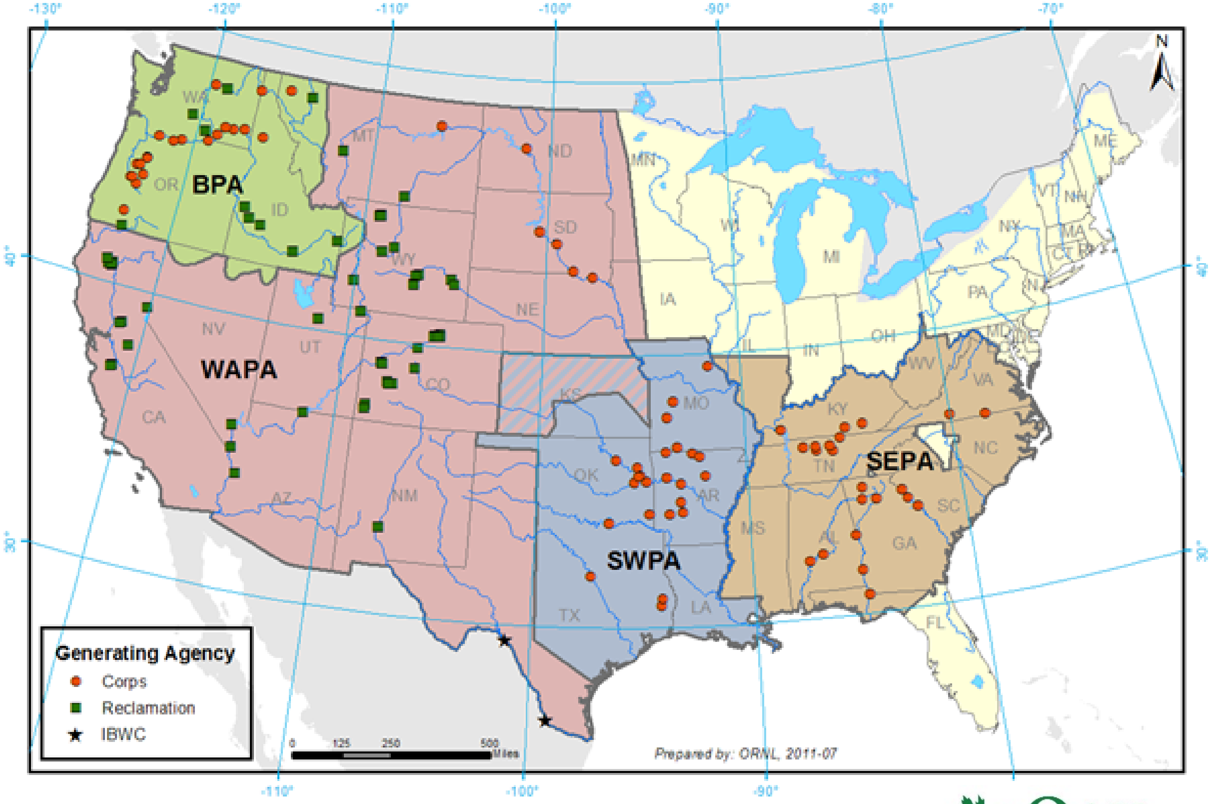
Executive Order 13905 of February 12, 2020

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.

Federal Power Marketing Administration territories and facilities



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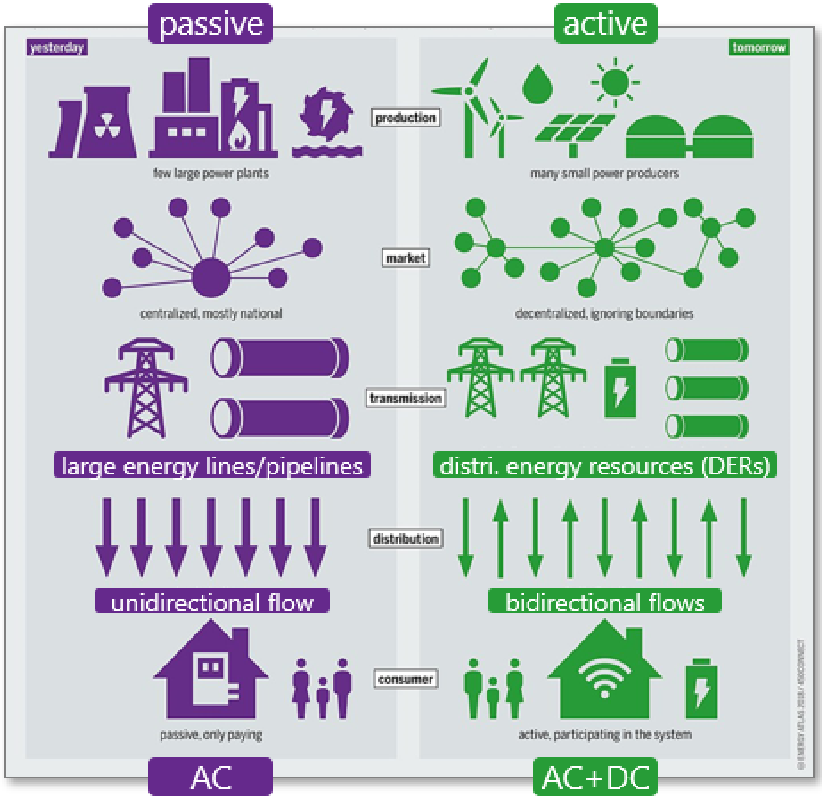
Tighter NTP-to-PTP data timestamping accuracy requirements



Grid applications	Timing requirements (min reporting resolution & accuracy relative to UTC)
Advanced time-of-use meters	15, 30, and 60 minute intervals are commonly specified (ANSI C12.1)
Non-TOU meters	Ongoing, with monthly reads or estimates
SCADA	Every 4-6 seconds reporting rate
Sequence of events recorder	50 µs to 2 ms
Digital fault recorder	50 µs to 1 ms
Protective relays	1 ms or better
Synchrophasor/phasor measurement unit (30 - 120 samples/second)	Better than 1 µs 30 to 120 Hz
Traveling wave fault location	100 ns
Micro-PMUs (sample at 512 samples/cycle)	Better than 1 µs
Substation communications protocols	
Substation local area network communication protocols (IEC 61850 GOOSE)	100 µs to 1 ms synchronization
Substation LANs (IEC 61850 Sample Values)	1 µs

source: NASPI Time Sync Task Force Report, 2017

Developing Wide-Area Time Synchronization Solutions to Augment GPS for US Critical Infrastructure

National Security & Modernization Imperative

- GPS is an amazing capability but is vulnerable to spoofing and other cyber threats
- Executive Order 13905 (2020): National Resilience through PNT
- PTP timing necessary for a smart grid

One-of-a-Kind Testbed with Dozens of Commercial Partners

- Leveraging COTS capabilities to evaluate against strict accuracy & cyber requirements of the grid
- Partnerships to improve, refine, and adapt OEM capabilities

R&D and T&E of Novel Timing Architectures for the Grid

- Developing nanosecond-scale secure timing solutions
- Testing across a variety of terrestrial and space-based comms links
- Evaluating integrations with existing utility equipment baselines

Established Capacity for Transition to Utilities

- CAST is collaborates with PMAs and utilities to demonstrate and implement new synchronization capabilities
- Team is documenting best practices for sharing with and supporting utilities

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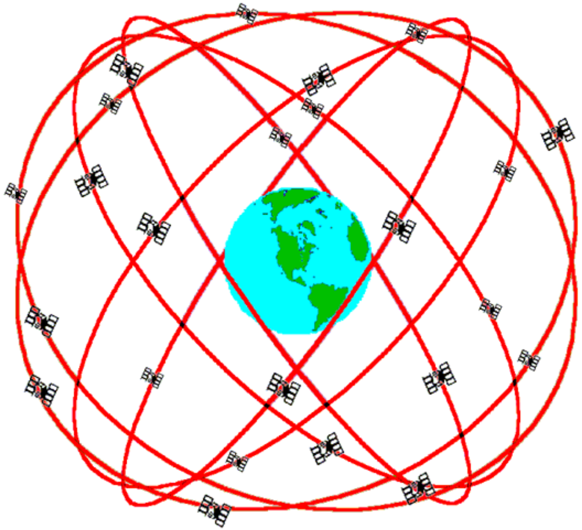
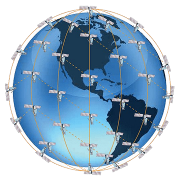
GPS Constellation vs Iridium (LEO) Constellation



GPS Nominal Constellation
24+ Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,180 km Altitude, 55 Degree Inclinations
Orbital speed 14,000 km/hr (9k mph)
Orbital period 12 hours (2x/day)
Different satellite in each plane every 3 hrs



Iridium Nominal Constellation
66 Satellites in 6 Orbital Planes
11 Satellites in each Plane
781 km Altitude, Polar orbits (86.4 degrees)
Orbital speed 27,000 km/hr (17k mph)
Orbital period 100 minutes (14x/day)
Different satellite in each plane every 9 min

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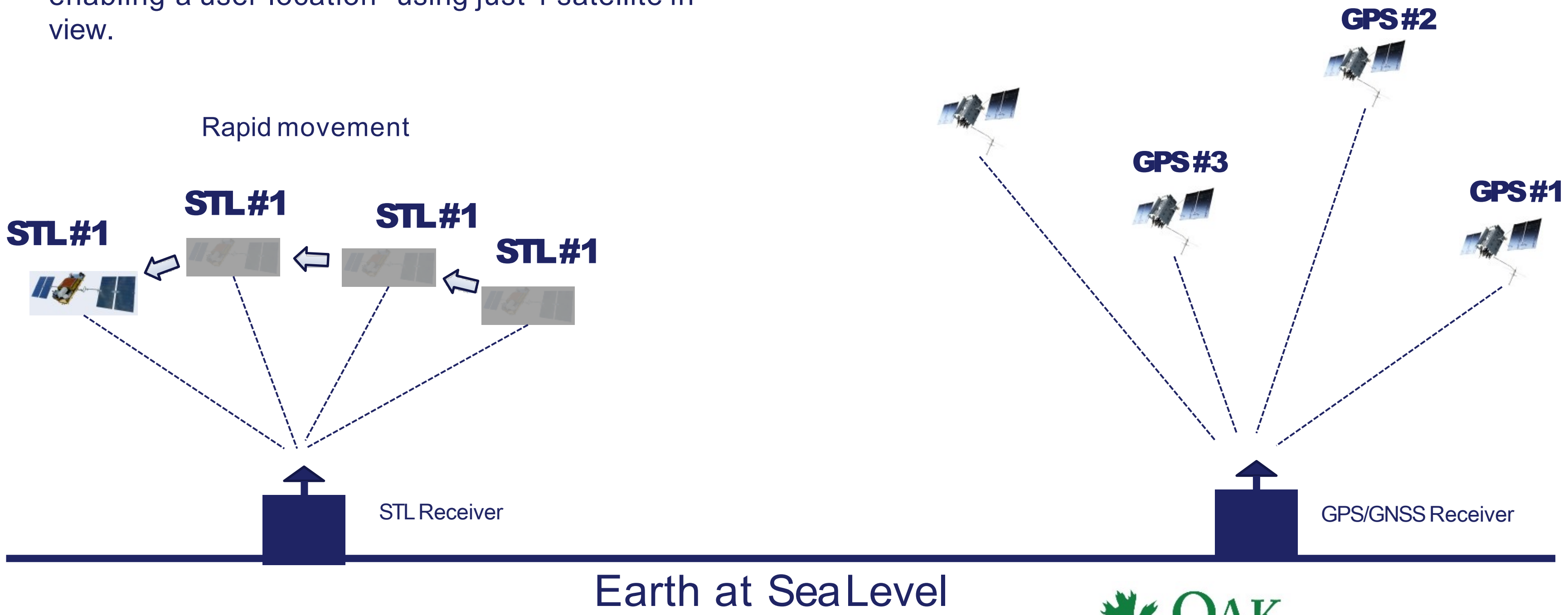
Satellites Needed for STL vs GPS/GNSS

Iridium (LEO) Satellites circle the Earth every **100 minutes**. They move so fast their ranging angle can change up to 1 degree every 4 seconds, enabling a user location using just 1 satellite in view.

GPS/GNSS (MEO) Satellites circle the Earth every **12 hours**. They move so slowly that at least 4 satellites must be used to determine a user's location.



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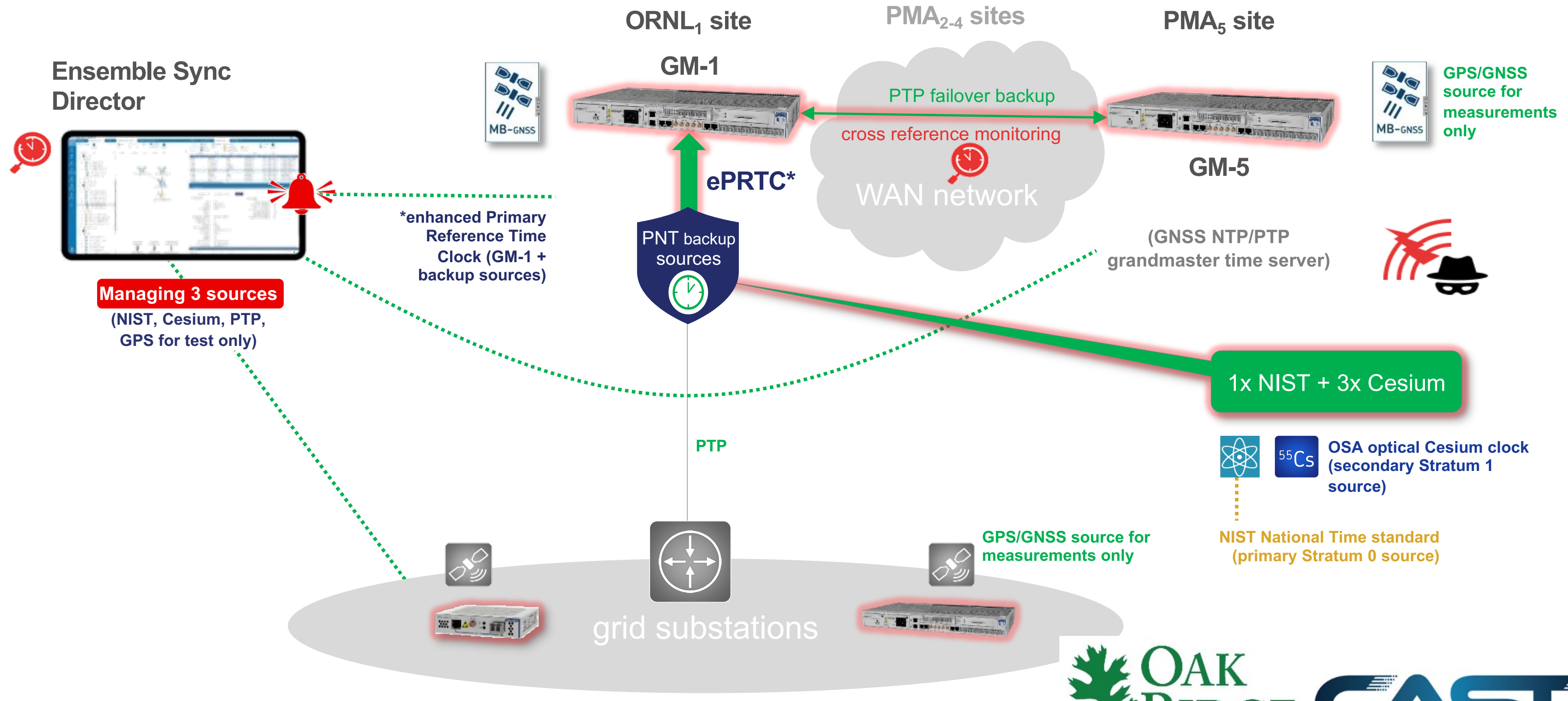
ORNL zero-trust multisource backup timing architecture



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CAST Current R&D Priorities

PTP over OTN
Critical for private and protected high-speed networks

PTP over 5G
Critical for low-cost distribution to austere environments

PTP over Satellite Internet
Critical for low-cost distribution to austere environments and mobile deployments

Geographic Redudency
Critical for authoritative time strata fail-over to ensure master clock resilience

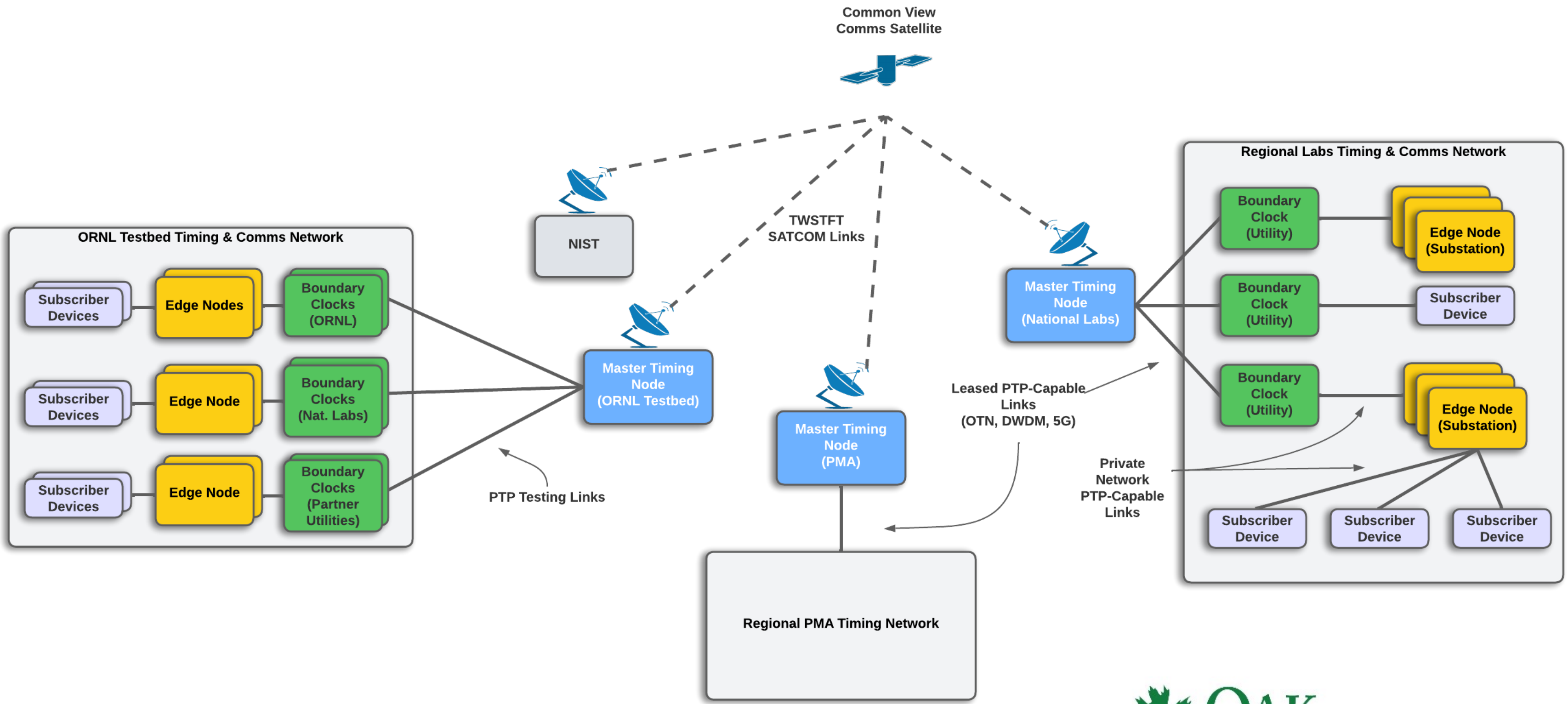
Multi Source Common View
Critical for synchronization of disconnected grand master clocks

NTS4PTP Security
Critical for securing the timing signal at a low cost

Operations Insights
Critical for sharing the best practices for timing equipment operations

Real-Time Dashboard
Critical for monitoring, visualizing, and analyzing system state and performance

Multi-Tier Timing Architecture for Resilient PNT



ORNL Timing & Synchronization Test-Bed: Industry-Leading Technologies and Nationwide Partnerships

One-of-a-Kind Technology Baseline

Multiple **atomic clocks**

- One optically-pumped cesium clock
- Two magnetic cesium clocks
- Two rubidium clocks

Cyber accredited, industry leading firewall and signal **encryption**

Multiple **communications networks** integrated to the lab

- Dark fiber
- DWDM
- Carrier Ethernet
- OTN
- DOE ESNet
- Cellular/5G
- Dedicated SATCOM Satellite Internet

Industry and Lab Partnerships for Testing and Development

Hardware

- Adtran Oscilloquartz
- Microchip
- Palo Alto
- Juniper
- Arista
- Nokia
- Safran

Communications

- ESNet
- AT&T, Verizon
- SES Government
- InMarSat
- Iris Networks

R&D and Testing

- Idaho National Lab
- Sandia National Lab
- Savannah River National Lab
- National Institute of Standards of Technology (NIST)
- Electric Power Board of Chattanooga (EPB)
- Public Service Company of New Mexico (PNM)
- Dominion Energy
- Western Area Power Administration (WAPA)

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Real-Time Clock Measurements

Network Routing Change Affected Latency

Network Routing Change Affecting PTP

GM Normal ePRTC Locked

Identification

Entity ID : TIME CLOCK-1-1-1-1

Status

Selected Reference	: GPS-1-1-1-1	**TC Lock Progress (%)**	: 100
Clock Mode	: Locked	**ePRTC Holdover Ready Progress (%)**	: 100
Leap59	: False	**Holdover Estimated Drift (nSec)**	: Not Applicable
Leap61	: False	**Expected Time Left In EPRTC Holdover**	: Not Applicable
Time Traceability Status	: Time Locked	**Current Mode**	: EPRTC
UTC Offset	: 37	**Cross Reference Validation Status**	: N/A
Current QL	: QL-EPRTC		
Current Time Of Day	: 2024-04-10 19:09:17 **TAI**		

User Requests

Request : None
Target : None

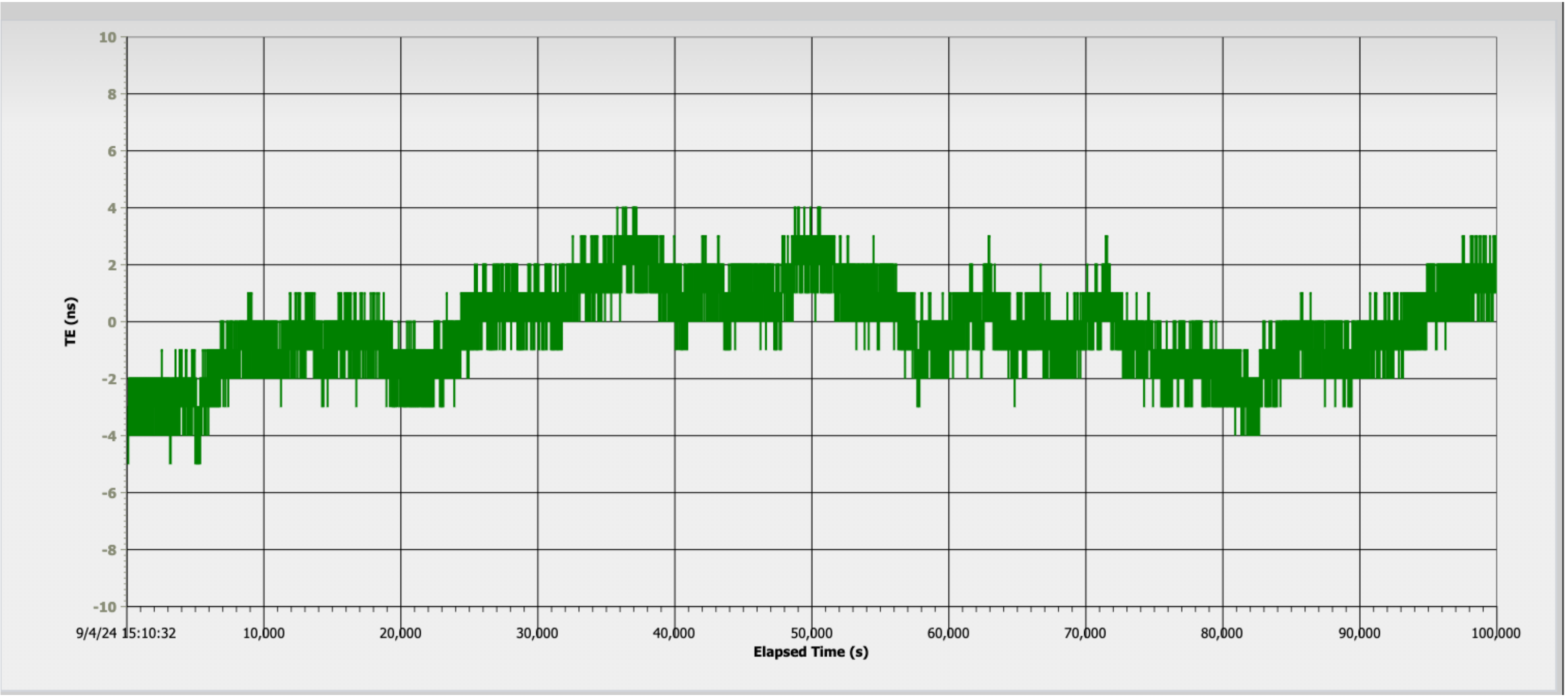
Output Steering

Steering Status : Idle
Time to target(sec) : 0
Accumulated Steering offset(sec) : 0
Accumulated Steering offset(nsec) : 0

Time Clock Reference List

Time Ref Eid	Priority	Source	Source Status	State	EPRTC Filter Type	Alias
TIMEREF-1-1-1-1-1	NA	GPS-1-1-1-1	Reference OK	Active	NA	
TIMEREF-1-1-1-1-2	NA	CLK-1-1-1-1	Reference Frequency OK	Active	Type II	

Clock Probe – GM locked ePRTC Mode



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GM GPS Lost but ePRTC Locked (Holdover to Cs)

Identification

Entity ID : TIME CLOCK-1-1-1-1

Status

Selected Reference	: CLK-1-1-1-1	**TC Lock Progress (%)**	: Not Applicable
Clock Mode	: Locked	**ePRTC Holdover Ready Progress (%)**	: Not Applicable
Leap59	: False	**Holdover Estimated Drift (nSec)**	: Not Applicable
Leap61	: False	**Expected Time Left In EPRTC Holdover**	: Not Applicable
Time Traceability Status	: Time Holdover	**Current Mode**	: EPRTC
UTC Offset	: 37		
Current QL	: QL-EEC1		
Current Time Of Day	: 2024-04-10 18:48:02 **TAI**		

User Requests

Request : None
Target : None

Time Clock Reference List

Time Ref Eid	Priority	Source	Source Status	State	Alias
TIMEREF-1-1-1-1-1	NA	GPS-1-1-1-1	Reference Failed	Unavailable	GNSS
TIMEREF-1-1-1-1-2	NA	CLK-1-1-1-1	Reference Frequency OK	Active	3230B

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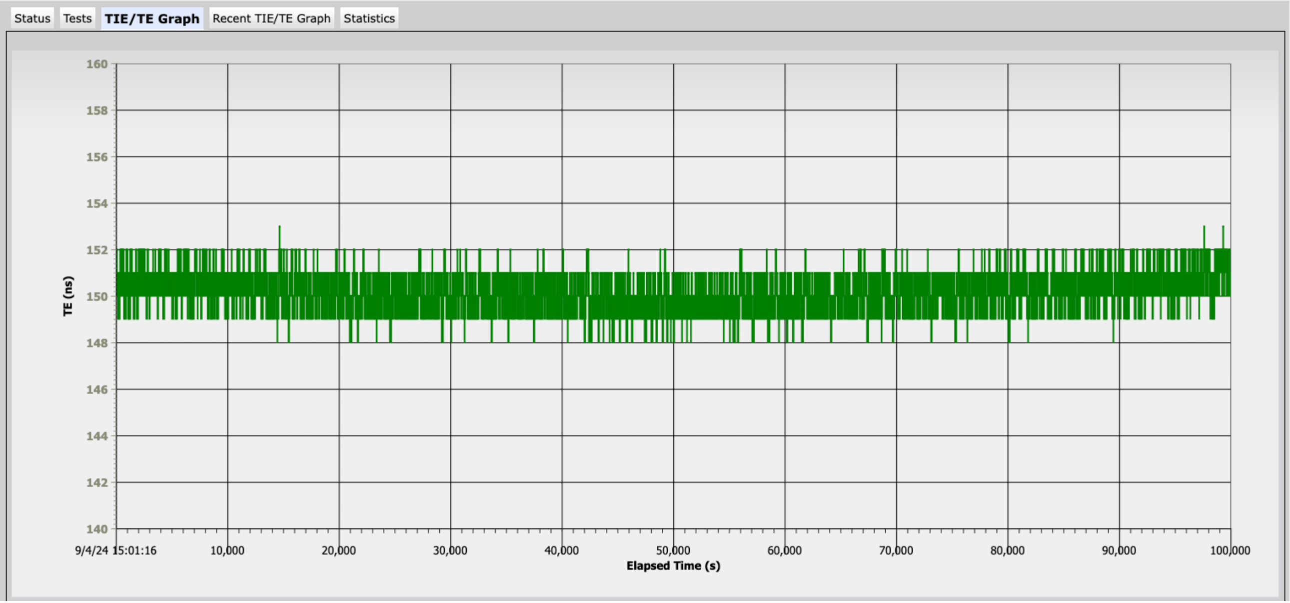
Clock Probe GM Holdover to Cs



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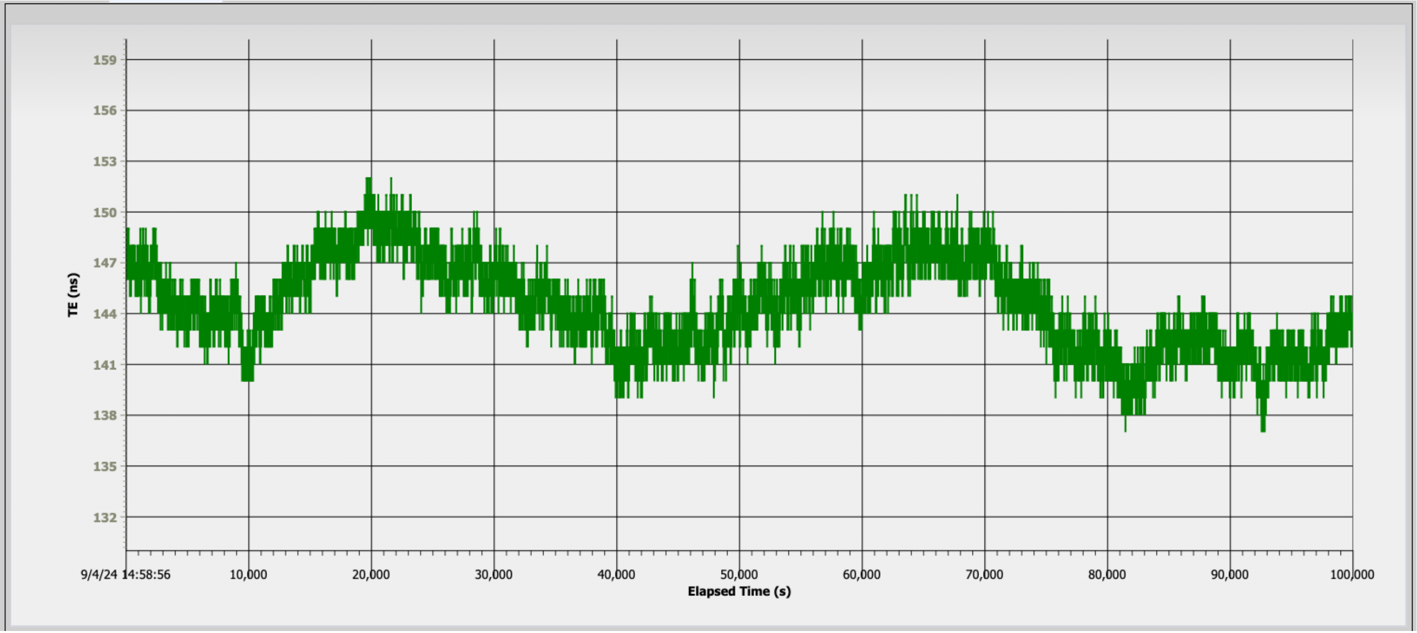
Clock Probe Time Receiver



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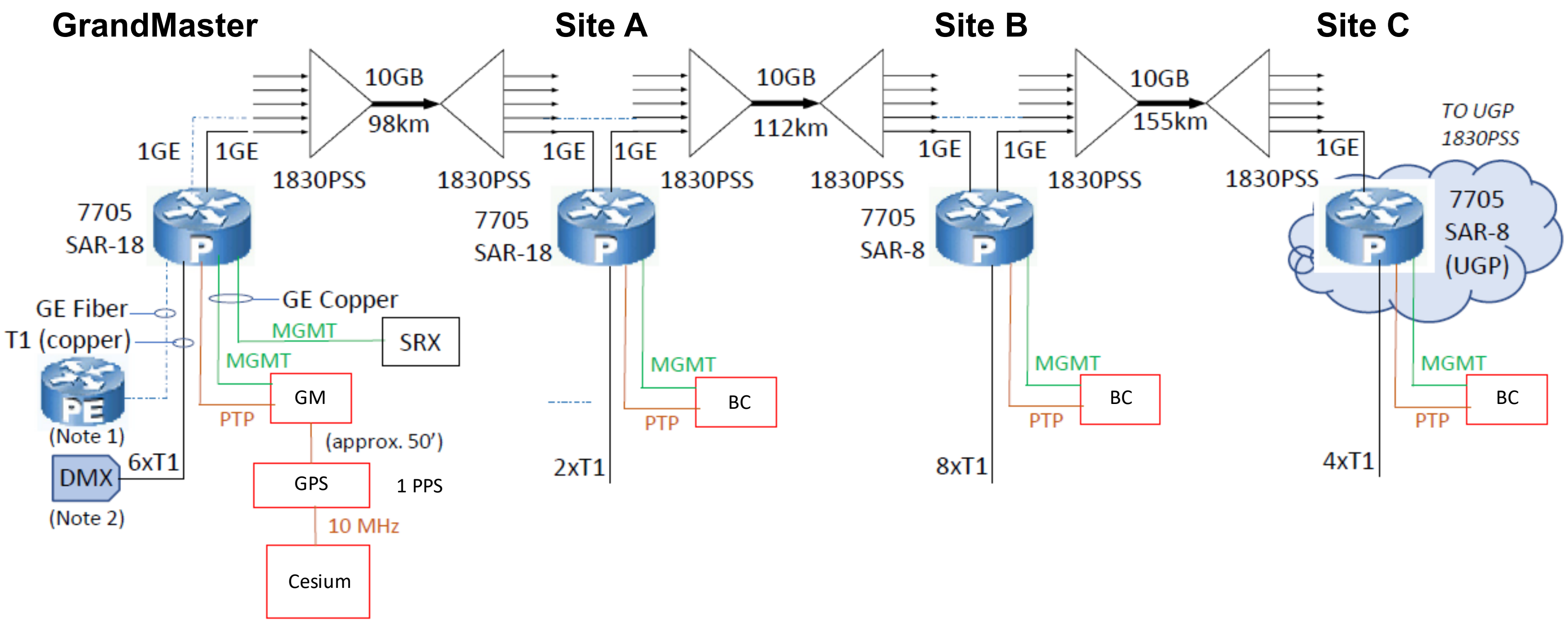
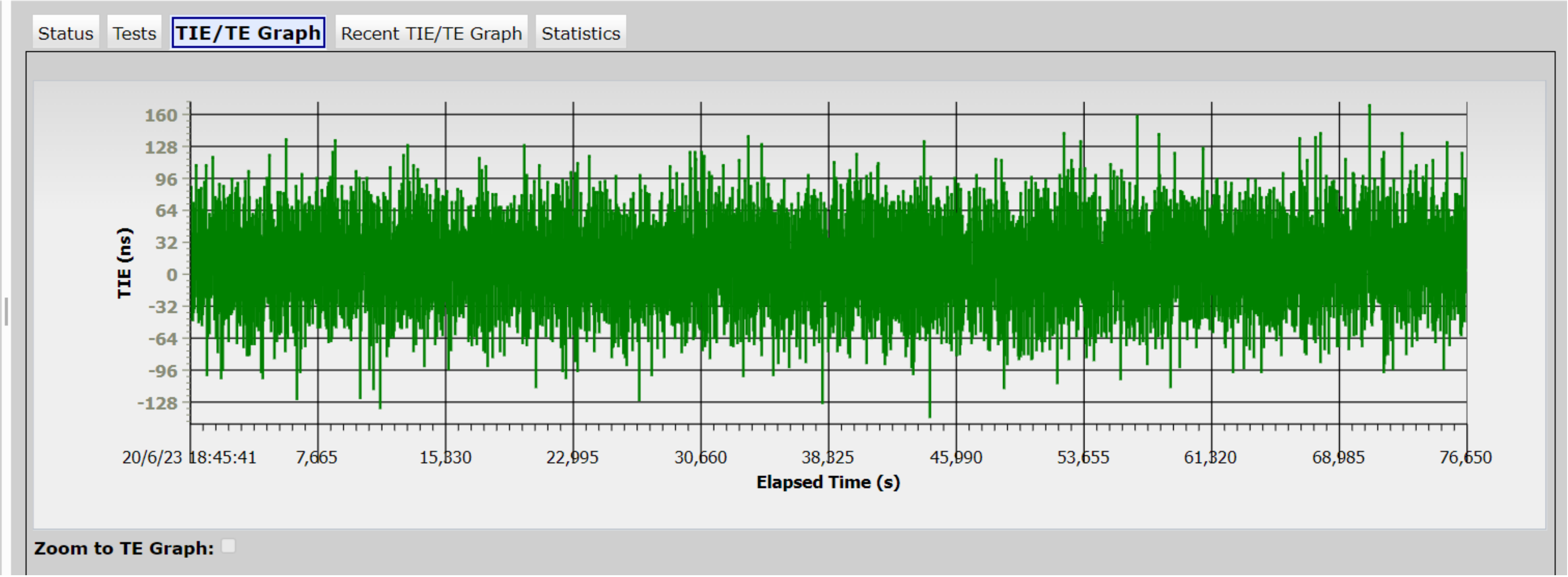
Testing in Real World Environment



PTP Probe – Site A - 98km from GM



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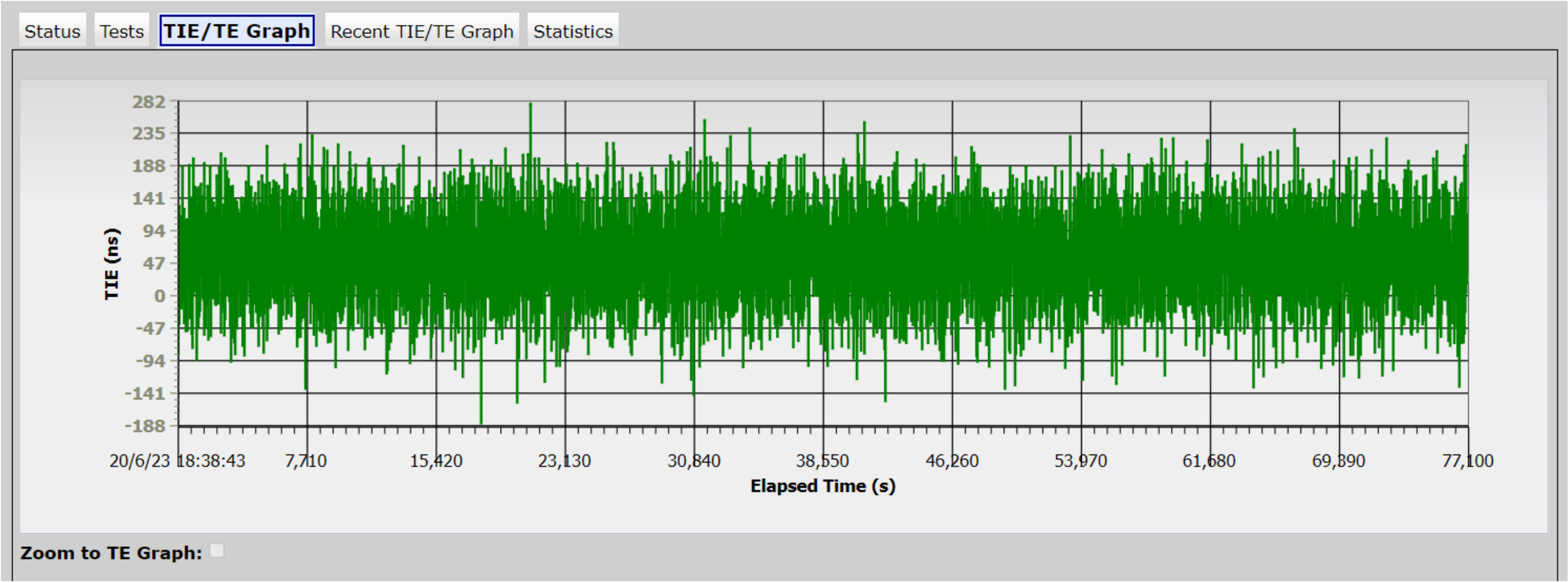
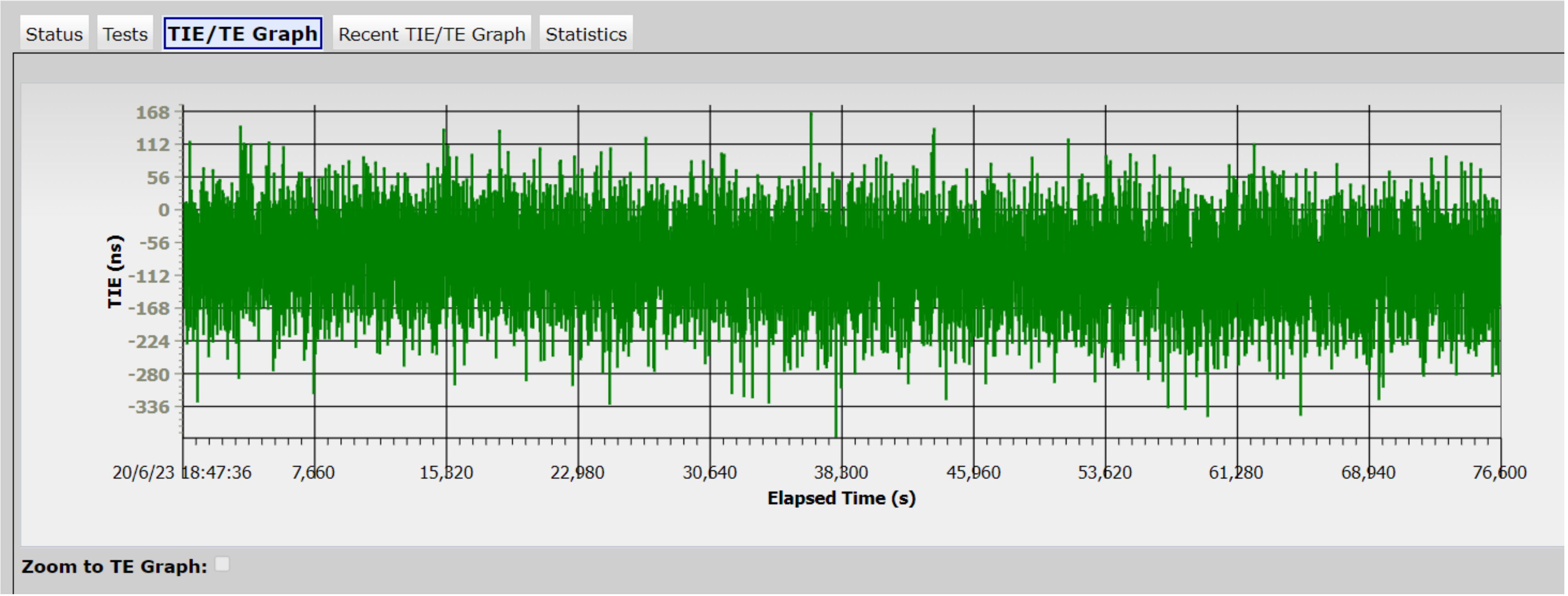
PTP Probe – Site B - 210km from GM



PTP Probe – Site C - 365km from GM



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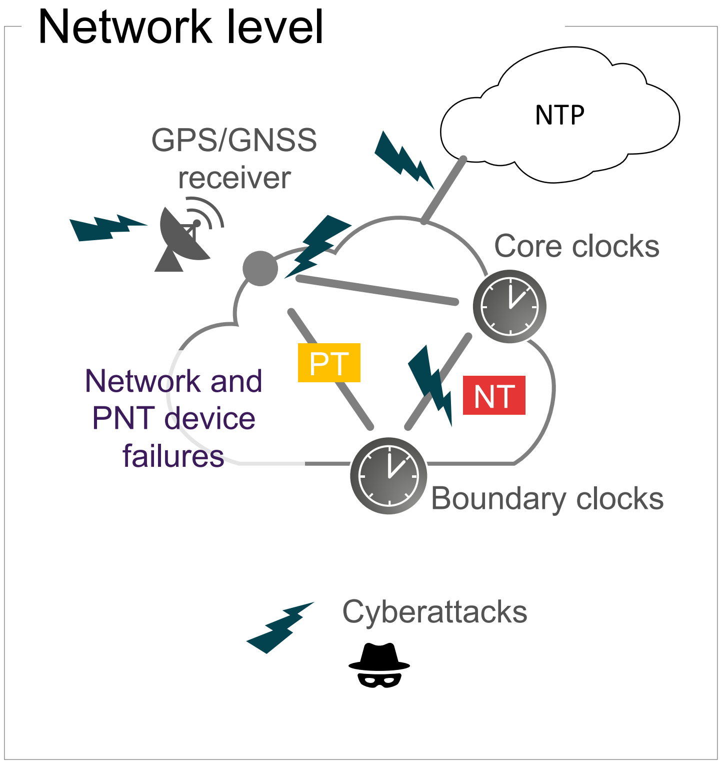
A word about NTP sourcing

- External NTP leaves your network vulnerable
- NTP packets and GPS signals can be manipulated to cause harm to your network
- Using internal NTP provided by a Grand Master Clock closes a pinhole into your network



Conclusions

- End users lack knowledge and experience required to deploy PTP in a network
- Must plan for and understand network rearrangements on the fly
- Ability for clocks to perform advanced testing is big plus (probing)
- PTP actually good tool for analyzing network performance (latency, etc.)
- Large installations require global view of timing (management system)
- Proving that network timing can be maintained during loss of GNSS/GPS (when properly planned)
- Prompt, expert vendor support is paramount to success
- Increased learning through partner participation
- Must be able to survive in multi-vendor environment
- Understanding how different network configurations, elements impact PTP

Learn more about the Center for Alternative Synchronization and Timing by visiting https://cast.ornl.gov/

Thank You!

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