WORKSHOP ON SYNCHRONIZATION AND TIMING SYSTEMS

Virtual Webinar Series
Session 3
Timing Security, Resilience and GNSS Issues

May 20, 2020

Sponsored by: MEINBERG

atis

WORKSHOP
ON
SYNCHRONIZATION
AND
TIMING SYSTEMS

Timing Security, Resilience and GNSS Issues Overview

Marc Weiss
Time & Frequency Expert
Consultant

Session 3: Timing Security, Resilience and GNSS Issues
May 20, 2020

Sponsored by: MEINBERG

- The vWSTS webinar series is being held in place of the annual face-to-face WSTS.
- Today’s webinar is the third in a series of three:
  - **May 6** – 5G and Smart Cities
  - **May 13** – Timing in Finance, Electric Power and Broadcast
  - **May 20** – Timing Security, Resilience and GNSS Issues
- Thank you to today's speakers, as well as Meinberg for sponsoring this webinar.
- Attendees will receive an email with the slides and a link to the recording shortly following today's broadcast.
- There are two Q&A sessions during this webinar.
  - Submit questions at any time using the question tab on the control panel located on the right side of your screen.
- Follow ATIS on Twitter @atisupdates

WORKSHOP ON SYNCHRONIZATION AND TIMING SYSTEMS

Chair: Marc Weiss – Time & Frequency Expert Consultant

Vice Chair: Kishan Shenoi – CTO, Qulsar

Speakers: Karen Van Dyke – Director, PNT & Spectrum Management, DOT

Heiko Gerstung – Managing Director, Meinberg

Karen O’Donoghue – Director, Internet Trust & Technology, Internet Society

Doug Arnold – Principal Technologist, Meinberg USA

Josh Clanton – Principal Engineer, IS4S

David Hodo – Director of Assured PNT, IS4S

Andreas Bauch – Head of Time Dissemination Working Group, PTB

Akis Drosinos – Member of the Technical Staff, Spirent Communications

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Session 3: Timing Security, Resilience and GNSS Issues
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- Resilient PNT for Transportation Applications, Karen Van Dyke
- Meinberg Sponsor Presentation, Heiko Gerstung
- Time Security – The Winding Path to Deployment, Karen O’Donoghue
- Secure PTP Using TLS Key Management, Doug Arnold
- A Multi-Level Approach for Integrating GNSS Integrity into Critical Timing Applications, Josh Clanton, David Hodo
- Timing Services Based on European GNSS Technologies, Andreas Bauch
- Effect of GNSS Multipath on Timing Receivers, Akis Drosinos

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Critical timing issues

- As seen in our previous two webinars timing is becoming a critical enabler in many industries: 5G, Smart Cities, Smart Grid, Finance, and Broadcast
- Our Keynote today brings in the importance of timing in transportation, touching on some of the US government efforts to support Resilience
- Since timing must be delivered from the source to the user, there are many places in the chain where vulnerabilities appear
- Our speakers today address issues both in using GNSS for timing, the method most use to receive UTC, and in using networks

WORKSHOP ON SYNCHRONIZATION AND TIMING SYSTEMS

Resilient PNT for Transportation Applications

Karen Van Dyke
Director
PNT & Spectrum Management
Department of Transportation

Session 3: Timing Security, Resilience and GNSS Issues
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Resilient PNT for Transportation Applications

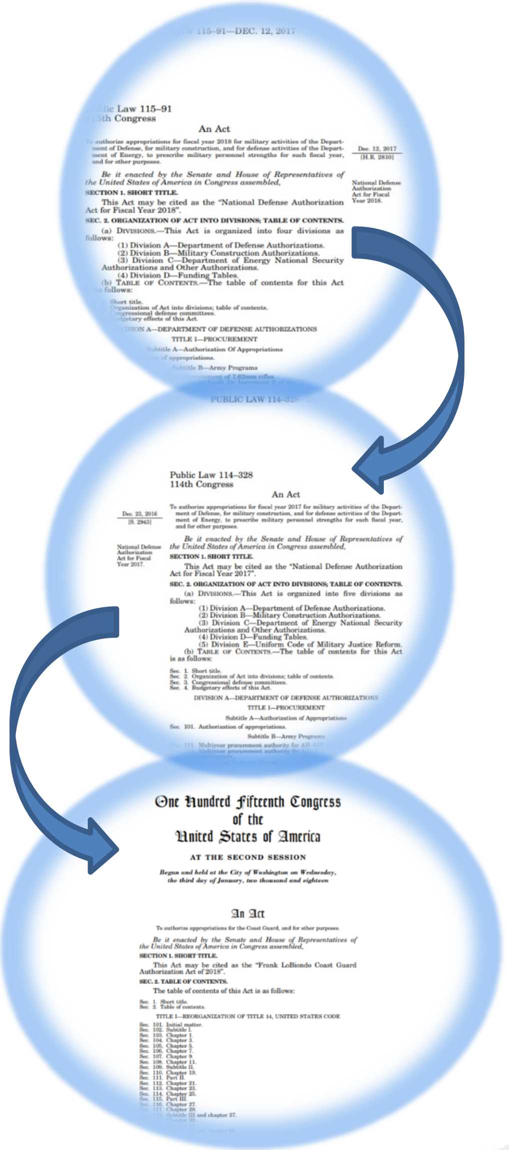
Virtual Workshop on Synchronization and Timing Systems

Karen L. Van Dyke

May 20, 2020

Congressional Motivation on GPS Backup and Complementary PNT Capability

- Sequential Legislation on Backup/Complementary PNT Service
  - <u>Needs</u> Established for PNT : **FY17 NDAA**
  - <u>Demonstrate</u> PNT Technologies: **FY18 NDAA**
  - <u>Procure</u> Alternate [to GPS] Timing System: **Frank LoBiondo Coast Guard Authorization Act/National Timing Resilience and Security Act (NTRSA) of 2018**
  - National Timing Resilience and Security Act Places Procurement on DOT



115–91—DEC. 12, 2017

Public Law 115–91
115th Congress

An Act

To authorize appropriations for fiscal year 2018 for military activities of the Department of Defense, for military construction, and for defense activities of the Department of Energy, to prescribe military personnel strengths for such fiscal year, and for other purposes.

Dec. 12, 2017
[H.R. 2810]

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

National Defense Authorization Act for Fiscal Year 2018.

SECTION 1. SHORT TITLE.

This Act may be cited as the "National Defense Authorization Act for Fiscal Year 2018".

SEC. 2. ORGANIZATION OF ACT INTO DIVISIONS; TABLE OF CONTENTS.

(a) DIVISIONS.—This Act is organized into four divisions as follows:

(1) Division A—Department of Defense Authorizations.
(2) Division B—Military Construction Authorizations.
(3) Division C—Department of Energy National Security Authorizations and Other Authorizations.
(4) Division D—Funding Tables.

(b) TABLE OF CONTENTS.—The table of contents for this Act is as follows:

Short title.
Organization of Act into divisions; table of contents.
Congressional defense committees.
Budgetary effects of this Act.

DIVISION A—DEPARTMENT OF DEFENSE AUTHORIZATIONS

TITLE I—PROCUREMENT

Subtitle A—Authorization Of Appropriations

of appropriations.

Subtitle B—Army Programs

procurement of 7.62mm rifles.

PUBLIC LAW 114–328

Public Law 114–328
114th Congress

An Act

Dec. 23, 2016
[S. 2943]

To authorize appropriations for fiscal year 2017 for military activities of the Department of Defense, for military construction, and for defense activities of the Department of Energy, to prescribe military personnel strengths for such fiscal year, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

National Defense Authorization Act for Fiscal Year 2017.

SECTION 1. SHORT TITLE.

This Act may be cited as the "National Defense Authorization Act for Fiscal Year 2017".

SEC. 2. ORGANIZATION OF ACT INTO DIVISIONS; TABLE OF CONTENTS.

(a) DIVISIONS.—This Act is organized into five divisions as follows:

(1) Division A—Department of Defense Authorizations.
(2) Division B—Military Construction Authorizations.
(3) Division C—Department of Energy National Security Authorizations and Other Authorizations.
(4) Division D—Funding Tables.
(5) Division E—Uniform Code of Military Justice Reform.

(b) TABLE OF CONTENTS.—The table of contents for this Act is as follows:

Sec. 1. Short title.
Sec. 2. Organization of Act into divisions; table of contents.
Sec. 3. Congressional defense committees.
Sec. 4. Budgetary effects of this Act.

DIVISION A—DEPARTMENT OF DEFENSE AUTHORIZATIONS

TITLE I—PROCUREMENT

Subtitle A—Authorization of Appropriations

Sec. 101. Authorization of appropriations.

Subtitle B—Army Programs

Sec. 111. Multiyear procurement authority for AH–64E
112. Multiyear procurement authority for
helicopters.

One Hundred Fifteenth Congress
of the
United States of America

AT THE SECOND SESSION

Begun and held at the City of Washington on Wednesday, the third day of January, two thousand and eighteen

An Act

To authorize appropriations for the Coast Guard, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE.

This Act may be cited as the "Frank LoBiondo Coast Guard Authorization Act of 2018".

SEC. 2. TABLE OF CONTENTS.

The table of contents of this Act is as follows:

Sec. 1. Short title.
Sec. 2. Table of contents.

TITLE I—REORGANIZATION OF TITLE 14, UNITED STATES CODE

Sec. 101. Initial matter.
Sec. 102. Subtitle I.
Sec. 103. Chapter 1.
Sec. 104. Chapter 3.
Sec. 105. Chapter 5.
Sec. 106. Chapter 7.
Sec. 107. Chapter 9.
Sec. 108. Chapter 11.
Sec. 109. Subtitle II.
Sec. 110. Chapter 19.
Sec. 111. Part II.
Sec. 112. Chapter 21.
Sec. 113. Chapter 23.
Sec. 114. Chapter 25.
Sec. 115. Part III.
Sec. 116. Chapter 27.
Sec. 117. Chapter 29.
Sec. 118. Subtitle III and chapter 37.

GPS Backup Demonstration Overview

High-level Demonstration Plan Developed Under FY18 NDAA

- Joint DOT/DHS/DOD congressional briefing given Nov 2018
  - Coordination and planning efforts presented
  - DOT had yet to receive funds, transportation demonstration concept presented
  - DOD legislative affairs drafted FY20 NDAA extension to Dec 2020
- DHS Science and Technology conducted timing and positioning demonstration
  - Dec 2018 at NASA Langley/Insurance Institute for Highway Safety (IIHS) Ruckersville, VA
  - Technologies demonstrated: Locata, NextNav, Satelles (those already available at Langley)
  - Results and interim report in process
- DOT Volpe Center funded to execute demonstration (Jan’19 - Dec ’20)

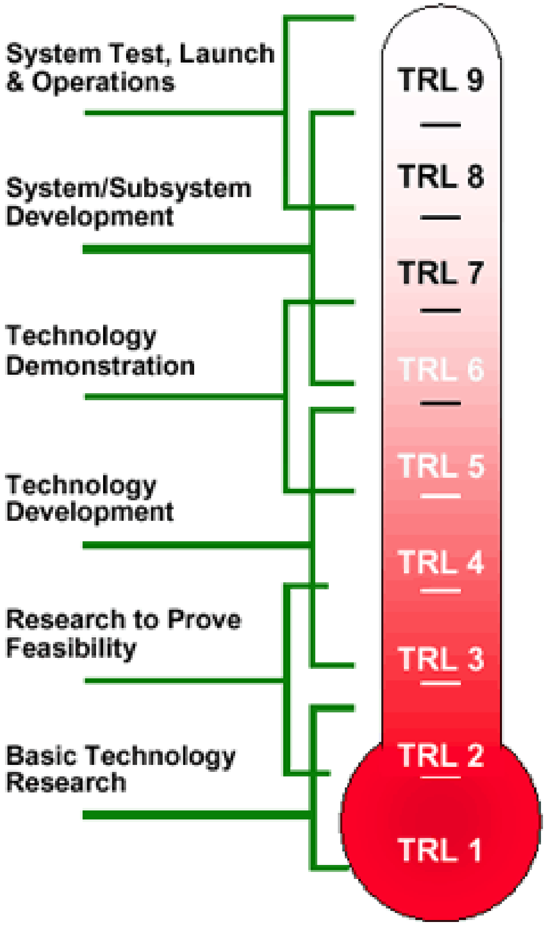
NDAA GPS Backup Demonstration

Demonstration Scope for FY18 NDAA

- Commercial services with a high Technical Readiness Level (TRL >6)
- Scenario based demonstration plan (agnostic of technology)
- Dynamic 2D/3D positioning, timing, varied service areas, and scenario durations
- Field teams across JBCC, NASA Langley, Wildwood, NJ, and FAA Tech Center

Demonstration Schedule

- ✓ DOT sponsored technology vendor round tables, Mar & Apr 2019
- ✓ Request For Information (RFI) conducted, Jun 2019
- ✓ Vendor engagement and rapid acquisition process for demo support, Aug 2019
- ✓ Contract award to technology vendors, Oct 2019
- ✓ Demonstration(s) at FAA Tech Center, JBCC, NASA Langley, & Wildwood, NJ, Mar 2020
- National Space-Based PNT EXCOM Recommendations: Aug 2020
- FY18 NDAA Report [coordination with DHS/DOD] to Congress after interagency review


System Test, Launch & Operations
System/Subsystem Development
Technology Demonstration
Technology Development
Research to Prove Feasibility
Basic Technology Research
TRL 9
TRL 8
TRL 7
TRL 6
TRL 5
TRL 4
TRL 3
TRL 2
TRL 1

DOT/Volpe Contracted Vendors

NEXTNAV

SKYHOOK

SEVEN Solutions

UrsaNav
Leaders in what's now. Innovators of what's next.

Satelles

ECHO RIDGE

serco & ALION

HELLEN systems

PHASORLAB
NEXT GENERATION WIRELESS TECHNOLOGIES

TRX systems

opnt.
TIME PROVISIONING

GPS Backup/Complementary PNT Demonstration

NASA Langley

Map Match	1	TRX
Terrestrial RF	2	NextNav, Skyhook
Satellite	1	Echo Ridge
Fiber Optic	2	OPNT & Seven Solutions

JBCC

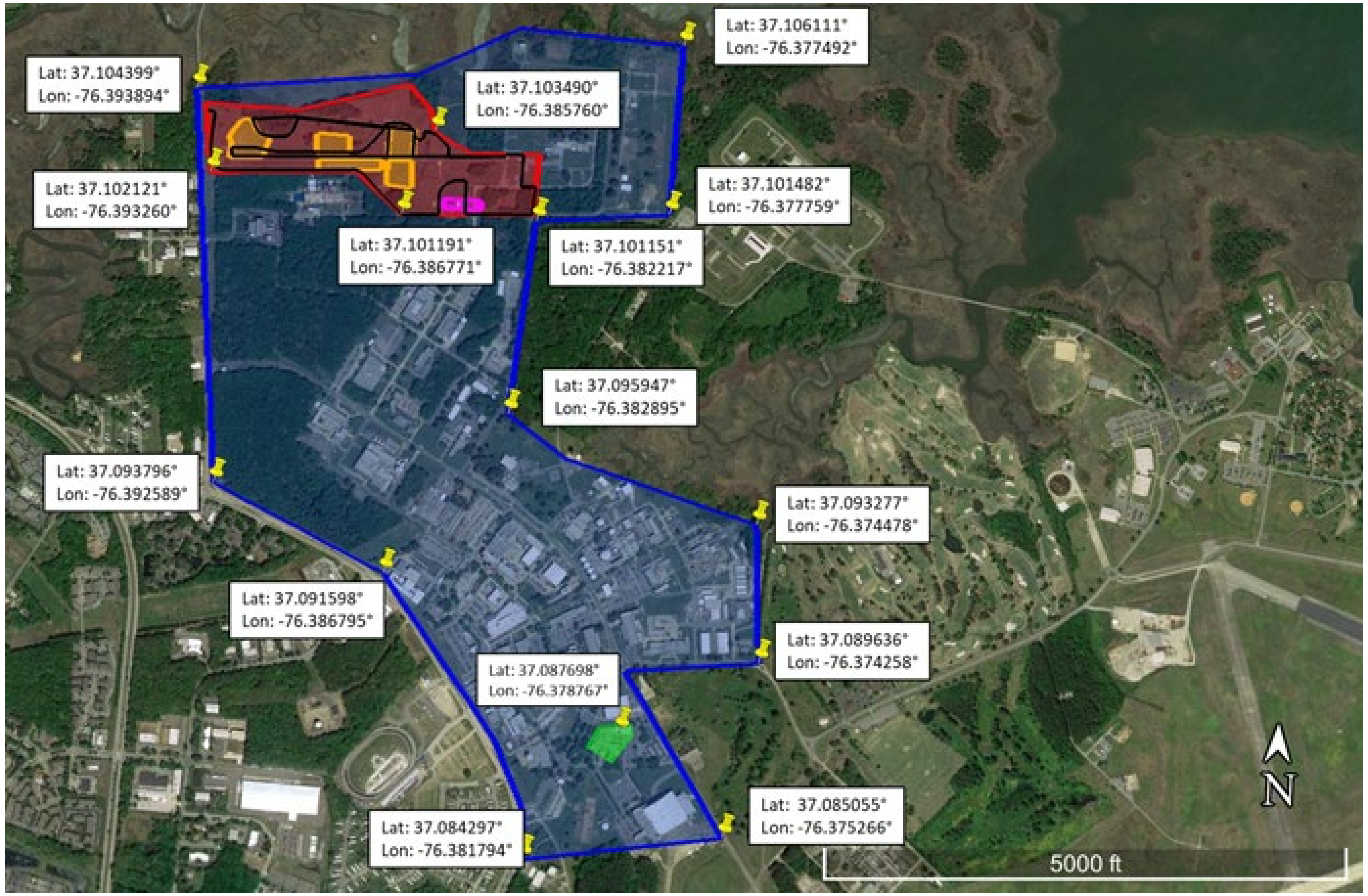
Map Match	0	
Terrestrial RF	4	Hellen Systems, UrsaNav, Serco, & Phasor Lab
Satellite	1	Satelles
Fiber Optic	0	

Demonstration Plan Detail

				Technologies							Demo Platforms				
				In Situ	Terrestrial RF				Satellite	Fiber Optic	Fixed		Moving		
VIP Demo	day	start	end	Map Match	LF (Loran)	MF (R-mode)	VHF (passive)	WiFI (2.4 GHz)	L-Band (LEO)	PTP	Outdoor	Indoor	Static	2D (van)	3D (uas)
LaRC	13-Mar	9:00	16:00	x			x	x	x	x	x	x	x	x	x
JBCC	20-Mar	9:00	16:00		x	x		x	x		x	x	x	x	x
			Vendors	TRX	Hellen Systems UrsaNav	Serco	NextNav	PhasorLab Skyhook	Echo Ridge Satelles	OPNT Seven Solutions					

GPS Backup Demonstration: Vendor Travel and Deliverables Schedule - Through Demonstration																						
	2019									2020												
Weeks from Award	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Week Start Date	4-Nov	11-Nov	18-Nov	25-Nov	2-Dec	9-Dec	16-Dec	23-Dec	30-Dec	6-Jan	13-Jan	20-Jan	27-Jan	3-Feb	10-Feb	17-Feb	24-Feb	2-Mar	9-Mar	16-Mar	23-Mar	30-Mar
Demonstration Site Visits			✱																			
Site Plan					★																	
UE Integration Verification					★ ✱																	
UE Hardware							★ ✱															
Vendor Technology Setup										▨	✱	★										
Dry Run														▨	✱	★						
Demonstration																		▨	✱	★		
✱= Travel ★ = Deliverable	Date of Award = November 4, 2019																					

NASA Langley Research Center Field Facility

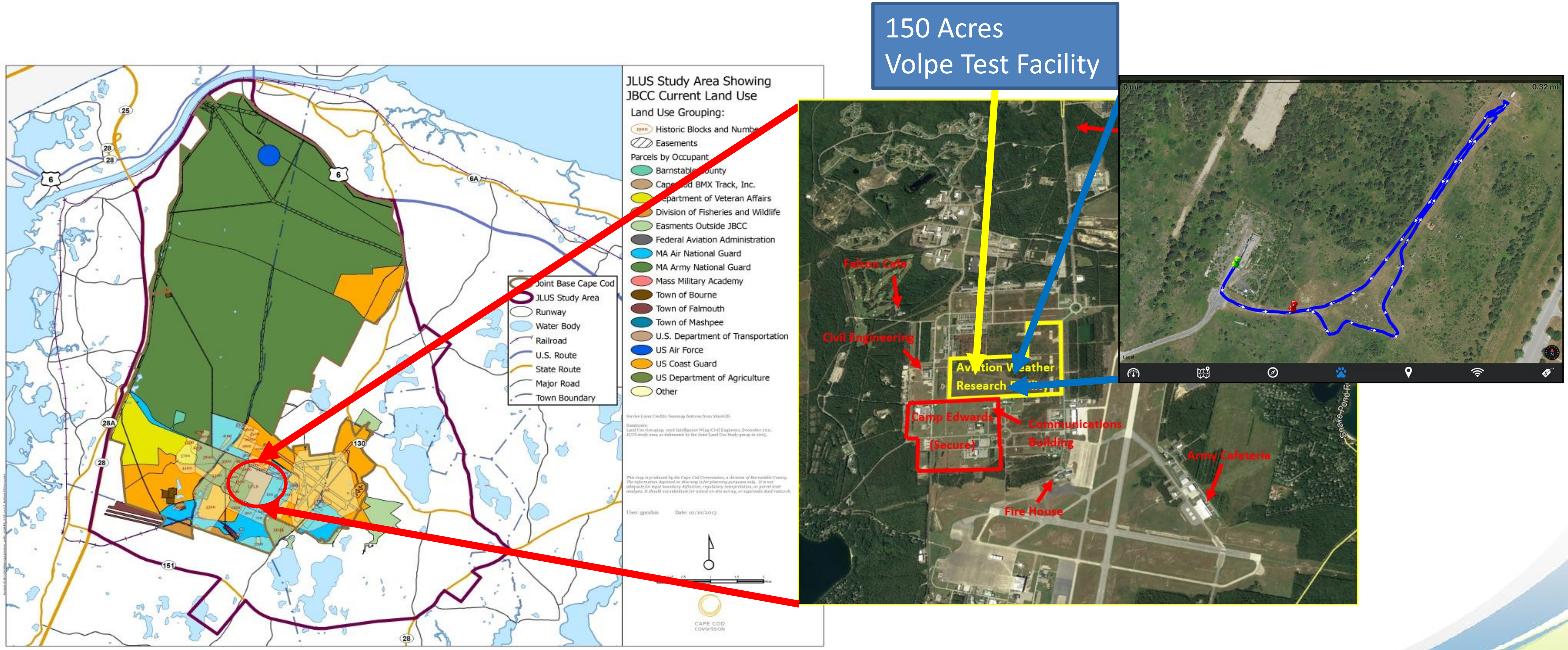


Lat: 37.104399° Lon: -76.393894°
Lat: 37.106111° Lon: -76.377492°
Lat: 37.103490° Lon: -76.385760°
Lat: 37.102121° Lon: -76.393260°
Lat: 37.101482° Lon: -76.377759°
Lat: 37.101191° Lon: -76.386771°
Lat: 37.101151° Lon: -76.382217°
Lat: 37.095947° Lon: -76.382895°
Lat: 37.093796° Lon: -76.392589°
Lat: 37.093277° Lon: -76.374478°
Lat: 37.091598° Lon: -76.386795°
Lat: 37.089636° Lon: -76.374258°
Lat: 37.087698° Lon: -76.378767°
Lat: 37.085055° Lon: -76.375266°
Lat: 37.084297° Lon: -76.381794°
N
5000 ft

- Black track used for static timing, static positioning, and dynamic positioning scenarios
- Orange areas used for static timing, static positioning, and dynamic UAS/3D positioning scenarios
- Magenta area (hangar) used for indoor timing and positioning scenarios
- The green area (test building, Lat: 37.087698, Lon: -76.378767) used for fixed and underground/degraded timing scenarios

2D & 3D Platform & Reference System NASA Langley Research Center

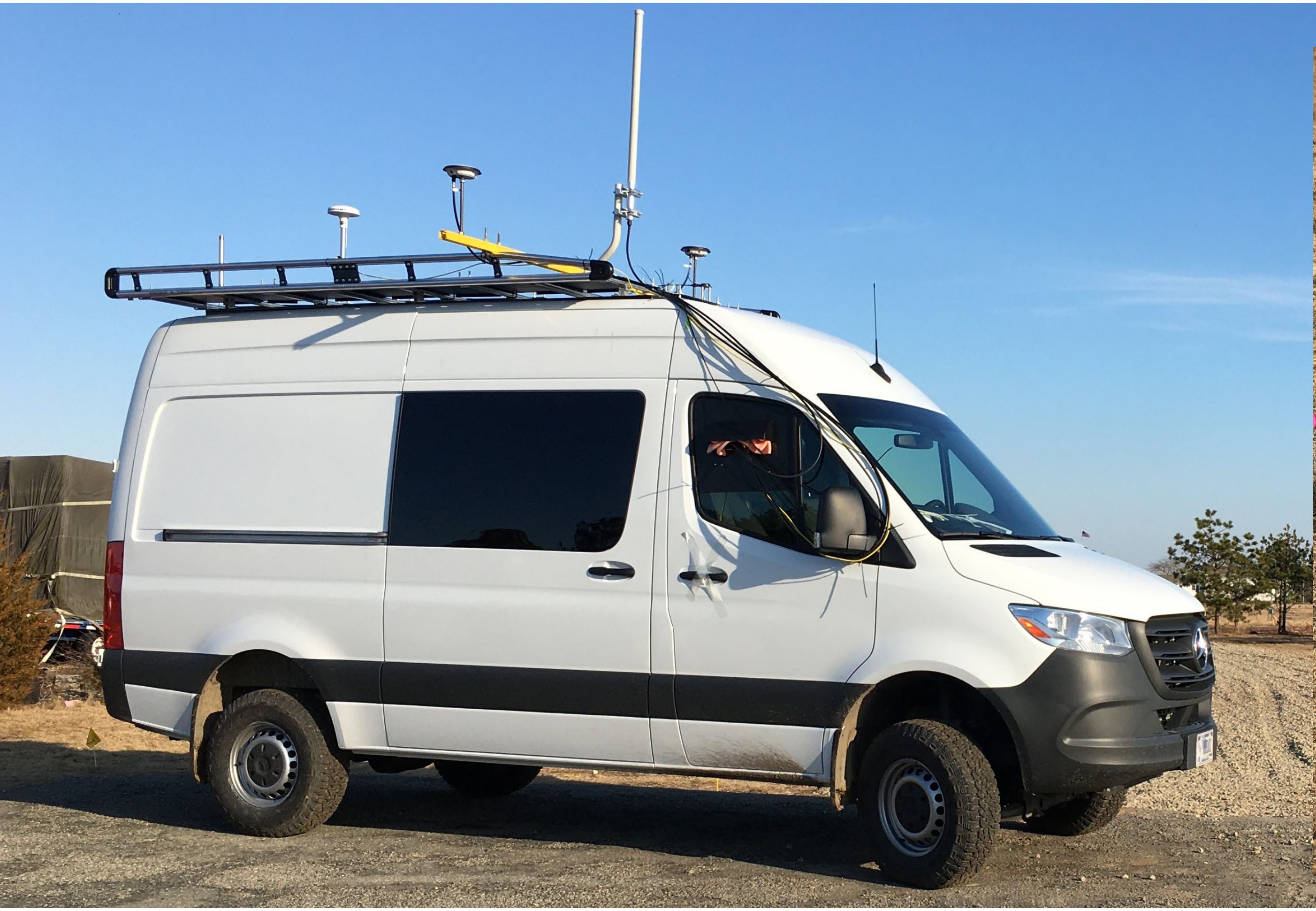
Joint Base Cape Cod (JBCC) DOT/Volpe Field Facility

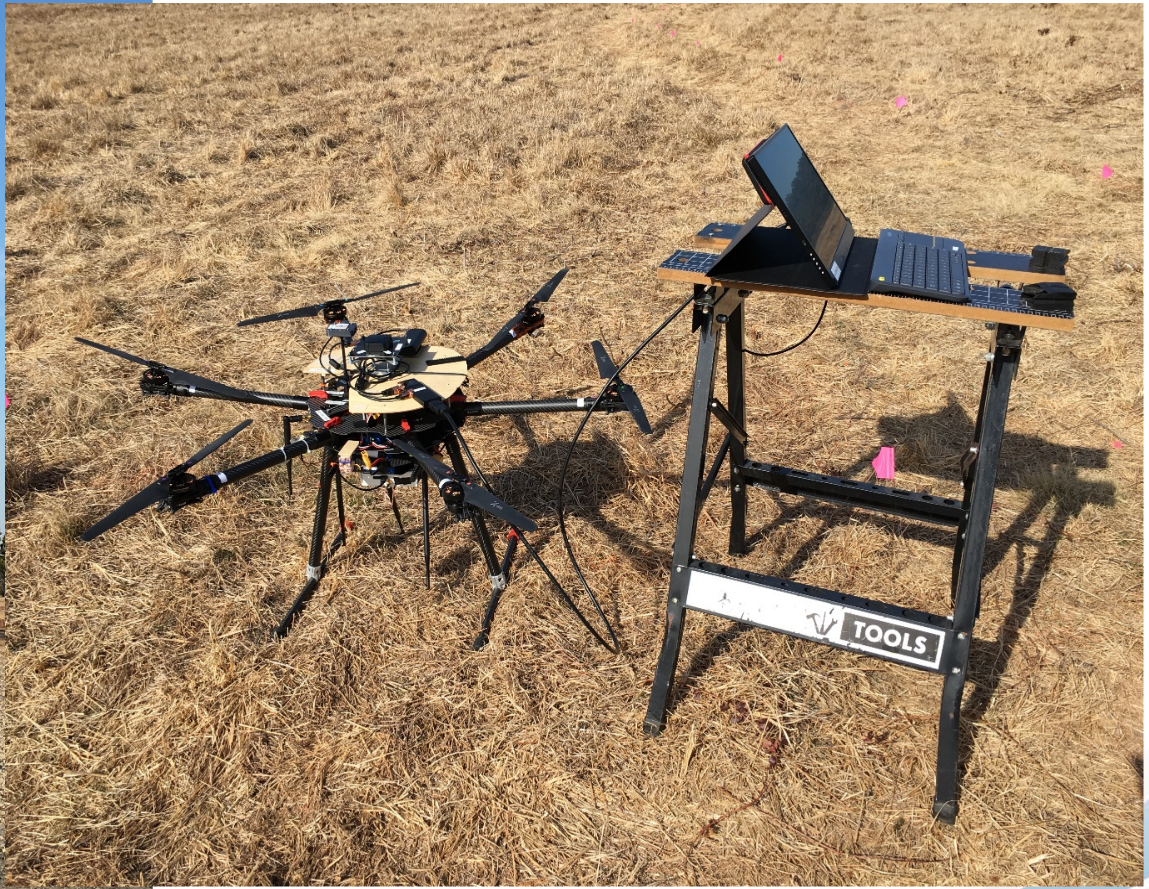


150 Acres
Volpe Test Facility

JLUS Study Area Showing
JBCC Current Land Use
Land Use Grouping:
1900 Historic Blocks and Numbe
Easements
Parcels by Occupant
Barnstable ounty
Cape od BMX Track, Inc.
epartment of Veteran Affairs
Division of Fisheries and Wildlife
Easments Outside JBCC
Federal Aviation Administration
MA Air National Guard
MA Army National Guard
Mass Military Academy
Town of Bourne
Town of Falmouth
Town of Mashpee
U.S. Department of Transportation
US Air Force
US Coast Guard
US Department of Agriculture
Other
Joint Base Cape Cod
JLUS Study Area
Runway
Water Body
Railroad
U.S. Route
State Route
Major Road
Town Boundary
Service Layer Credits: basemap features from MassGIS.
Datalayers:
Land Use Grouping: 102d Intelligence Wing/Civil Engineers, December 2011.
JLUS study area, as delineated by the Joint Land Use Study group in 2005.
This map is produced by the Cape Cod Commission, a division of Barnstable County. The information depicted on this map is for planning purposes only. It is not adequate for legal boundary definition, regulatory interpretation, or parcel level analysis. It should not substitute for actual on-site survey, or supersede deed research.
User: gprahm
Date: 10/10/2013
CAPE COD COMMISSION
25
28
28
6
6
6A
28A
28
130
151
28
Falcon Cafe
Civil Engineering
Aviation Weather Research
Camp Edwards (Secure)
Communications Building
Army Cafeteria
Fire House
Snake Pond
0 mi
0.32 mi
Legal

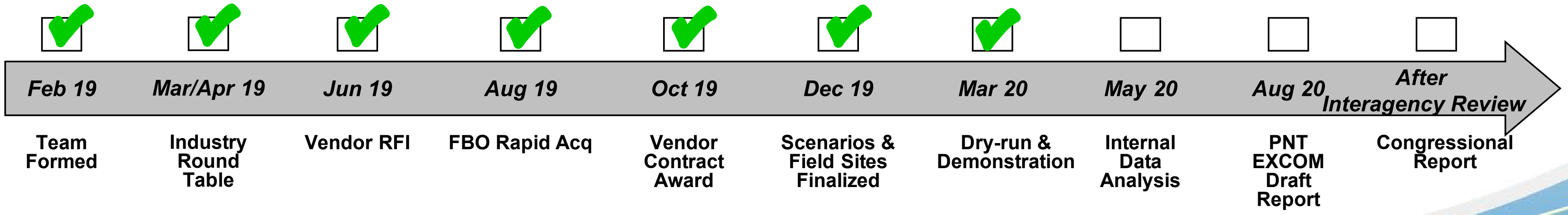
2D & 3D Platform & Reference System (JBCC)





NDAA GPS Backup/Complementary PNT Demonstration Work Plan

- Executed two acquisitions, three field campaigns, technology demonstrations, and preparing PNT performance analysis report
- Awarded *11* PNT vendor demonstration contracts on rapid acquisition purchase orders
- Demonstration output products:
  - Performance report with PNT roadmap and measures of effectiveness for DOT leadership
  - Draft PNT strategy guide and cross-departmental coordination for PNT EXCOM



☑	☑	☑	☑	☑	☑	☑	□	□	□
Feb 19	*Mar/Apr 19*	*Jun 19*	*Aug 19*	*Oct 19*	*Dec 19*	*Mar 20*	*May 20*	*Aug 20*	*After Interagency Review*
Team Formed	Industry Round Table	Vendor RFI	FBO Rapid Acq	Vendor Contract Award	Scenarios & Field Sites Finalized	Dry-run & Demonstration	Internal Data Analysis	PNT EXCOM Draft Report	Congressional Report

Executive Order 13905: Strengthening National Resilience Through Responsible Use of PNT Services - February 12, 2020

- **Purpose: Foster responsible use of PNT services by critical infrastructure owners and operators to strengthen national resilience**
- **Policy: Ensure disruption or manipulation of PNT services does not undermine reliability or efficiency of critical infrastructure**
  - Raise awareness of the extent to which critical infrastructure depends on PNT services
  - Ensure critical infrastructure can withstand disruption or manipulation of PNT services
  - Engage public and private sectors to promote responsible use of PNT services

Implementation: Nine point implementation framework

- DOC and Sector Specific Agencies (SSAs) to develop PNT Profiles—responsible usage aligned with standards, guidelines and requirements
- DoD/DHS/DOT to update Federal Radionavigation Plan with PNT Profiles
- DHS and SSAs to develop test plan against PNT service vulnerabilities and inform PNT Profile update
- DHS to coordinate with departments and agencies on contractual language for federal contracts the integrate or utilize PNT services
- Federal Acquisition Regulatory Council to incorporate PNT Profile contract language in FAR codes
- SSAs to update PNT Profiles biennially through DHS and report to White House Office of Science and Technology Policy (OSTP)
- DOT/DOE/DHS to engage with critical infrastructure owners and operators to evaluate responsible use of PNT services
- OSTP to develop national R&D plan for PNT services that are not dependent on GNSS and update quadrennially
- DOC to provide a GNSS independent source of UTC accessible to public and private sector

EO 13905 Timelines

Timelines and Coordination

- DOC Provision for Accessible UTC—180 days
- DHS/DOT/DOE Plan for Critical Infrastructure Engagement and Pilot Programs —180 days
- FAR Contractual Language Update with PNT Profiles—180 days
- OSTP R&D Plan for GNSS Independent PNT Service—1 year
- DOC/SSAs PNT Profiles—1 year, then biennial update
- DHS/SSAs PNT Service Test Plan on Vulnerabilities—1 year
- DHS/SSAs Report to OSTP on PNT Profile Adoption—1 year
- DoD/DHS/DOT Incorporation PNT Profiles to FRP--biennial

Questions?

QUESTIONS: Submit using the questions tab on the control panel located on the right side of your screen.

Moderator

Marc Weiss
Time & Frequency
Expert Consultant

Karen Van Dyke
PNT and
Spectrum Management
DOT

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May 20, 2020

WORKSHOP ON SYNCHRONIZATION AND TIMING SYSTEMS

Meinberg Technology Sponsor Presentation

Heiko Gerstung
Managing Director
Meinberg

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MEINBERG

The Synchronization Experts.

Universal Sync Solutions for Critical Network Infrastructures

Heiko Gerstung, Managing Director

vWSTS 2020

Introducing Meinberg

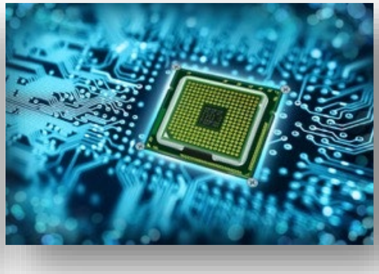
Founded in 1979

- HQ in Bad Pyrmont, Northern Germany
- Entirely Focused on Synchronization
- Global NTP & PTP Technology Leader
- Consistent Track Record of Growth

Meinberg – Global Leadership in Time Synchronization

Meinberg products synchronize a lot of critical infrastructure on this planet:

- Many of the top tier international stock exchanges and some of the largest banks and financial institutions
- Power grid control systems and substation automation networks in more than 80 countries
- Bleeding edge live TV production facilities and OB trucks
- Major mobile telecommunication networks providing voice and data services to tens of millions of customers
- Large scale communication networks in the defense domain as well as a lot of tactical networks on land-based, maritime and airborne platforms
- Radar and control center systems of several national of multinational air traffic control authorities



Meinberg Products – Three Main Platforms

M200

M300

LANTIME NTP Server

- Synchronize all systems which support NTP or SNTP
- Highly stable internal oscillator bridges periods of interference or temporary loss of synchronization signal
- Guarantees high accuracy at any time
- Can be individually configured
- Suitable for almost any application

IMS-M1000

IMS-M3000

IMS-Series

- Combines a universal Sync Core with application specific input and output interfaces
- Allows in-the-field upgrades and replacements with hot-swapping and hot-plugging support
- Almost no hardware dependencies allow uncounted combinations of interfaces and modules
- Unmatched scalability and future-proofness with zero or minimum costs for the end user

microSync^{HR}

microSync^{RX}

microSync-Series

- Compact and powerful IEEE 1588 PTP Time Server
- High performance (S)NTP server
- DIN rail, half rack and full rack solution for a space efficient design
- Different Oscillator options for advanced holdover performance
- Modern software architecture
- Meinberg Device Manager for configuration and status monitoring

Timing Security, Resilience and GNSS Issues

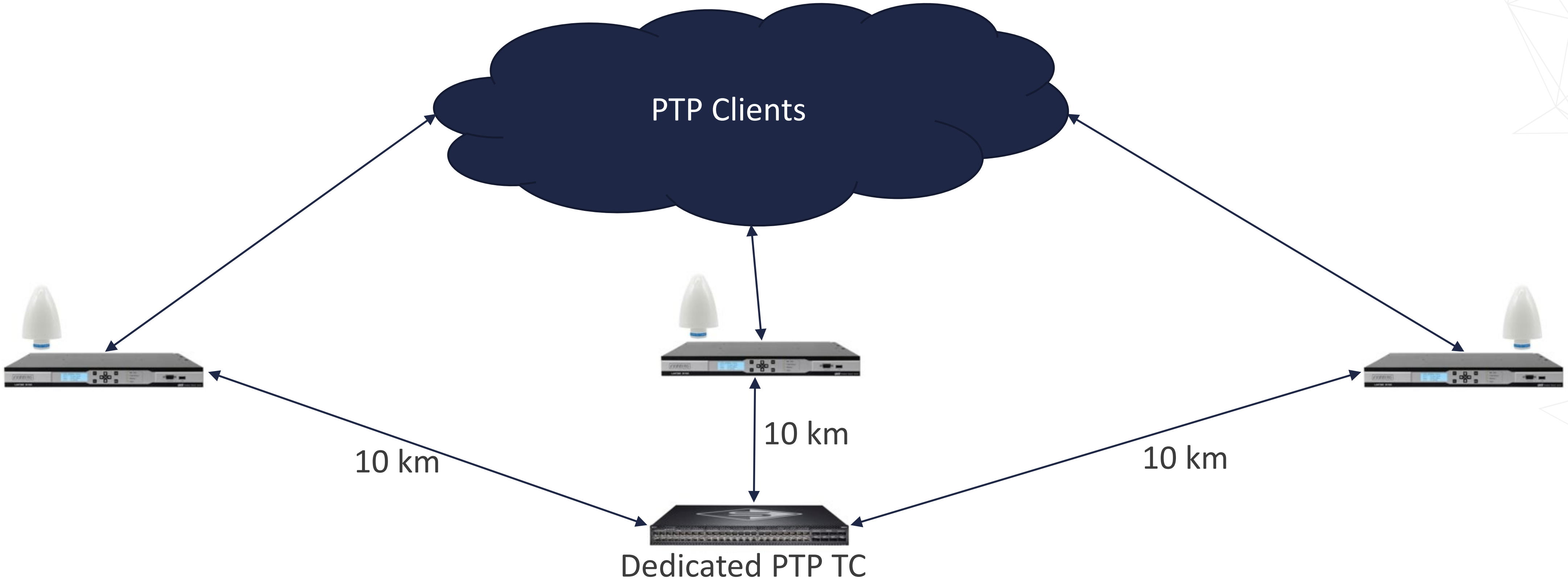
Multiple Strategies for Protecting GNSS and Other Timing Sources:

1. **Maximizing Holdover Capabilities**
   - Better Oscillators
   - External Atomic Clocks (Rubidium, Cesium, Hydrogen Maser)
2. **Implementing Consistency and Integrity Checks in GNSS Receiver Firmware**
3. **Support Multiple Sources and Compare Them**
   - Dual GNSS Receivers in a Chassis
   - PTP, NTP, IRIG
   - Serial Time Strings and PPS
4. **Use PTP to Connect Multiple Systems and Allow to Failover**
   - Comparison Allows to Detect Spoofing/Time Manipulation on One Device
5. **Trusted Reference Source (TRS)**
   - Use a Very Stable External Rubidium to Detect Anomalies in the GNSS and Ignore Them

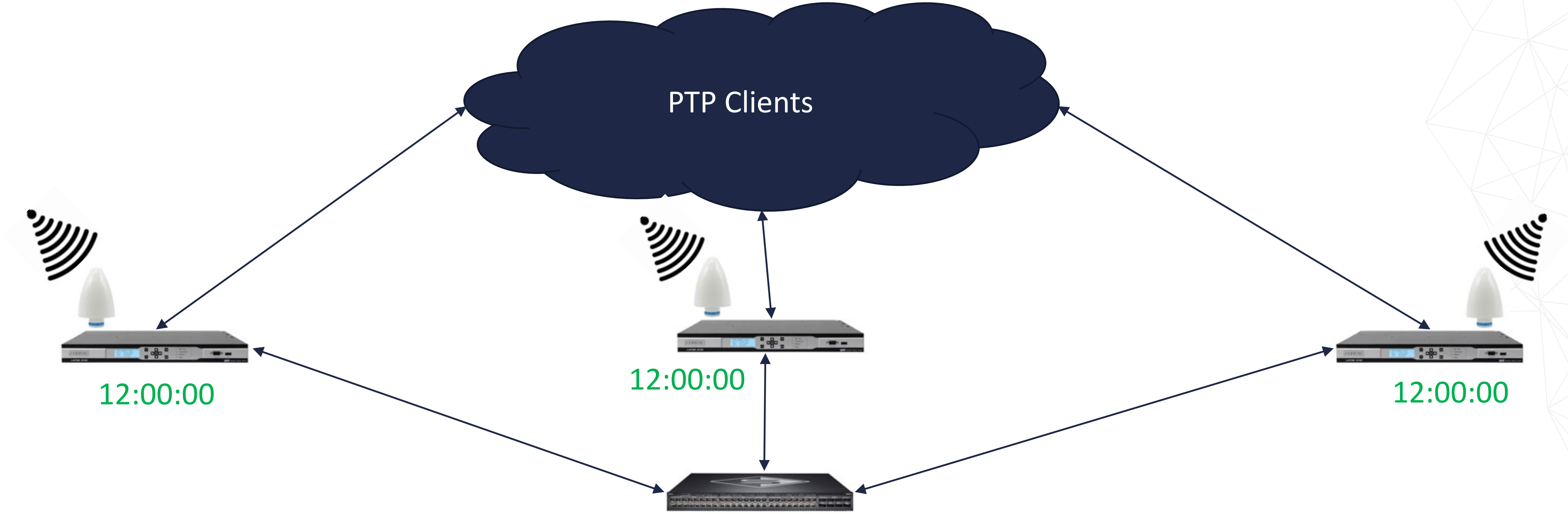
Timing Security, Resilience and GNSS Issues

Example: using PTP to connect multiple systems, detect spoofing and allow to failover

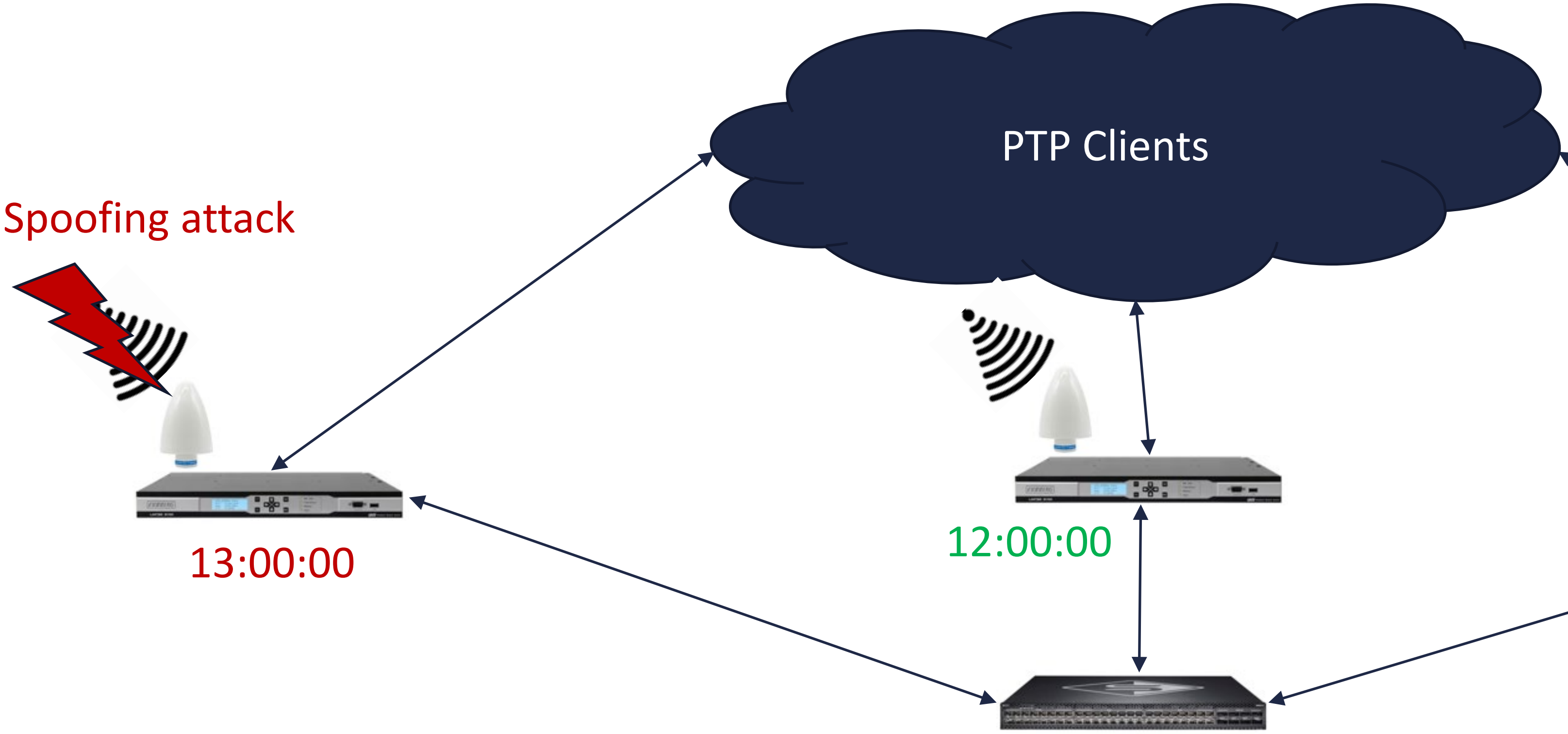
- System A, B and C connected via dedicated PTP network
- Comparison allows to detect spoofing/time manipulation on one device
- Using Single Mode Fiber means up to 10km distance between each device and the central switch



Timing Security, Resilience and GNSS Issues



Timing Security, Resilience and GNSS Issues



PTP Clients

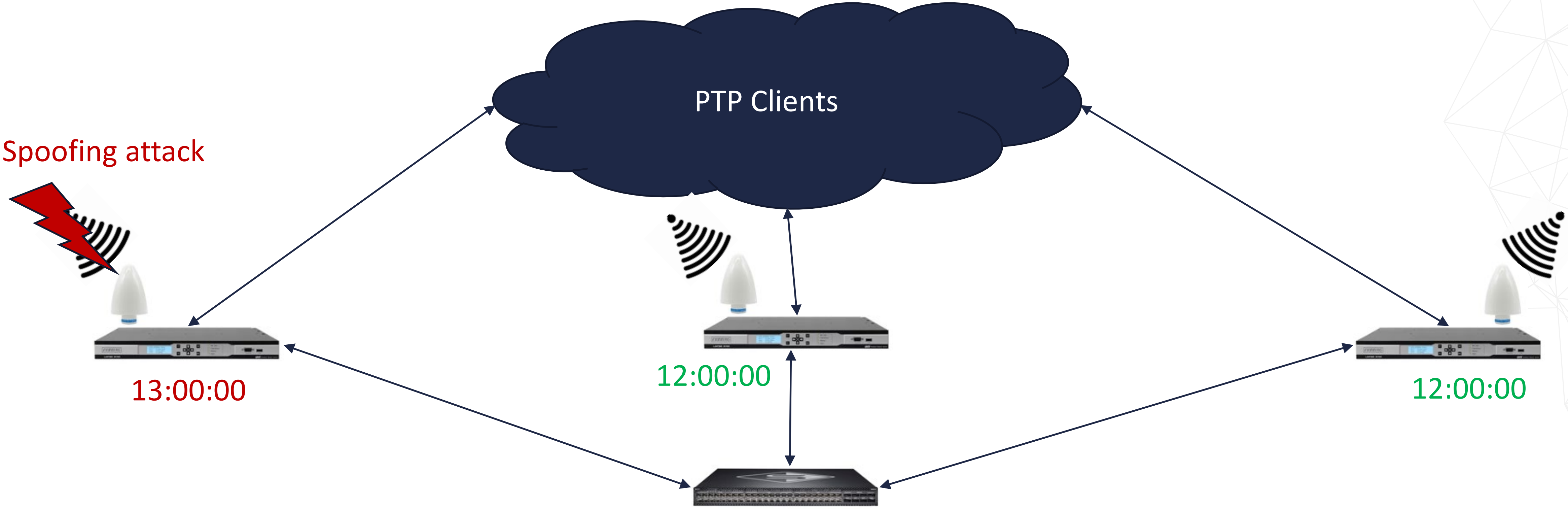
Spoofing attack

13:00:00

12:00:00

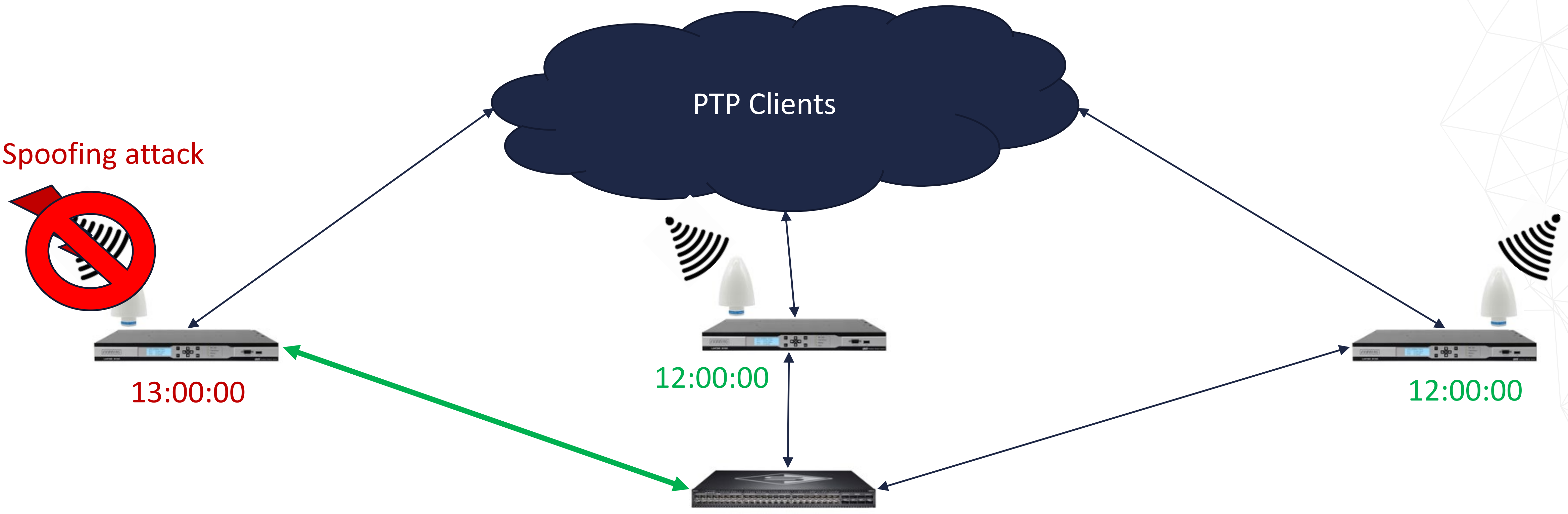
12:00:00

Timing Security, Resilience and GNSS Issues



Comparison shows outlier 13:00:00
Device A != B != C
Device B = C but != A
Device C = B but != A

Timing Security, Resilience and GNSS Issues



On Device A: disable GNSS and use PTP as fallback and send alarms to NOC/operators on A, B and C

Fallback can also be used to protect against jamming or other failures (antenna, constellation, etc.)

Meinberg Leadership – High Quality Combined with Expertise

- 40+ years of Experience in Synchronization
- Complete knowledge of trends and new requirements due to the broad market approach
- Participation in important standardization work and industry bodies

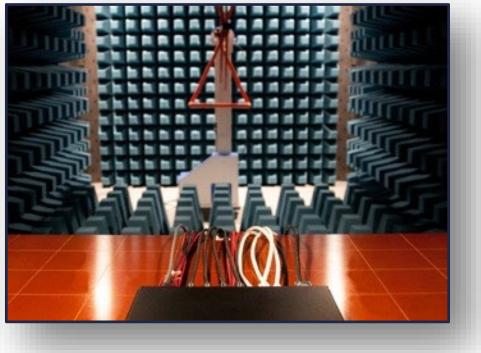
Manufacturing

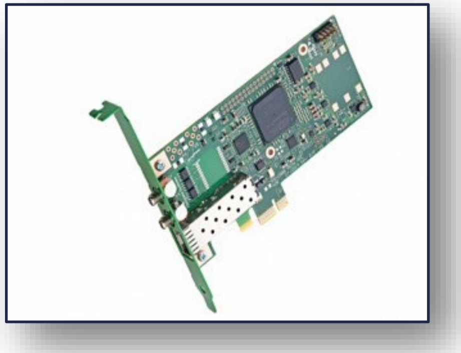
- Own in-house production facilities
- All products go through a full 7-day burn-in test procedure before being shipped to customers
- Integrated Optical Tests in Production plus multi-level functional tests (boards, modules, systems)

Global Subsidiaries

- Oregano Systems, a Meinberg Company in Vienna, Austria
- Meinberg USA Inc. in Santa Rosa, CA to serve and support US customers

Distributors and Partners in over 40 countries





Thank You!

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Time Security – The Winding Path to Deployment

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Director
Internet Trust and Technology
Internet Society

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Session 3: Timing Security, Resilience and GNSS Issues
May 20, 2020

WSTS – 20 May 2020

Time Security

The Winding Path to Deployment

Internet Society

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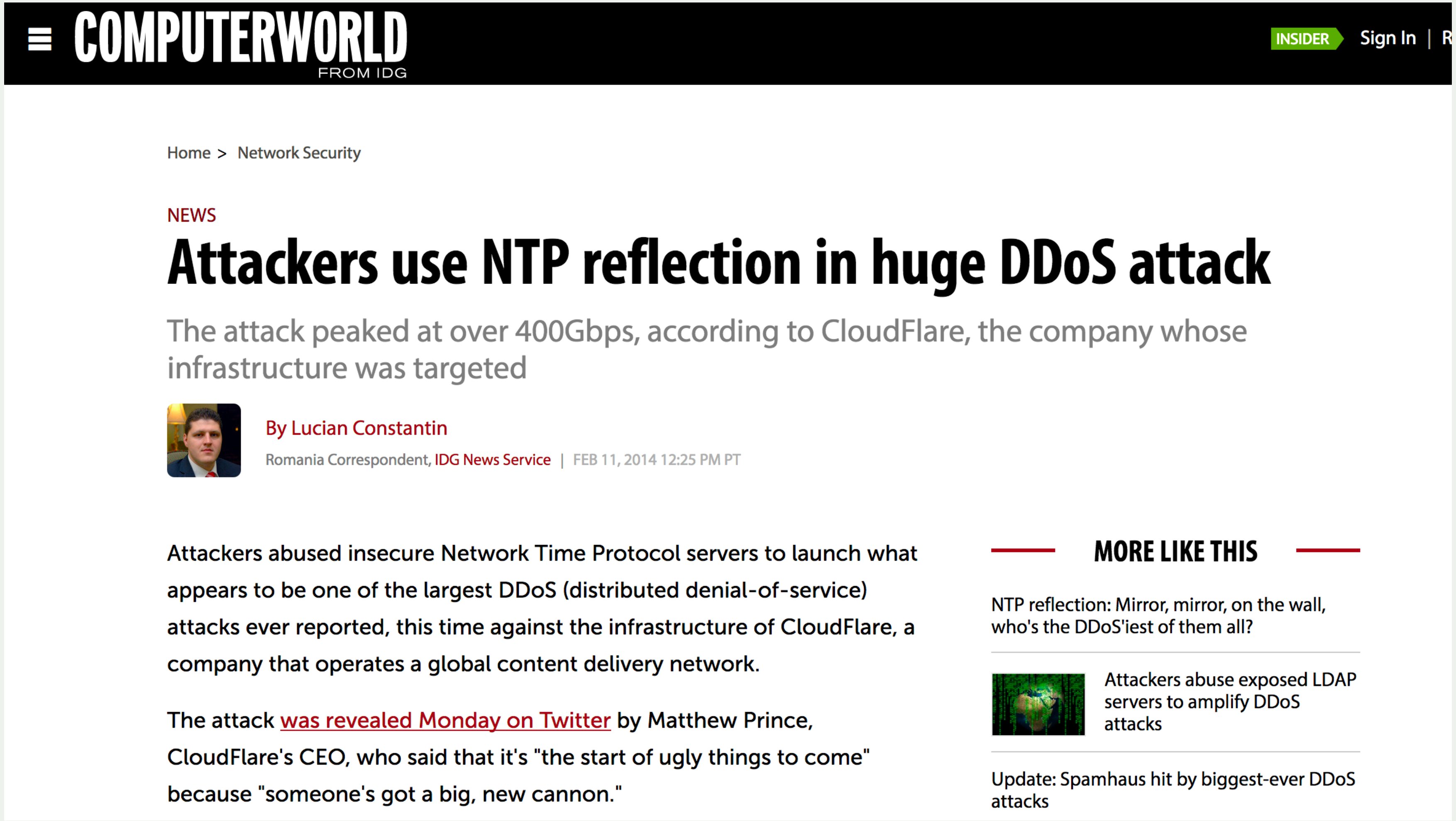
Time ⟷ Security

Security was historically not a high priority of the network time synchronization community…

- But this has changed...
  - Increasing interconnection and decentralization
  - Increasing evidence of the impact of inadequate security
  - Interdependency between security and time
  - Legal and Compliance requirements

Attacks are occurring…



COMPUTERWORLD
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Home > Network Security

NEWS

Attackers use NTP reflection in huge DDoS attack

The attack peaked at over 400Gbps, according to CloudFlare, the company whose infrastructure was targeted

By Lucian Constantin
Romania Correspondent, IDG News Service | FEB 11, 2014 12:25 PM PT

Attackers abused insecure Network Time Protocol servers to launch what appears to be one of the largest DDoS (distributed denial-of-service) attacks ever reported, this time against the infrastructure of CloudFlare, a company that operates a global content delivery network.

The attack was revealed Monday on Twitter by Matthew Prince, CloudFlare's CEO, who said that it's "the start of ugly things to come" because "someone's got a big, new cannon."

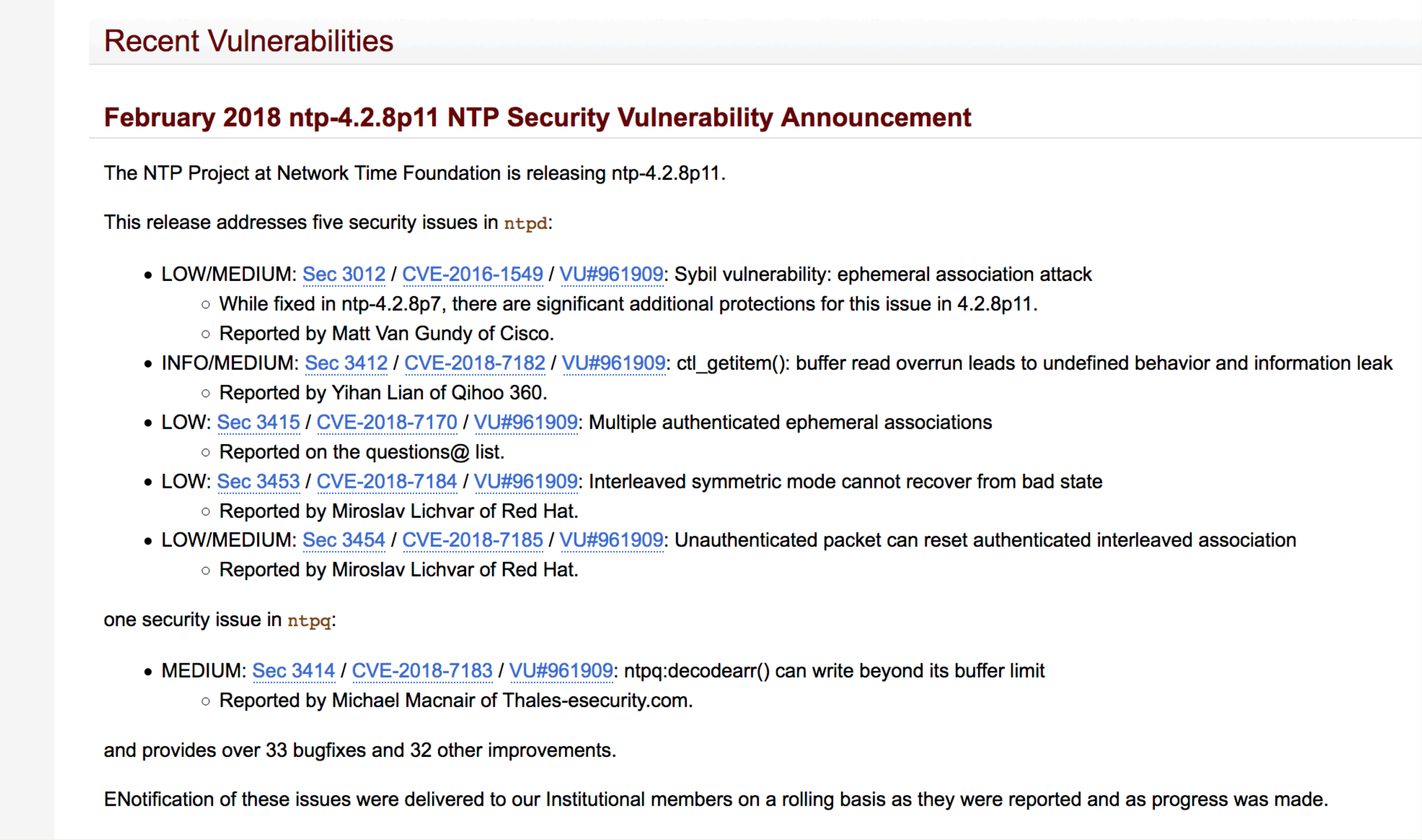
MORE LIKE THIS

NTP reflection: Mirror, mirror, on the wall, who's the DDoS'iest of them all?

Attackers abuse exposed LDAP servers to amplify DDoS attacks

Update: Spamhaus hit by biggest-ever DDoS attacks

Vulnerabilities are being discovered…



Recent Vulnerabilities

February 2018 ntp-4.2.8p11 NTP Security Vulnerability Announcement

The NTP Project at Network Time Foundation is releasing ntp-4.2.8p11.

This release addresses five security issues in `ntpd`:

- LOW/MEDIUM: Sec 3012 / CVE-2016-1549 / VU#961909: Sybil vulnerability: ephemeral association attack
  - While fixed in ntp-4.2.8p7, there are significant additional protections for this issue in 4.2.8p11.
  - Reported by Matt Van Gundy of Cisco.
- INFO/MEDIUM: Sec 3412 / CVE-2018-7182 / VU#961909: ctl_getitem(): buffer read overrun leads to undefined behavior and information leak
  - Reported by Yihan Lian of Qihoo 360.
- LOW: Sec 3415 / CVE-2018-7170 / VU#961909: Multiple authenticated ephemeral associations
  - Reported on the questions@ list.
- LOW: Sec 3453 / CVE-2018-7184 / VU#961909: Interleaved symmetric mode cannot recover from bad state
  - Reported by Miroslav Lichvar of Red Hat.
- LOW/MEDIUM: Sec 3454 / CVE-2018-7185 / VU#961909: Unauthenticated packet can reset authenticated interleaved association
  - Reported by Miroslav Lichvar of Red Hat.

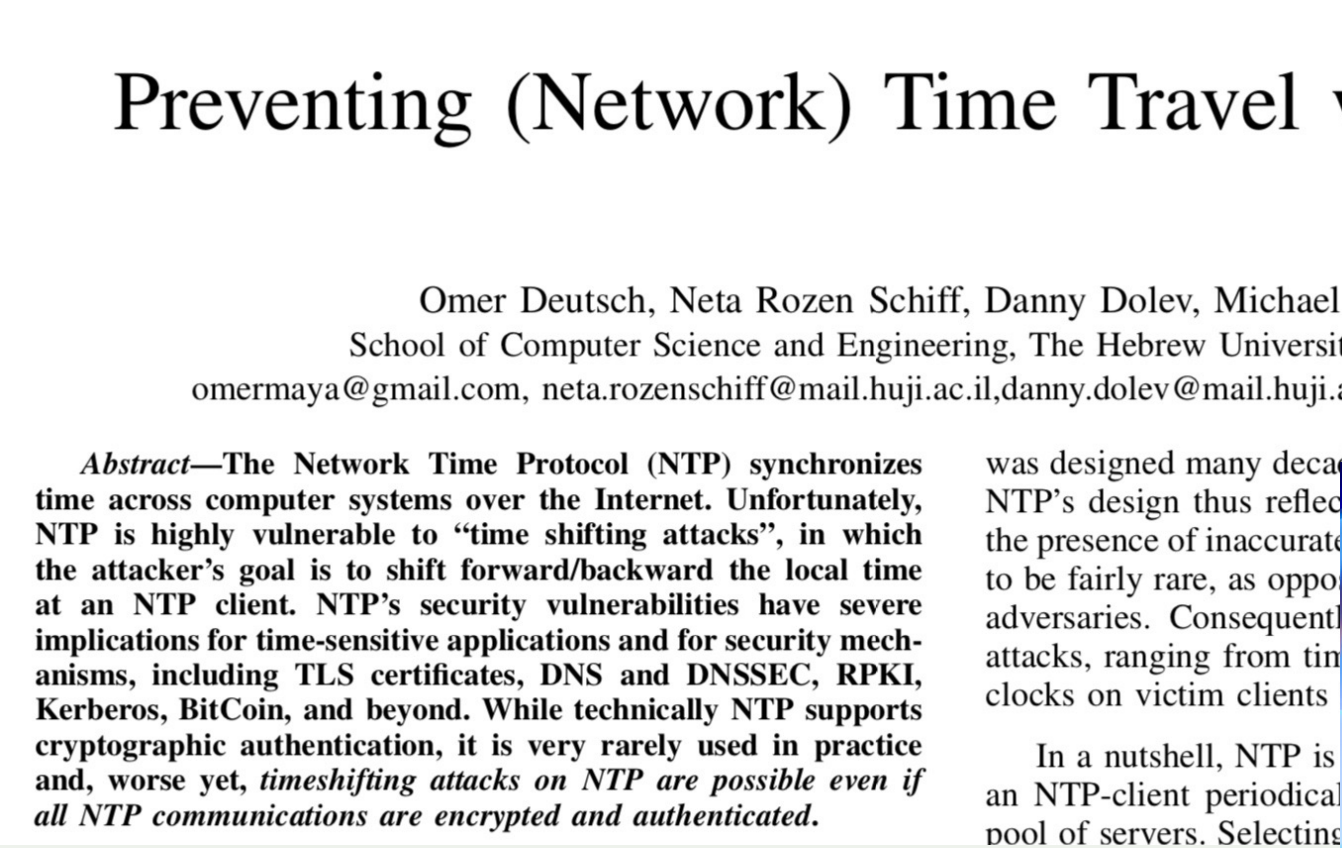
one security issue in `ntpq`:

- MEDIUM: Sec 3414 / CVE-2018-7183 / VU#961909: ntpq:decodearr() can write beyond its buffer limit
  - Reported by Michael Macnair of Thales-esecurity.com.

and provides over 33 bugfixes and 32 other improvements.

ENotification of these issues were delivered to our Institutional members on a rolling basis as they were reported and as progress was made.

Research is occurring…



Preventing (Network) Time Travel with Chronos

Omer Deutsch, Neta Rozen Schiff, Danny Dolev, Michael Schapira
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Abstract**—The Network Time Protocol (NTP) synchronizes time across computer systems over the Internet. Unfortunately, NTP is highly vulnerable to "time shifting attacks", in which the attacker's goal is to shift forward/backward the local time at an NTP client. NTP's security vulnerabilities have severe implications for time-sensitive applications and for security mechanisms, including TLS certificates, DNS and DNSSEC, RPKI, Kerberos, BitCoin, and beyond. While technically NTP supports cryptographic authentication, it is very rarely used in practice and, worse yet, *timeshifting attacks on NTP are possible even if all NTP communications are encrypted and authenticated.***

was designed many decades ago and without security in mind.
NTP's design thus reflec
the presence of inaccurate
to be fairly rare, as oppo
adversaries. Consequentl
attacks, ranging from tim
clocks on victim clients

In a nutshell, NTP is
an NTP-client periodical
pool of servers. Selecting

Paper from NDSS 2018. (https://www.ndss-symposium.org/ndss2018/programme/#02A

Image courtesy of Wes Hardaker

Multiple causes of these security problems…

Flaws in configuration and implementation

Weaknesses in the actual protocol itself

Lack of adequate security mechanisms

And yet…

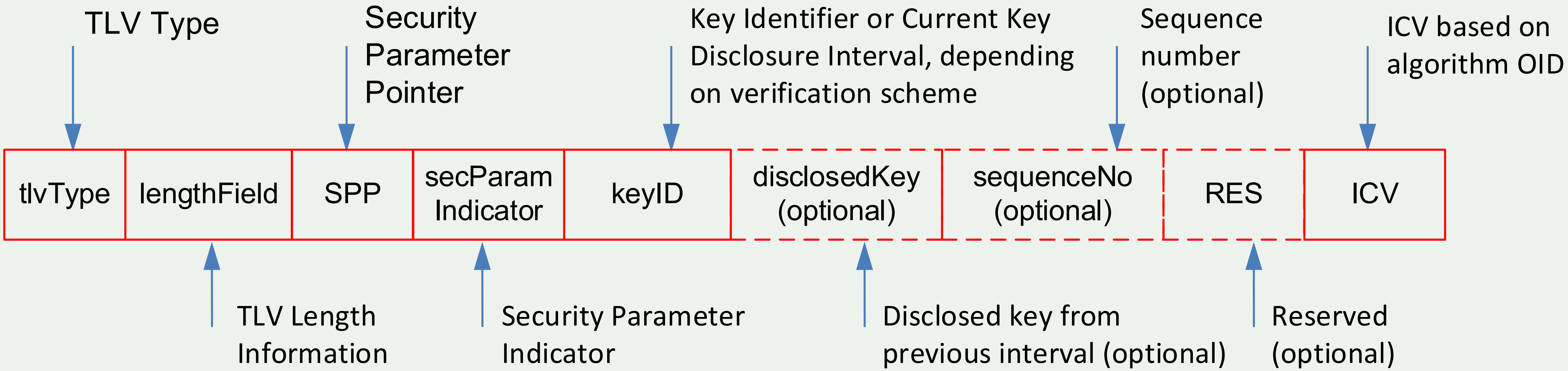
We had not had an updated specification for time synchronization security in 8+ years.

Until 2020!

IEEE approach to the problem…

- PTP Integrated Security Mechanisms (Prong A)
- External Transport Security Mechanisms (Prong B)
- Architecture Guidance (Prong C)
- Monitoring and Management Guidance (Prong D)

IEEE PTP Integrated Security Mechanism (Prong A) – The AUTHENTICATION TLV



TLV Type

Security Parameter Pointer

Key Identifier or Current Key Disclosure Interval, depending on verification scheme

Sequence number (optional)

ICV based on algorithm OID

tlvType	lengthField	SPP	secParam Indicator	keyID	disclosedKey (optional)	sequenceNo (optional)	RES	ICV

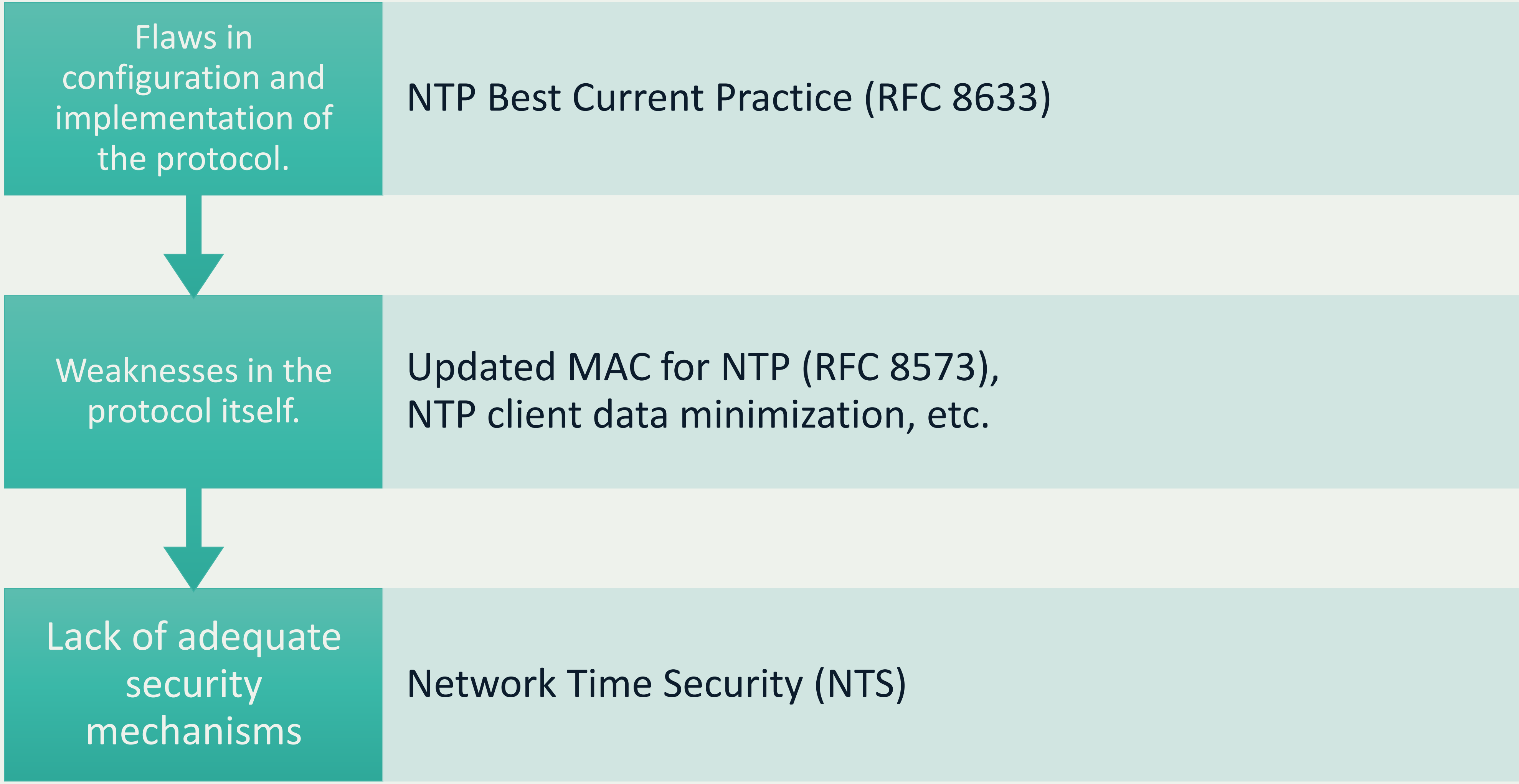
TLV Length Information

Security Parameter Indicator

Disclosed key from previous interval (optional)

Reserved (optional)

IETF approach to the problem…



Flaws in configuration and implementation of the protocol.

NTP Best Current Practice (RFC 8633)

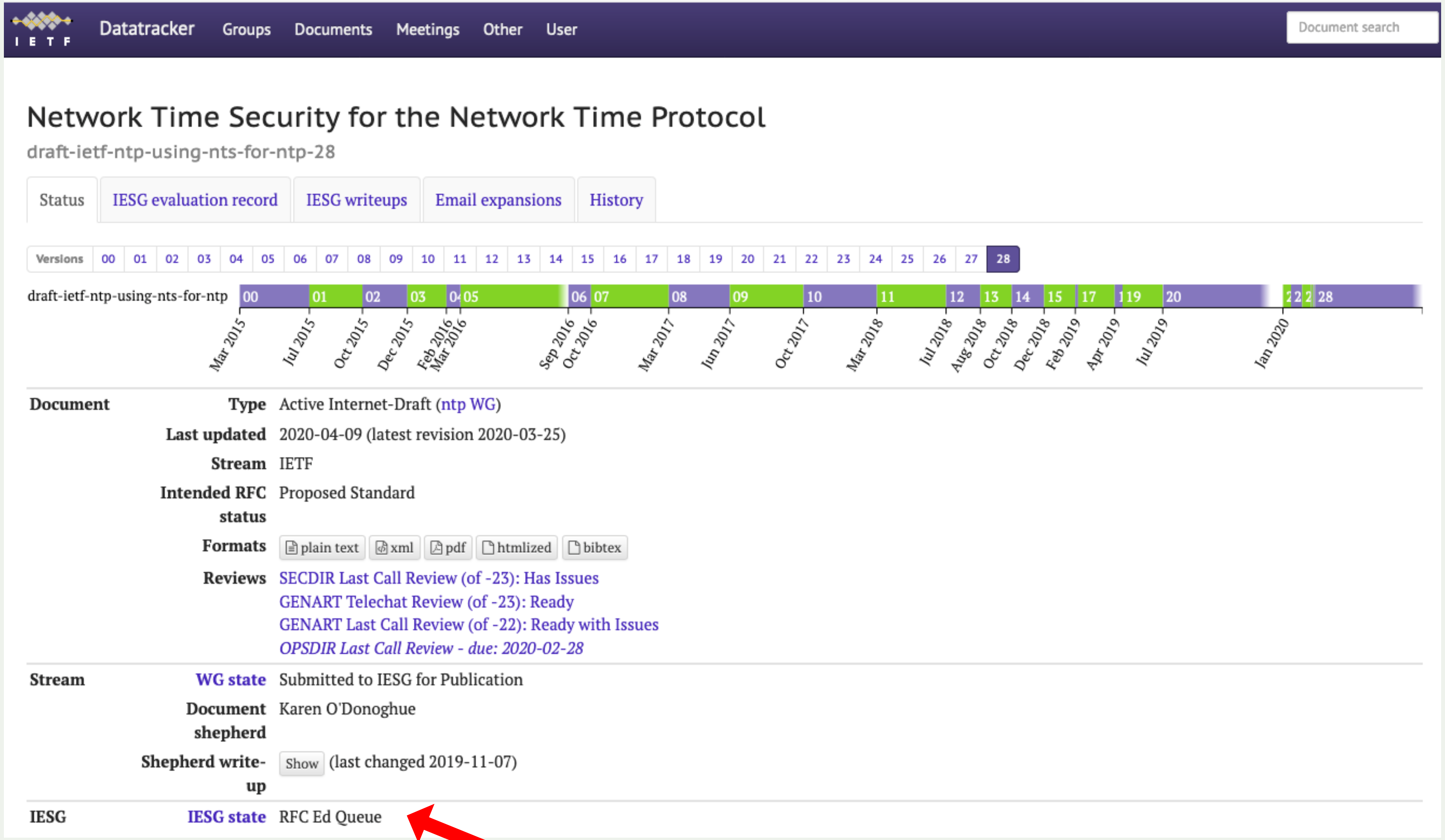
Weaknesses in the protocol itself.

Updated MAC for NTP (RFC 8573),
NTP client data minimization, etc.

Lack of adequate security mechanisms

Network Time Security (NTS)

Network Time Security (NTS)



Network Time Security for the Network Time Protocol

draft-ietf-ntp-using-nts-for-ntp-28

Versions	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28

Document	**Type**	Active Internet-Draft (ntp WG)
	Last updated	2020-04-09 (latest revision 2020-03-25)
	Stream	IETF
	Intended RFC status	Proposed Standard
	Formats	plain text xml pdf htmlized bibtex
	Reviews	SECDIR Last Call Review (of -23): Has Issues GENART Telechat Review (of -23): Ready GENART Last Call Review (of -22): Ready with Issues *OPSDIR Last Call Review - due: 2020-02-28*
Stream	**WG state**	Submitted to IESG for Publication
	Document shepherd	Karen O'Donoghue
	Shepherd write-up	Show (last changed 2019-11-07)
IESG	**IESG state**	RFC Ed Queue

NTS Approved by IESG in March 2020!

Basic phases of NTS secured NTP

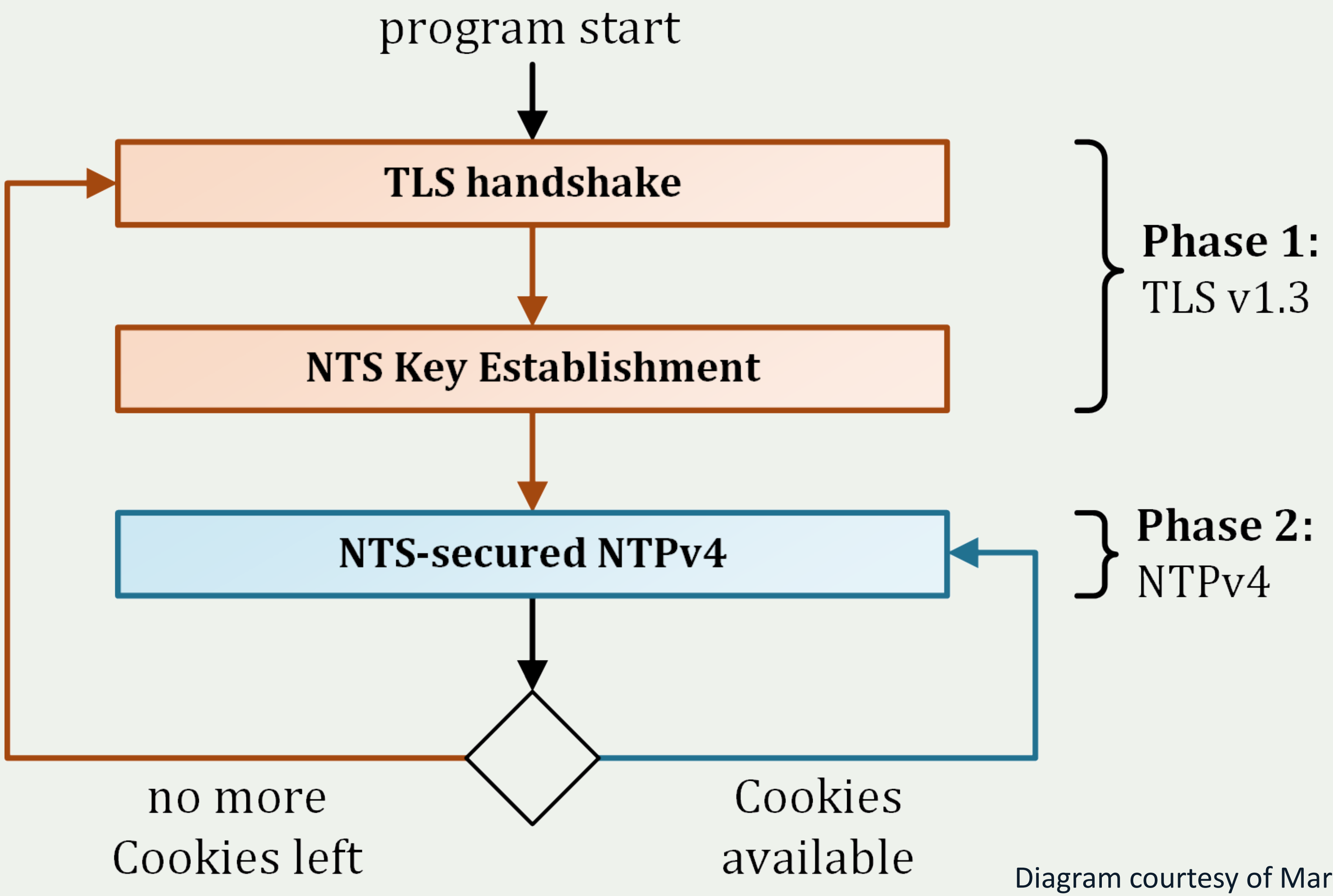


Diagram courtesy of Martin Langer, Ph.D. student, Ostfalia University of Applied Sciences, Germany.

NTS secured NTP system components

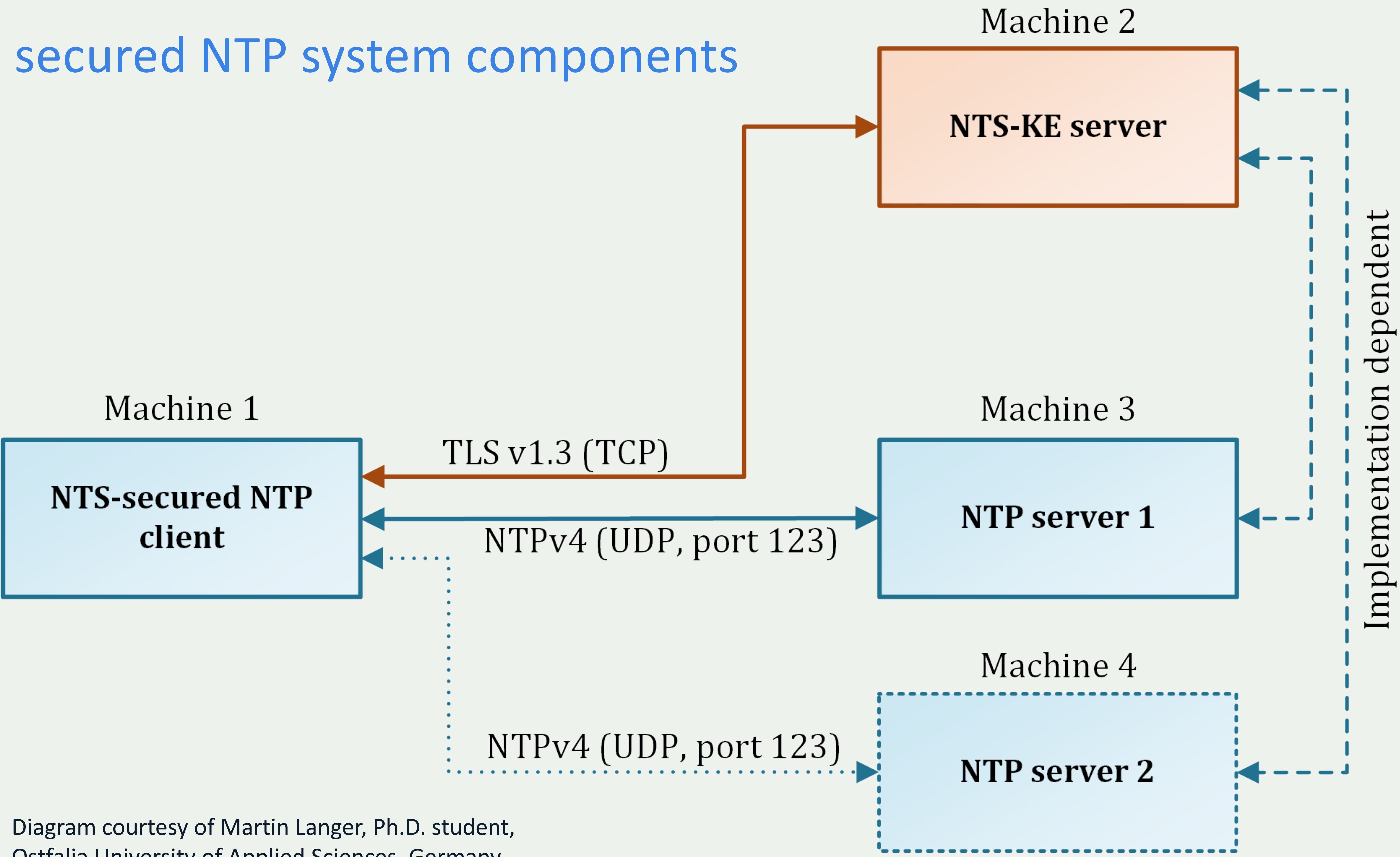
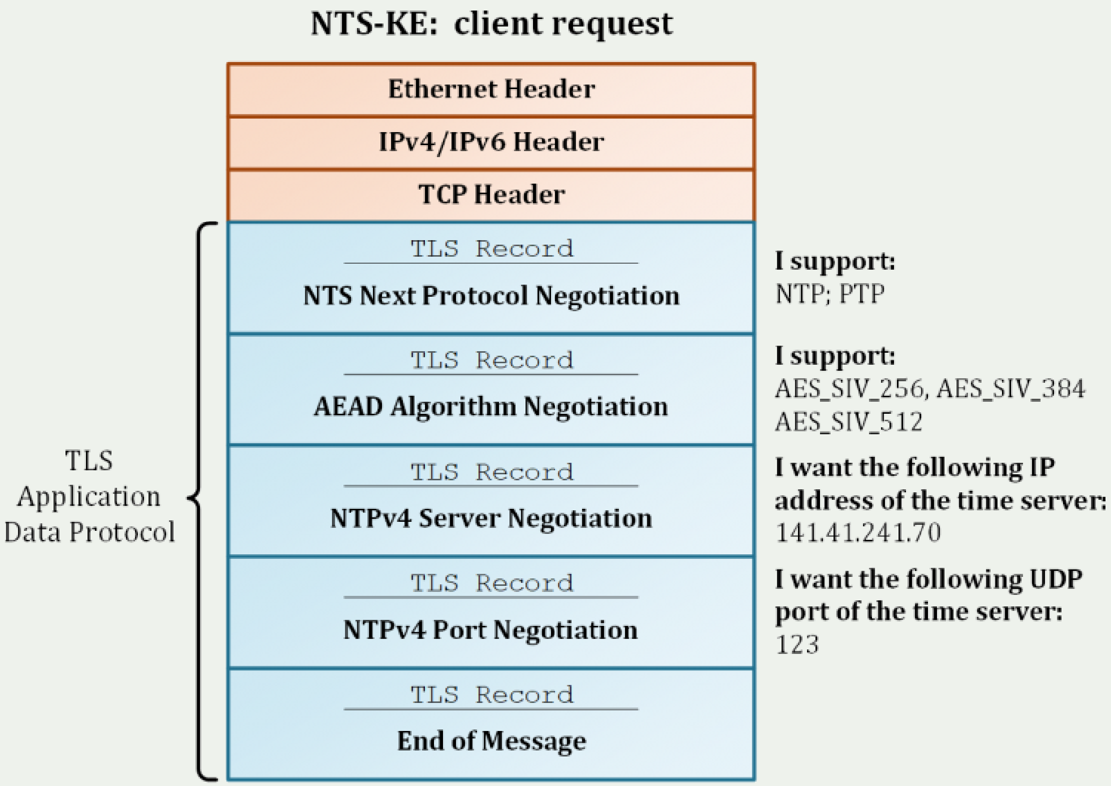


Diagram courtesy of Martin Langer, Ph.D. student,
Ostfalia University of Applied Sciences, Germany.

NTS Key Exchange phase



NTS-KE: client request

Ethernet Header

IPv4/IPv6 Header

TCP Header

TLS Application Data Protocol

TLS Record
NTS Next Protocol Negotiation

I support:
NTP; PTP

TLS Record
AEAD Algorithm Negotiation

I support:
AES_SIV_256, AES_SIV_384
AES_SIV_512

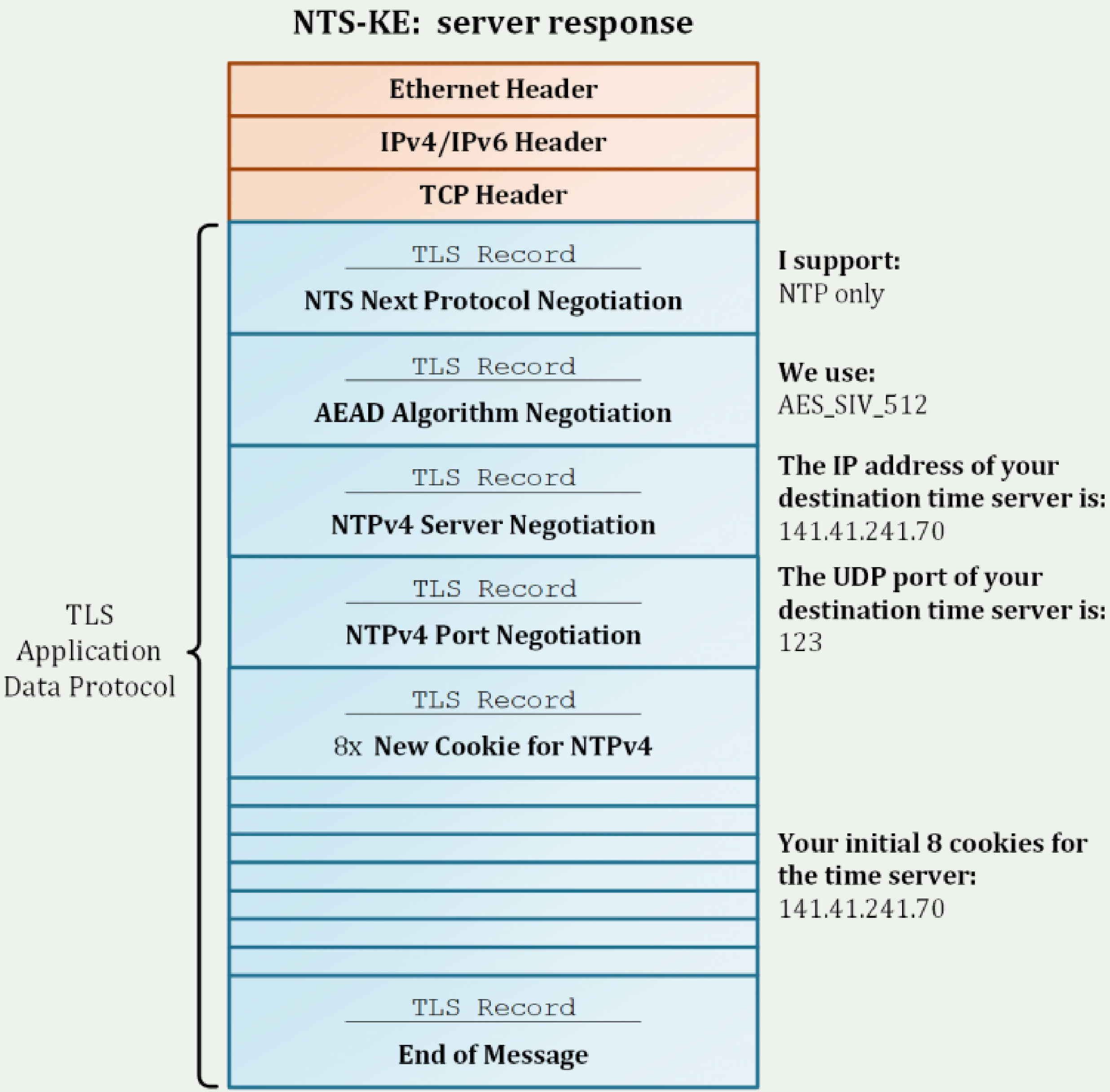
TLS Record
NTPv4 Server Negotiation

I want the following IP address of the time server:
141.41.241.70

TLS Record
NTPv4 Port Negotiation

I want the following UDP port of the time server:
123

TLS Record
End of Message



NTS-KE: server response

Ethernet Header

IPv4/IPv6 Header

TCP Header

TLS Application Data Protocol

TLS Record
NTS Next Protocol Negotiation

I support:
NTP only

TLS Record
AEAD Algorithm Negotiation

We use:
AES_SIV_512

TLS Record
NTPv4 Server Negotiation

The IP address of your destination time server is:
141.41.241.70

TLS Record
NTPv4 Port Negotiation

The UDP port of your destination time server is:
123

TLS Record
8x New Cookie for NTPv4

Your initial 8 cookies for the time server:
141.41.241.70

TLS Record
End of Message

Diagram courtesy of Martin Langer, Ph.D. student,
Ostfalia University of Applied Sciences, Germany.

NTS Extension Fields for NTP

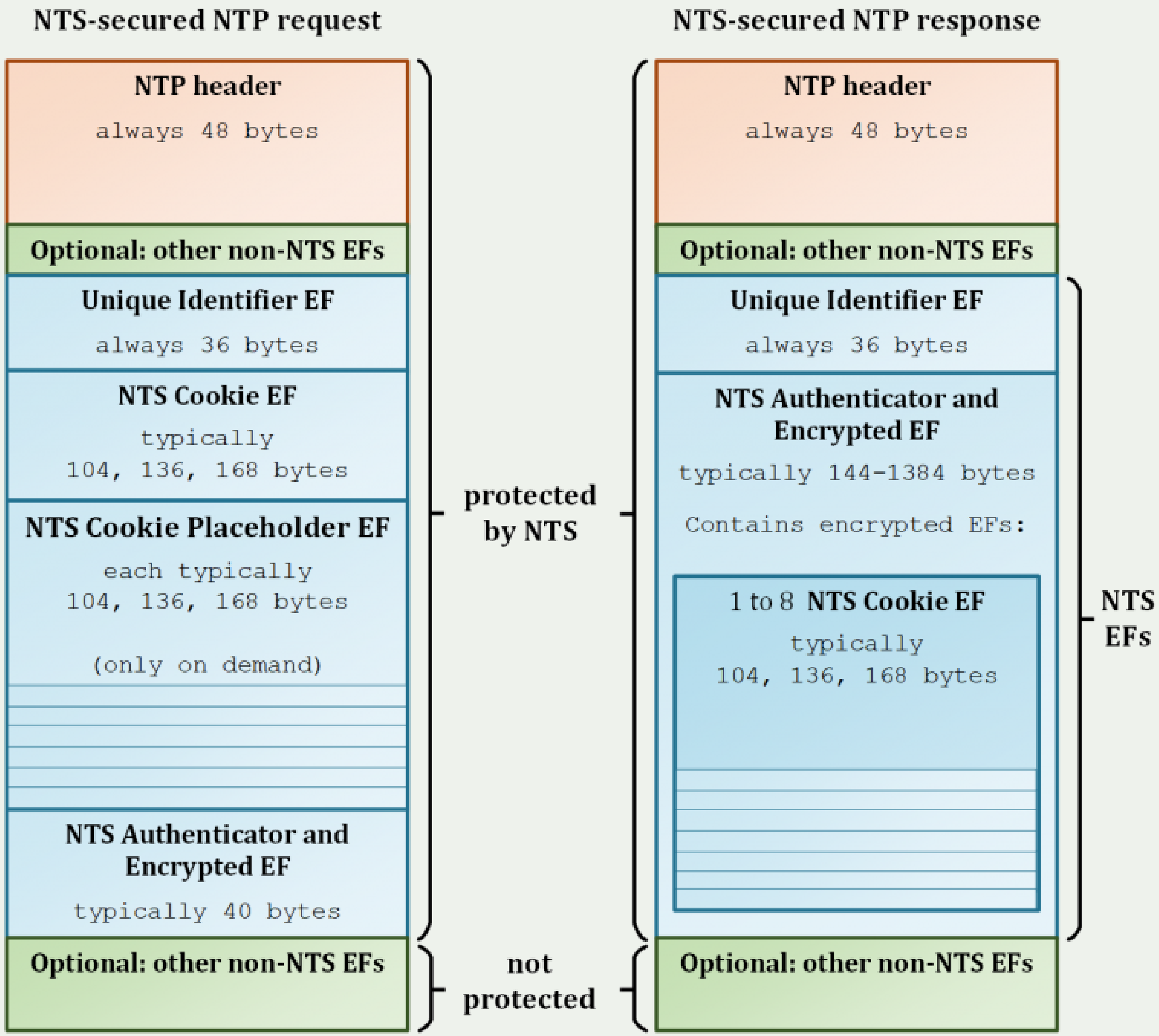


Diagram courtesy of Martin Langer, Ph.D. student, Ostfalia University of Applied Sciences, Germany.

Recent basic interoperability testing

IETF 104/105 Hackathon results						
	NTS/NTP server					
		Ostfalia	**NTPsec**	**Chrony**	**Netnod**	**Cloudflare**
NTP/NTS client	**Ostfalia**	works	works	works	works	break
	NTPsec	works	works	works	works	works
	Chrony	works	works	works	works	works
	Netnod	works	works	works	works	---
	Cloudflare	cert issues	works	break	works	works

Note: This table represents the results of two specific test event and may not reflect current operational status.

It's time to focus on the road to deployment…

- Technology / Standards Development
- Preliminary / Prototype Implementations
- Interoperability Testing ←
- Production quality open source implementations
- Commercial products
- Tools for testing and troubleshooting
- Preliminary deployments
- Lessons Learned and Best Practices
- Large scale deployments

Internet Society Time Security Project

Building a community

- Network operators
- Time service providers
- Enterprise IT groups

Maturing the products

- Distributed multi-party testbed
- Virtual test events
- Test and measurement tools

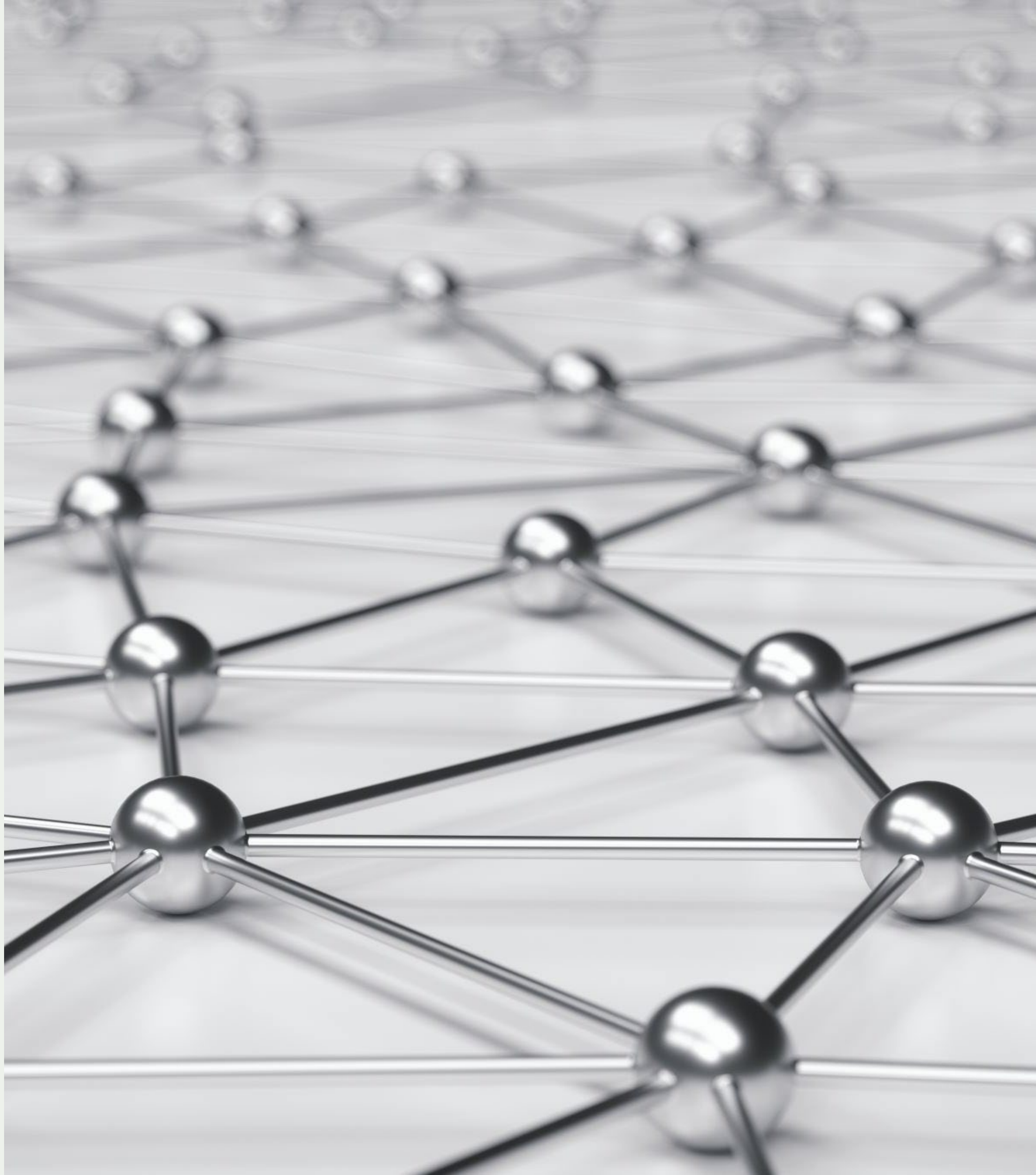
Developing deployment guidance

- Lessons Learned and Best Current Practices
- Monitoring Tools

Expanding deployment

- Outreach
- Training

https://www.internetsociety.org/issues/time-security/



It is Time to Act!

- The NTS for NTP specification is technically finished (in the final editing steps).
- Discussions are underway in IEEE 1588 to specify NTS for PTP.
- Prototype implementations and testing are underway.
- It is time to build solutions, test deployments, and gather lessons learned.
- Contact me if you want to participate in any of these activities: odonoghue@isoc.org

Resources

NTP Working Group

- https://datatracker.ietf.org/group/ntp/about/

NTS Specification

- https://datatracker.ietf.org/doc/draft-ietf-ntp-using-nts-for-ntp/

IEEE 1588 Working Group

- https://ieee-sa.imeetcentral.com/1588public/

Recent NTS Blog Posts:

- https://weberblog.net/network-time-security-new-ntp-authentication-mechanism/
- https://www.netnod.se/time-and-frequency/network-time-security
- https://www.netnod.se/time-and-frequency/how-to-use-nts
- https://blog.cloudflare.com/secure-time/

Thank you.

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WORKSHOP ON SYNCHRONIZATION AND TIMING SYSTEMS

Secure PTP Using TLS Key Management

Doug Arnold
Principal Technologist
Meinberg

Session 3: Timing Security, Resilience and GNSS Issues
May 20, 2020

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The Synchronization Experts.

Secure PTP Using TLS Key Management

a proposal by

Douglas Arnold

Meinberg-USA

Agenda

Terminology

PTP AUTHENTICATION TLV

Network Time Security

TLS Key Exchange

PTP with NTS

Summary

First two stages of grieving about lack of network timing security

1. Denial

- Me: “Are you interested in security for timing protocols?”
- Network operator: “No. Our network is very secure.”
- Me: “Call me after something bad happens.”
- Perhaps network security and timing are handled by different groups in a large organization. And they don’t talk to each other.

2. Anger

- Network operator: “What security is there for NTP and PTP?”
- Me: “NTP has an obsolete security mechanism, and PTP has nothing yet.”
- Network operator: “What the heck are you standards people doing?”

Executive Summary / Glossary

Transport Layer Security (TLS)

- Cryptographic network security protocol
- Used in web browsing, email, messaging, and VoIP

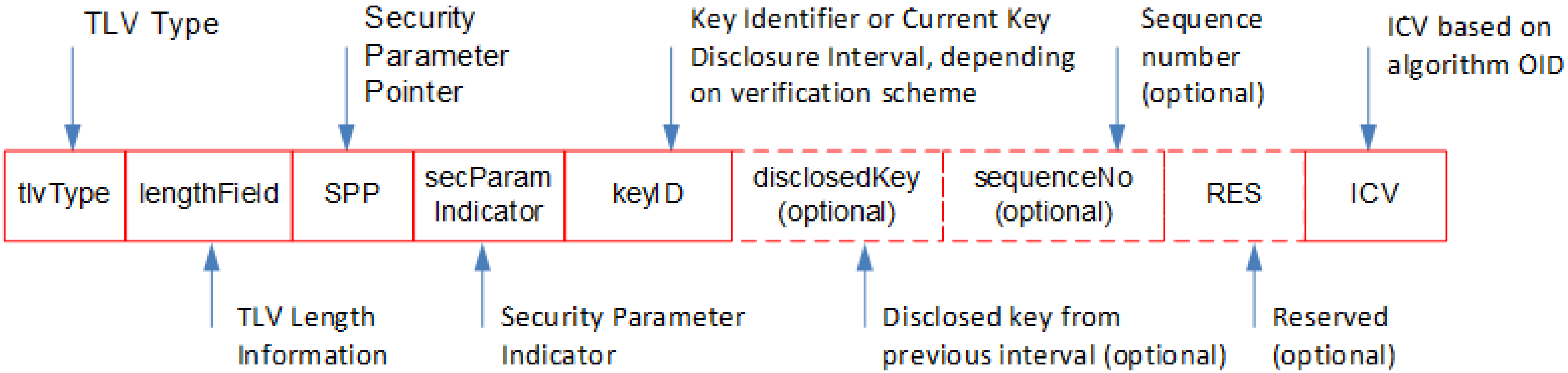
Network Time Security (NTS)

- Draft IETF RFC approved for publication
- https://datatracker.ietf.org/doc/draft-ietf-ntp-using-nts-for-ntp/
- Adaptation of TLS for unicast mode client-server NTP
- Time server manufacturers are going to implement this

Authentication TLV

- TLV = Type length value, a standard method for extending network messages
- PTP message extension for message integrity protection and possibly source authentication
- Defined in IEEE 1588-2019
- Requires a yet unspecified key management system to secure PTP
- NTS key management could be adapted for unicast PTP

PTP Authentication TLV



tlvType	lengthField	SPP	secParam Indicator	keyID	disclosedKey (optional)	sequenceNo (optional)	RES	ICV

TLV Type

Security Parameter Pointer

Key Identifier or Current Key Disclosure Interval, depending on verification scheme

Sequence number (optional)

ICV based on algorithm OID

TLV Length Information

Security Parameter Indicator

Disclosed key from previous interval (optional)

Reserved (optional)

PTP Authentication TLV

Security Parameter Pointer

- Indicates a specific entry in a security association database
- Allows a PTP instance to have secure communications with multiple network elements - for example a slave talking to a grandmaster and a monitoring node

Security Parameter Indicator

- Flags field indicating whether optional fields are present
- We don’t need any of the optional fields for NTS
- Set to all zeros

Key ID

- Indicates which key is being used
- Points to an entry in the security association database

ICV

- Integrity Check Value
- A hash code

Properties of NTS

Starts with TLS Key Establishment (KE) Server

- Needed to start
- Then client and server continue without KE server

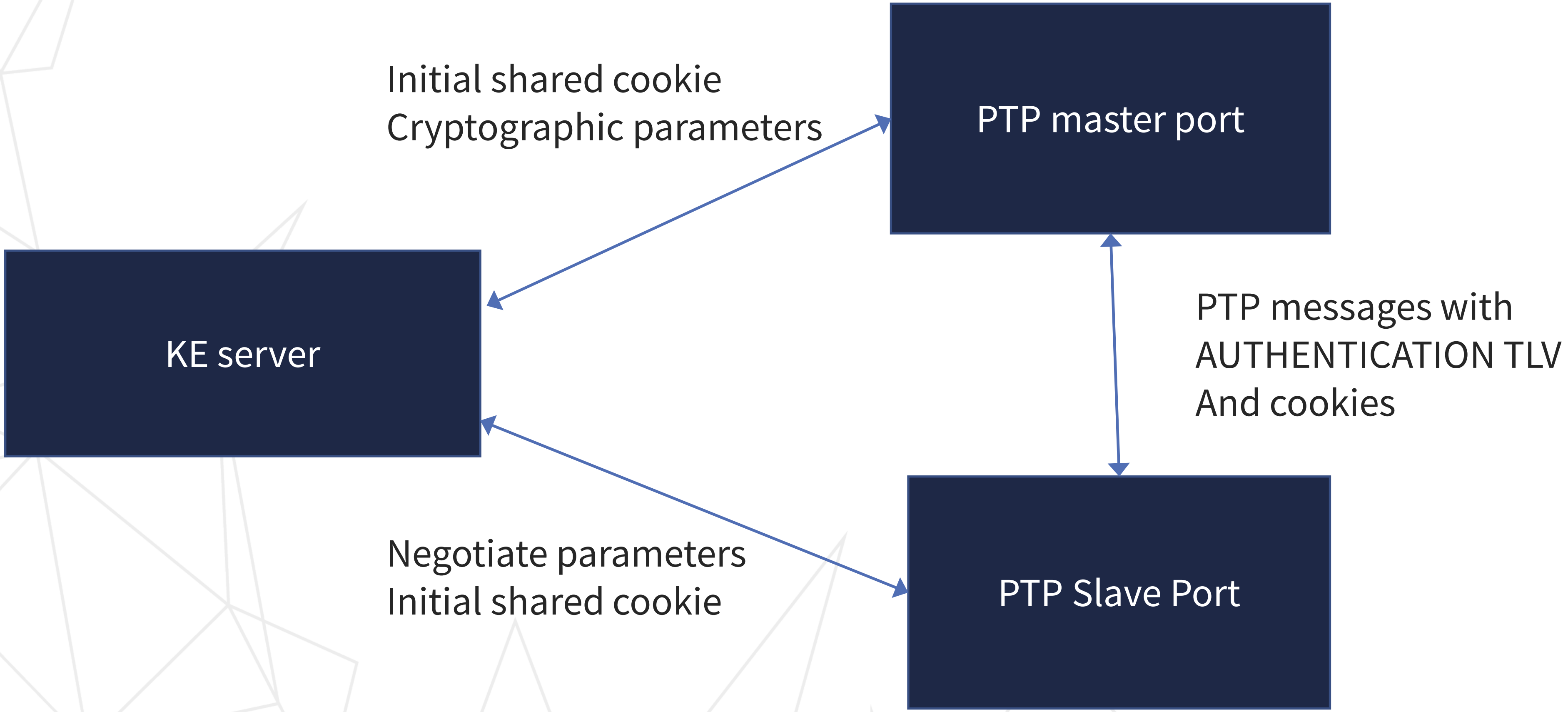
Properties of NTS

- NTP severs are stateless: don’t save data about any specific client
- Works only for unicast NTP
- Includes and ICV (hash code)
- Includes encryption
  - Needed to transfer keys, not to protect timestamps

PTP profile which could use NTS

- Unicast with negotiation
- IPv4 or IPv6 mapping

TLS Key Exchange Server



Initial shared cookie
Cryptographic parameters

PTP master port

KE server

PTP messages with
AUTHENTICATION TLV
And cookies

Negotiate parameters
Initial shared cookie

PTP Slave Port

NTS Cookies

S2M Cookie TLV

- ID of current S2M key
- ID of current M2S key (if different)
- Negotiated algorithm and parameters

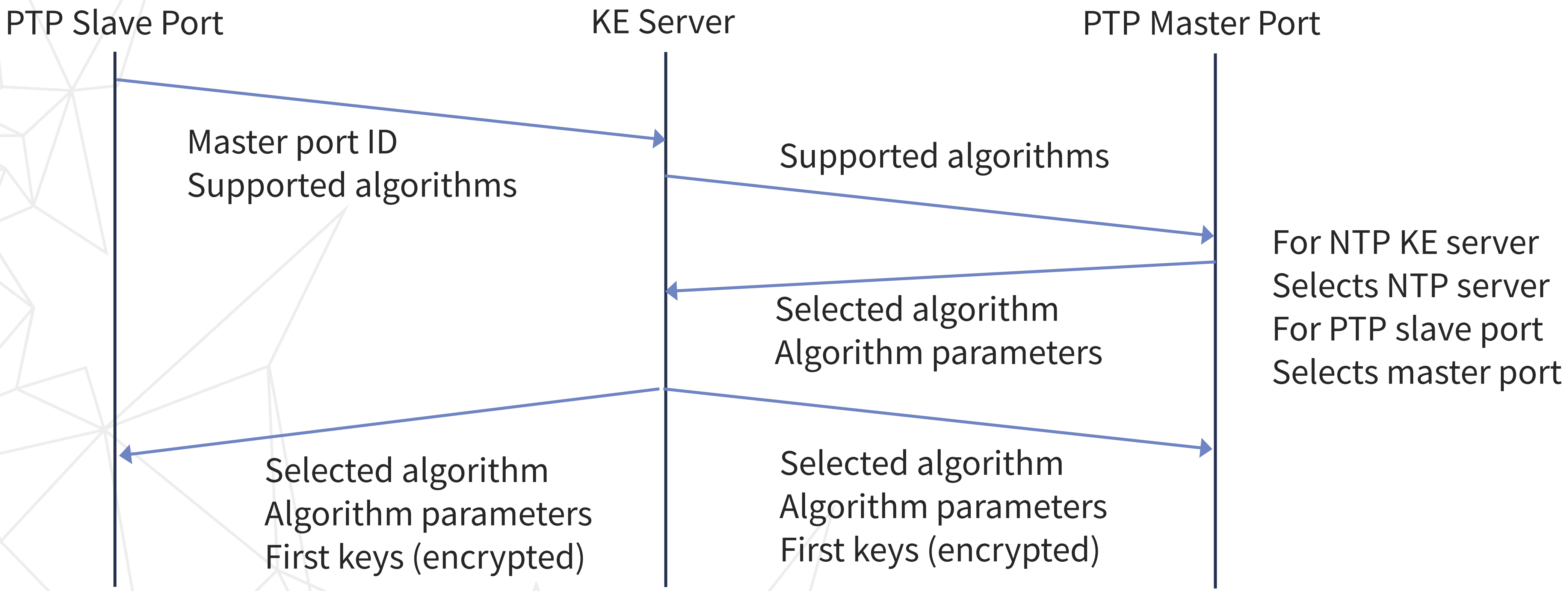
M2S Cookie TLV (Send encrypted)

- Next keys and IDs
- Negotiated algorithm and parameters

The cookie scheme allows NTP severs to not keep state for each client

- NTP servers can have a very large numbers or clients
- NTP servers do keep keys in a list with index numbers
- PTP master ports keep data on slaves, but we retain this scheme so that NTS can secure both NTP and PTP

TLS Handshake for PTP



PTP Slave Port

KE Server

PTP Master Port

Master port ID
Supported algorithms

Supported algorithms

For NTP KE server
Selects NTP server
For PTP slave port
Selects master port

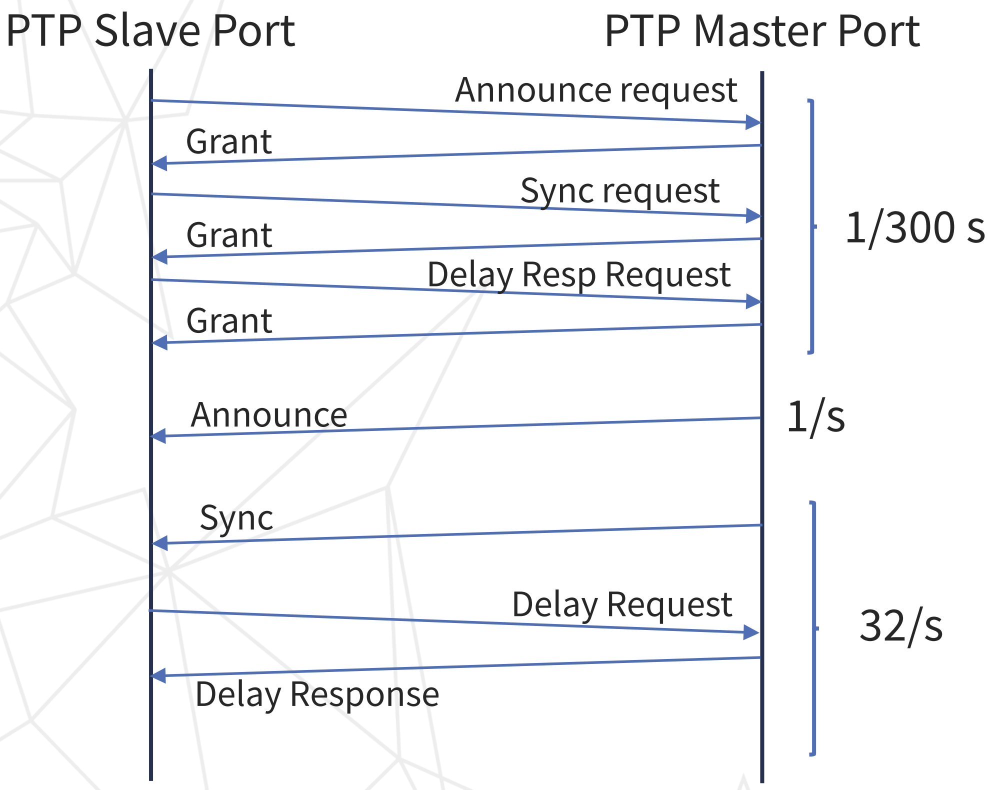
Selected algorithm
Algorithm parameters

Selected algorithm
Algorithm parameters
First keys (encrypted)

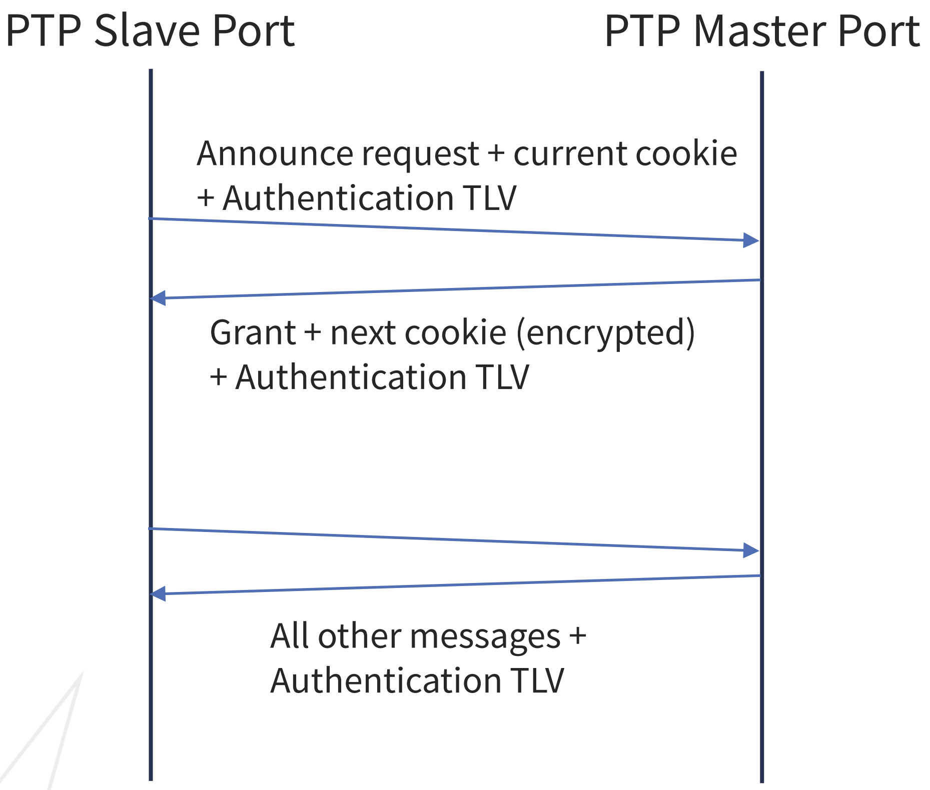
Selected algorithm
Algorithm parameters
First keys (encrypted)

After initial shared cookie, master port generates new cookies

TLS Handshake for PTP



Traditional Unicast PTP



Unicast PTP with NTS

Summary

NTS for NTP

- New security option to replace autokey
- Covers unicast client-server NTP only
- ~~Likely~~ Certain to be implemented in commercial time servers
- Uses TLS for algorithm negotiation and initial keys
- Subsequent keys generated by server

NTS for PTP

- Appropriate for layer 3 unicast PTP
- Cookies exchanged during announce message negotiation
- Keys used in AUTHENTICATION TLV

Dankeschön !!!

Questions and comments welcome:
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WORKSHOP
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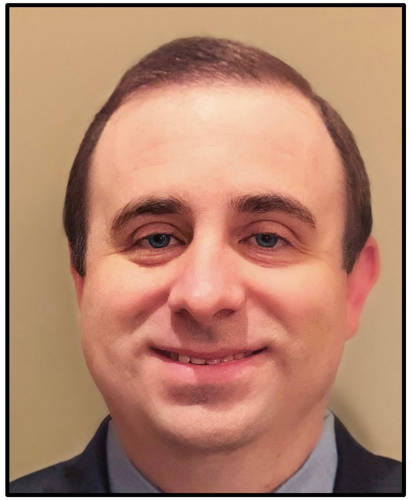
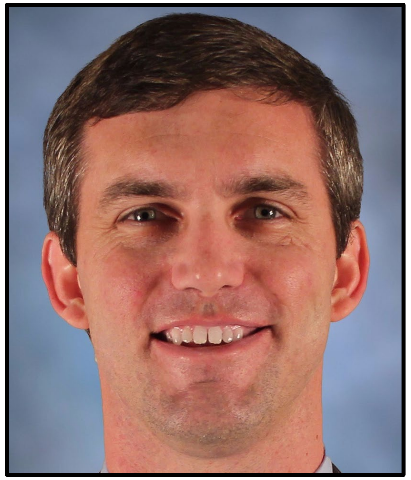
TIMING SYSTEMS

A Multi-Level Approach for Integrating GNSS Integrity into Critical Timing Applications



Josh Clanton
Principal Engineer
IS4S

David Hodo
Director
Assured PNT
IS4S



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Session 3: Timing Security, Resilience and GNSS Issues
May 20, 2020

IS4S

Integrated Solutions for Systems

A Multi-Level Approach for Integrating GNSS Integrity into Critical Timing Applications

WSTS 2020 – Virtual Webinar Series
Session 3: Timing Security, Resilience and GNSS Issues

Josh Clanton & David Hodo

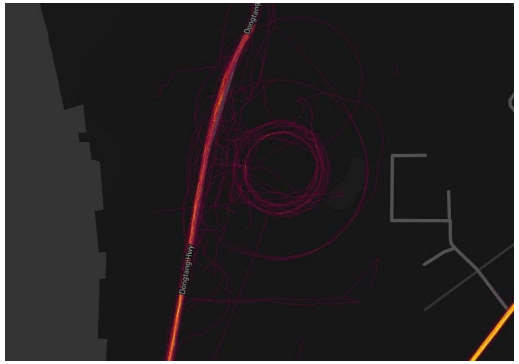
Integrated Solutions for Systems, Inc (IS4S)

This work is funded by the Department of Homeland Security, Science and Technology Directorate, contract # 70RSAT18CB0000020.

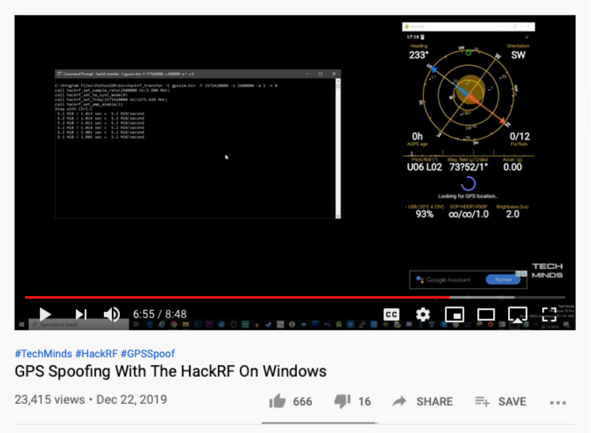
Motivation

- Critical infrastructure is heavily reliant on precision timing from GPS

- GPS spoofing is no longer just a lab experiment
  - –Many incidents documented in open literature
  - –Step by step guides freely available online



GPS “Crop Circles” near Port of Shanghai from Strava



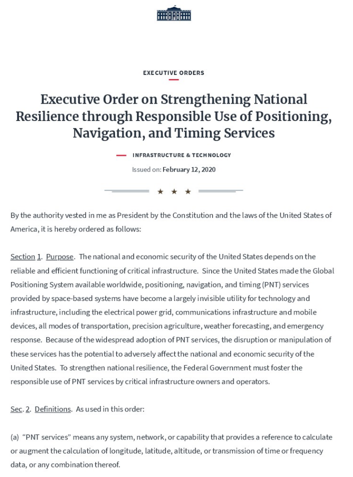
#TechMinds #HackRF #GPSSpoof

GPS Spoofing With The HackRF On Windows

23,415 views • Dec 22, 2019

Online Spoofing Tutorials Using Inexpensive Hardware

- Timing systems in critical infrastructure must be resilient to these threats



EXECUTIVE ORDERS

Executive Order on Strengthening National Resilience through Responsible Use of Positioning, Navigation, and Timing Services

INFRASTRUCTURE & TECHNOLOGY

Issued on: February 12, 2020

★ ★ ★

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.

February 2020 Executive Order Requiring Resilient PNT in CI

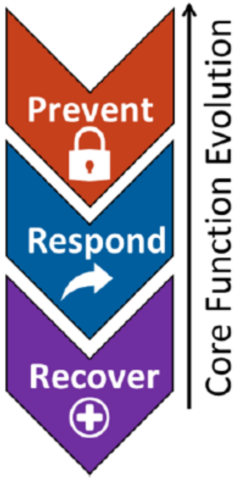
- IS4S and Auburn University funded by DHS S&T to develop a non-proprietary GPS Anti-Spoofing Toolkit for use by industry in developing resilient timing systems

Alignment with DHS Resilient PNT Conformance Framework

- Anti-Spoofing Toolkit is part of a larger effort by DHS S&T to develop a framework for resilient PNT (Positioning, Navigation, and Timing)

- Provides guidelines for creating and evaluating resilient timing sources with emphasis on:
  - Critical infrastructure applications
  - Timing sources that are tied to GPS and other satellite or terrestrial navigation systems

- Key Concepts
  - Provides guiding principles for system design that comprehensive, simple, consistent, and non-prescriptive
  - Defines resilience levels for quantifying performance of resilient PNT systems
  - Calls for a Defense-in-Depth with 3 core functions

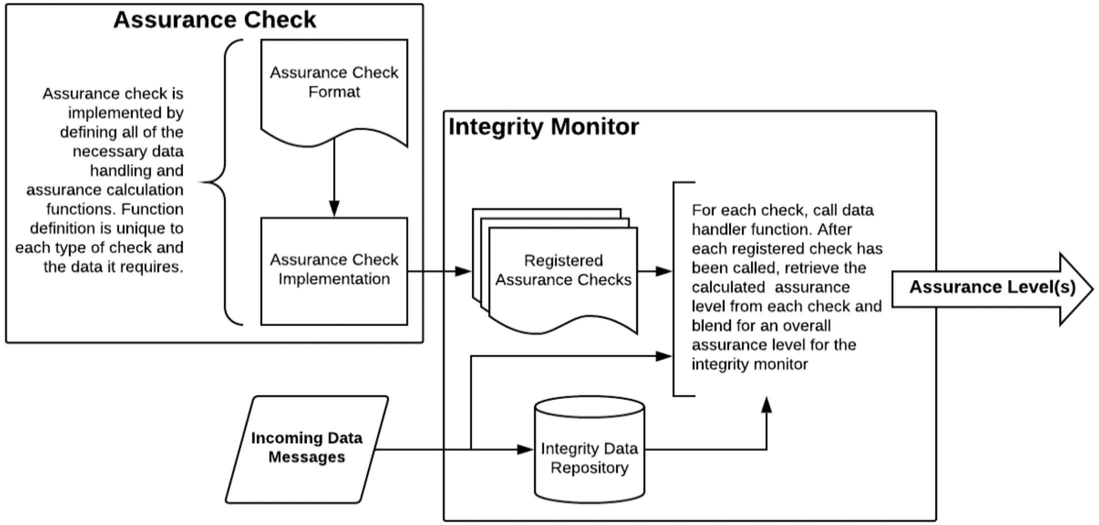


- Detection is needed across the core functions
  - Detecting anomalies in GPS measurements is challenging
  - Must be able to expand as threats and detection techniques evolve

Project Goals

- Project goal is to develop a set of GPS spoofing detection methods, software, and tools for use in critical timing applications
  - –Reduce development time required to develop resilient timing systems
  - –Lower burden on manufacturers / end users for deploying resilient timing systems
  - –Educate community
  - –***NOT** to provide a turn-key solution/product that competes with existing industry offerings*

- Resources provided
  - –Architecture and software implementation
    - Data model definitions for receiver observables
    - Initial set of configurable integrity checks
    - Extensible framework for adding additional checks
    - Cross-platform C++ implementation
  - –Demonstration Kit
    - Hardware design
    - User interface

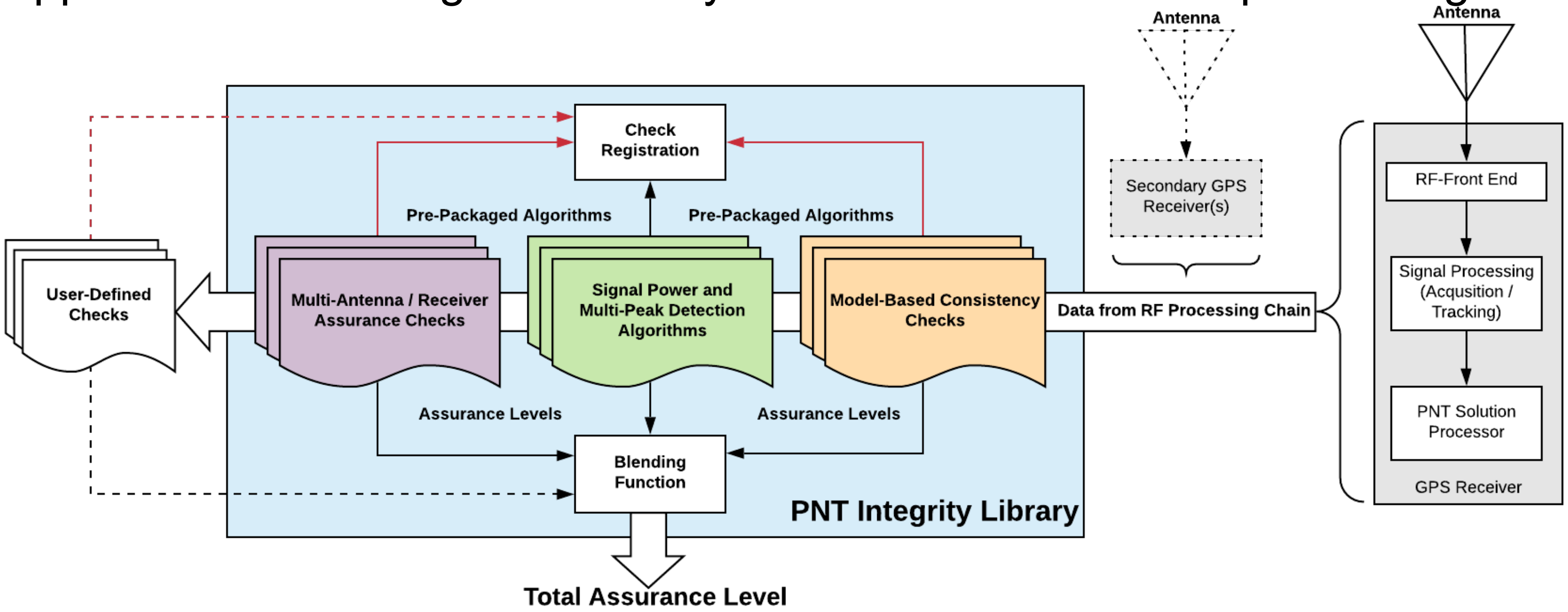

Assurance Check
Assurance check is implemented by defining all of the necessary data handling and assurance calculation functions. Function definition is unique to each type of check and the data it requires.
Assurance Check Format
Assurance Check Implementation
Integrity Monitor
Registered Assurance Checks
For each check, call data handler function. After each registered check has been called, retrieve the calculated assurance level from each check and blend for an overall assurance level for the integrity monitor
Assurance Level(s)
Incoming Data Messages
Integrity Data Repository

PNT Integrity Library Overview

- Open architecture approach to GPS spoofing detection

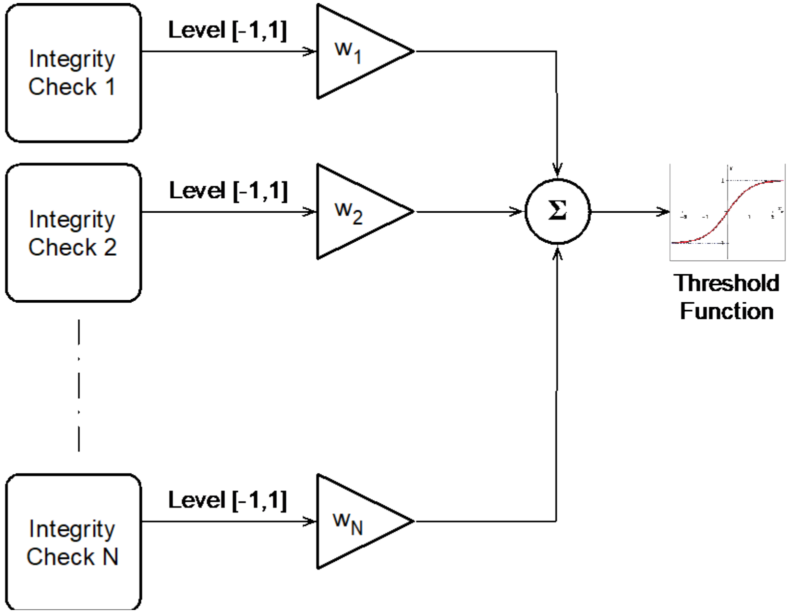
- Defines data models and API (application programming interface) for
  - Receiver observables (inputs)
  - Assurance check definitions (processing)
  - Assurance levels (output)

- Multi-layered approach allows integration at any level in the receiver RF-processing chain



Combining Assurance Checks

- Each registered check takes in receiver observables and outputs an assurance level
- A weight is assigned to each check
  - Assigned by integrator
  - User / platform specific
  - Ideally based on P_D / P_{FA}
- Weighted values are summed and thresholded to produce one of four assurance levels

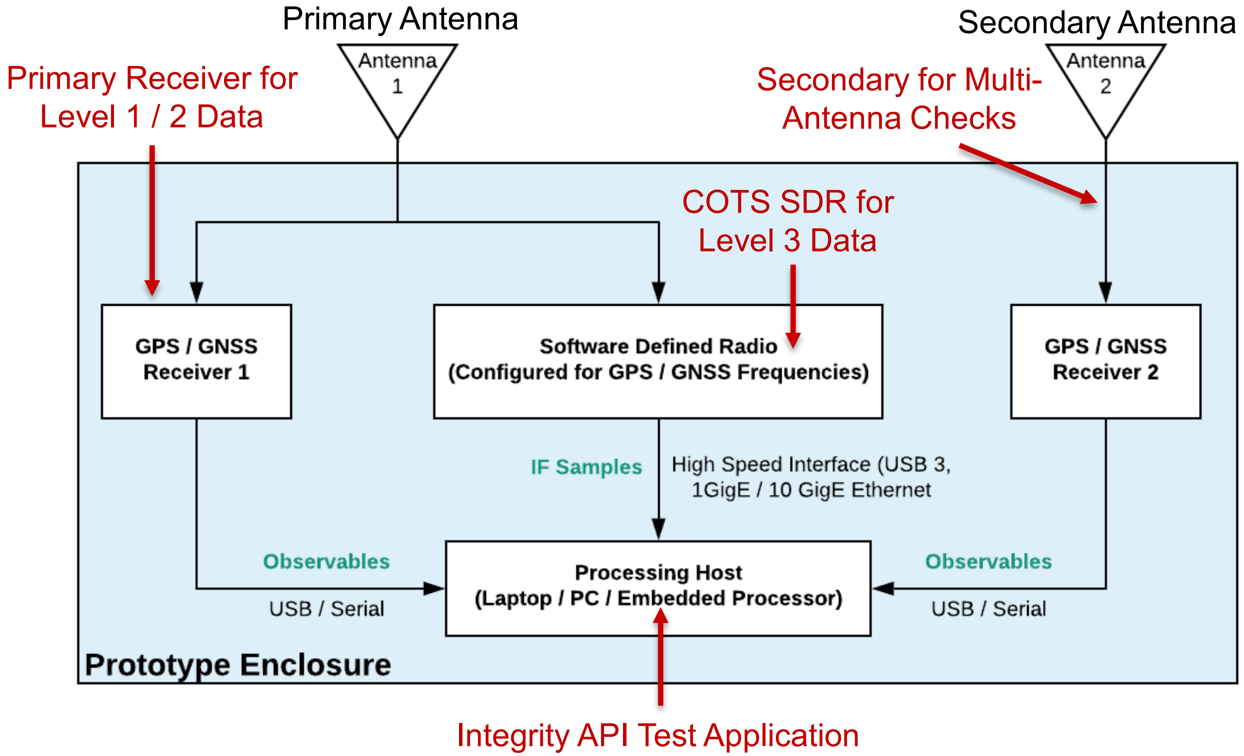


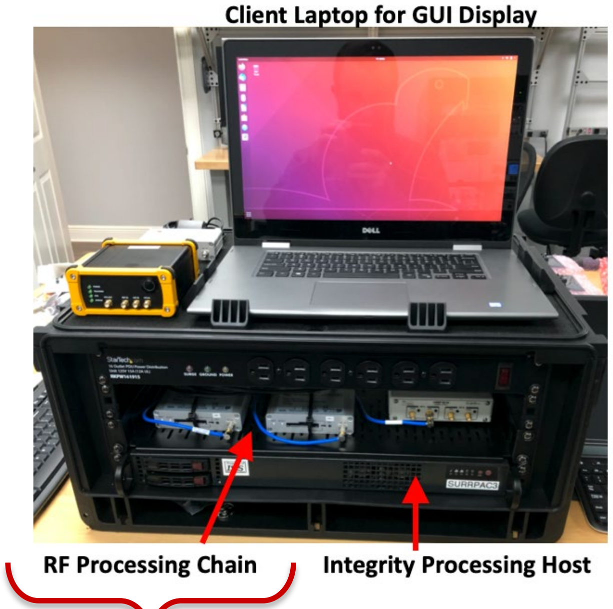
Level Name	Value	Description
Unavailable	0	Level is unavailable (insufficient data or has not yet been processed)
Unassured	1	Indicates a high likelihood that the measurement / source CANNOT be trusted
Inconsistent	2	Cannot reliably determine the validity of the measurement / source
Assured	3	Indicates a high-likelihood that measurement / source CAN be trusted

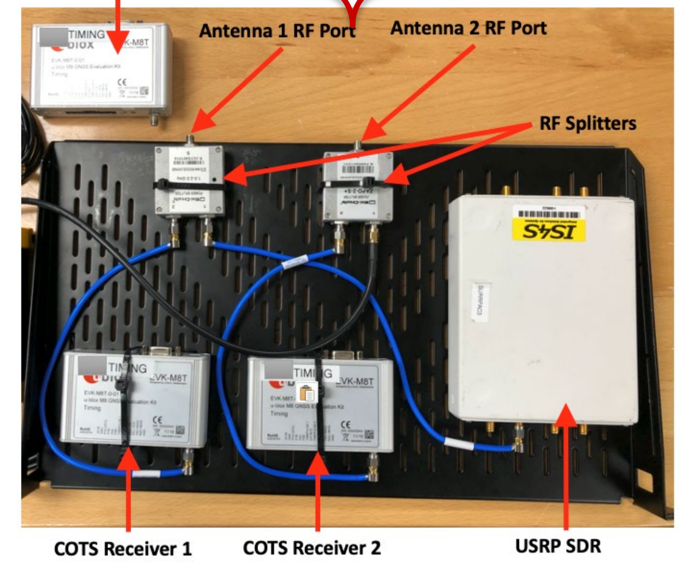
Demonstration Kit

- Assembling a portable platform to demonstrate integrity library and integration with RF processing chain

- Integrity library integrated with receiver drivers and COTS hardware

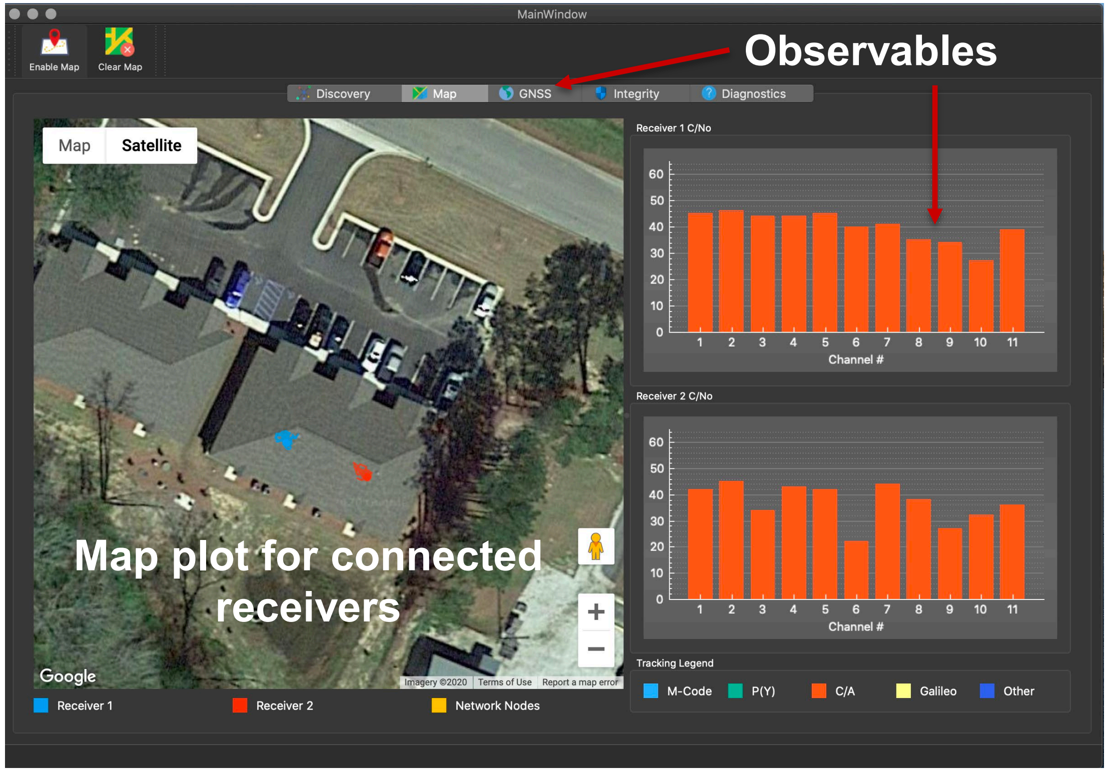

Primary Antenna
Antenna 1
Secondary Antenna
Antenna 2
Primary Receiver for Level 1 / 2 Data
Secondary for Multi-Antenna Checks
COTS SDR for Level 3 Data
GPS / GNSS Receiver 1
Software Defined Radio (Configured for GPS / GNSS Frequencies)
GPS / GNSS Receiver 2
IF Samples
High Speed Interface (USB 3, 1GigE / 10 GigE Ethernet
Observables
USB / Serial
Processing Host (Laptop / PC / Embedded Processor)
Observables
USB / Serial
Prototype Enclosure
Integrity API Test Application





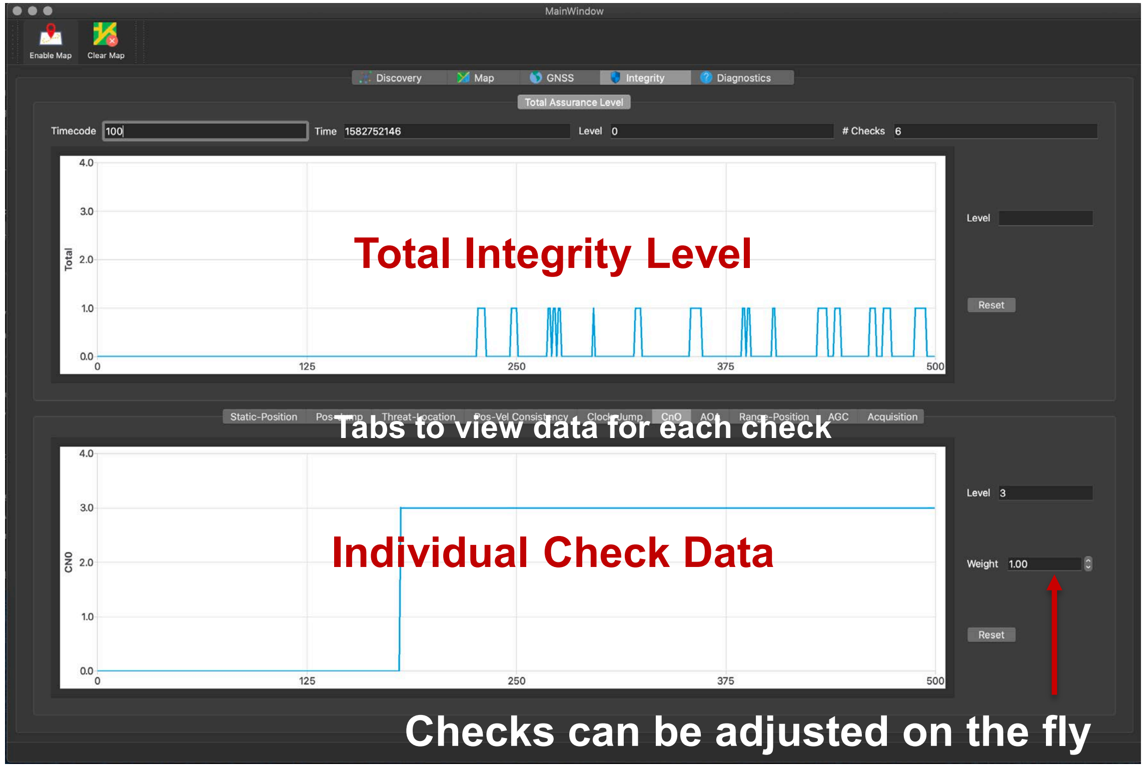
Demonstration Application and User Interface

- Receiver interfaces and GUI to demonstrate integrity library and processing chain integration
- Checks can be added or removed to demonstrate effectiveness at different integration levels
- Displays receiver observables as well as integrity library data



Observables

Map plot for connected receivers



Timecode 100 Time 1582752146 Level 0 # Checks 6

Level 3

Weight 1.00

Total Integrity Level

Tabs to view data for each check

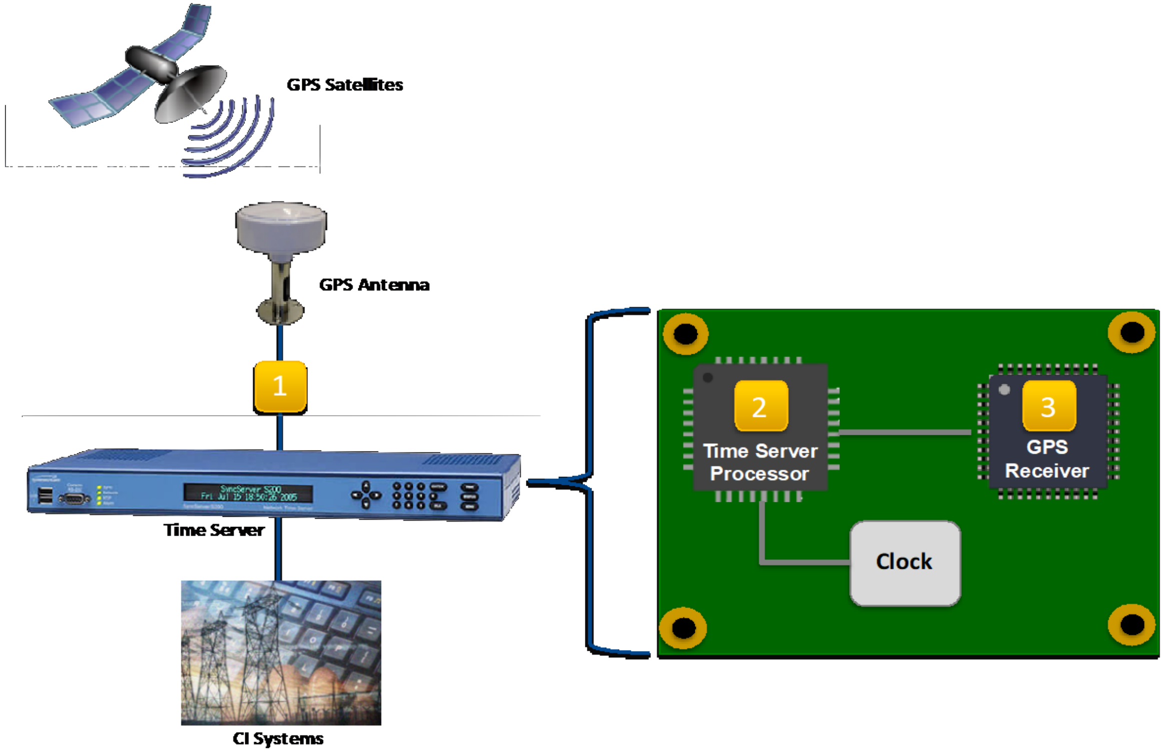
Individual Check Data

Checks can be adjusted on the fly

Integration Options

- Toolkit components can be integrated at multiple levels by:
  1. End Users
  2. System Integrators
  3. Manufacturers

- Integrity library can be embedded in receiver or timing devices
  - –Integrator responsible for reading GPS observables and converting to standardized data model
  - –Library provides assurance level to allow operating through the event or alerting a user



- End-User Development Kit can be used standalone to provide alerts to users or feed other legacy timing devices

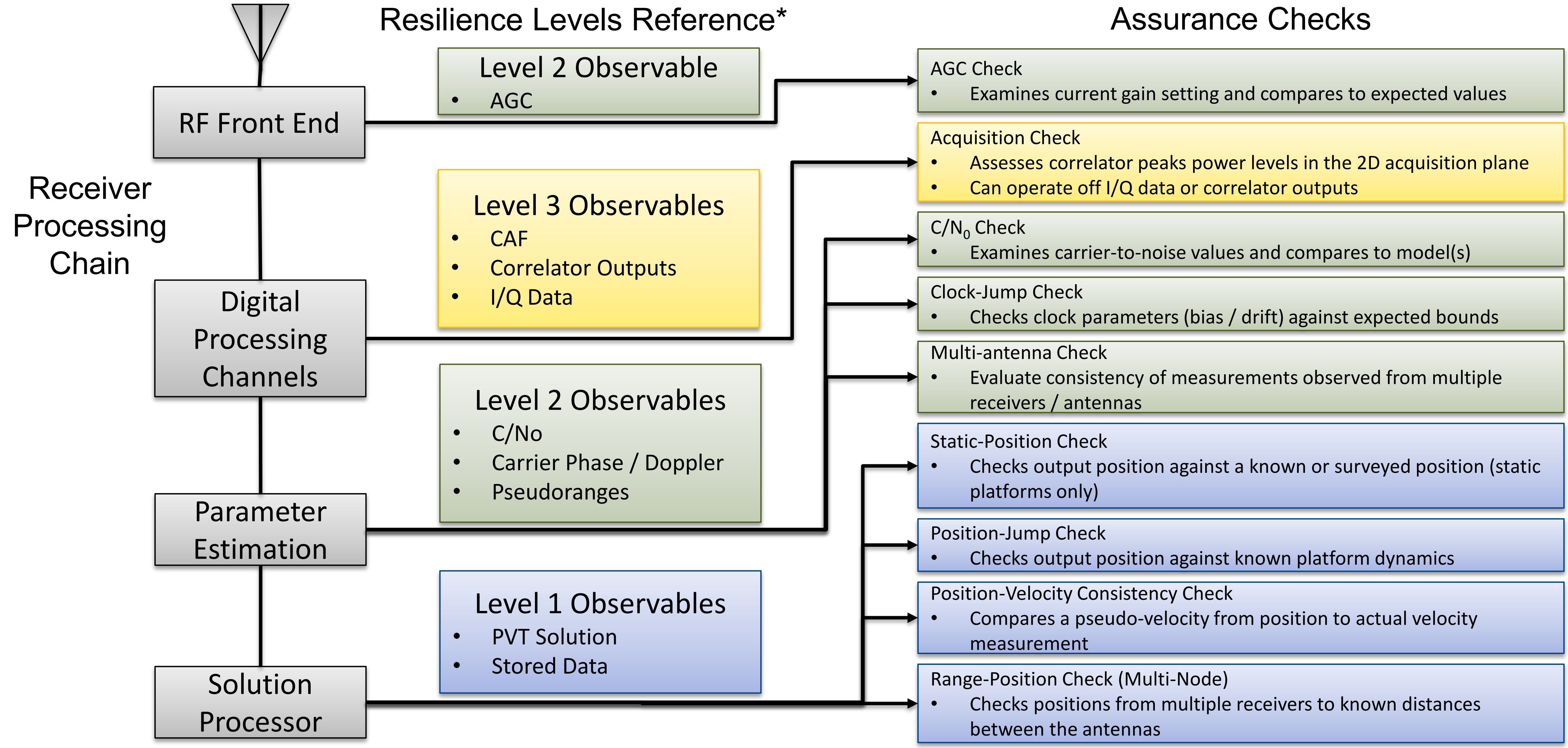
Wrap-Up

- Questions / Discussion

- Points of Contact
  - Josh Clanton, IS4S Technical Lead
    - josh.clanton@is4s.com
  - David Hodo, IS4S Program Manager
    - david.hodo@is4s.com

- IS4S would like to thank DHS S&T for their sponsorship of this effort

Alignment with PNT Conformance Framework



Receiver Processing Chain

- RF Front End
- Digital Processing Channels
- Parameter Estimation
- Solution Processor

Resilience Levels Reference*

Level 2 Observable
- AGC

Level 3 Observables
- CAF
- Correlator Outputs
- I/Q Data

Level 2 Observables
- C/No
- Carrier Phase / Doppler
- Pseudoranges

Level 1 Observables
- PVT Solution
- Stored Data

Assurance Checks

AGC Check
- Examines current gain setting and compares to expected values

Acquisition Check
- Assesses correlator peaks power levels in the 2D acquisition plane
- Can operate off I/Q data or correlator outputs

C/N_0 Check
- Examines carrier-to-noise values and compares to model(s)

Clock-Jump Check
- Checks clock parameters (bias / drift) against expected bounds

Multi-antenna Check
- Evaluate consistency of measurements observed from multiple receivers / antennas

Static-Position Check
- Checks output position against a known or surveyed position (static platforms only)

Position-Jump Check
- Checks output position against known platform dynamics

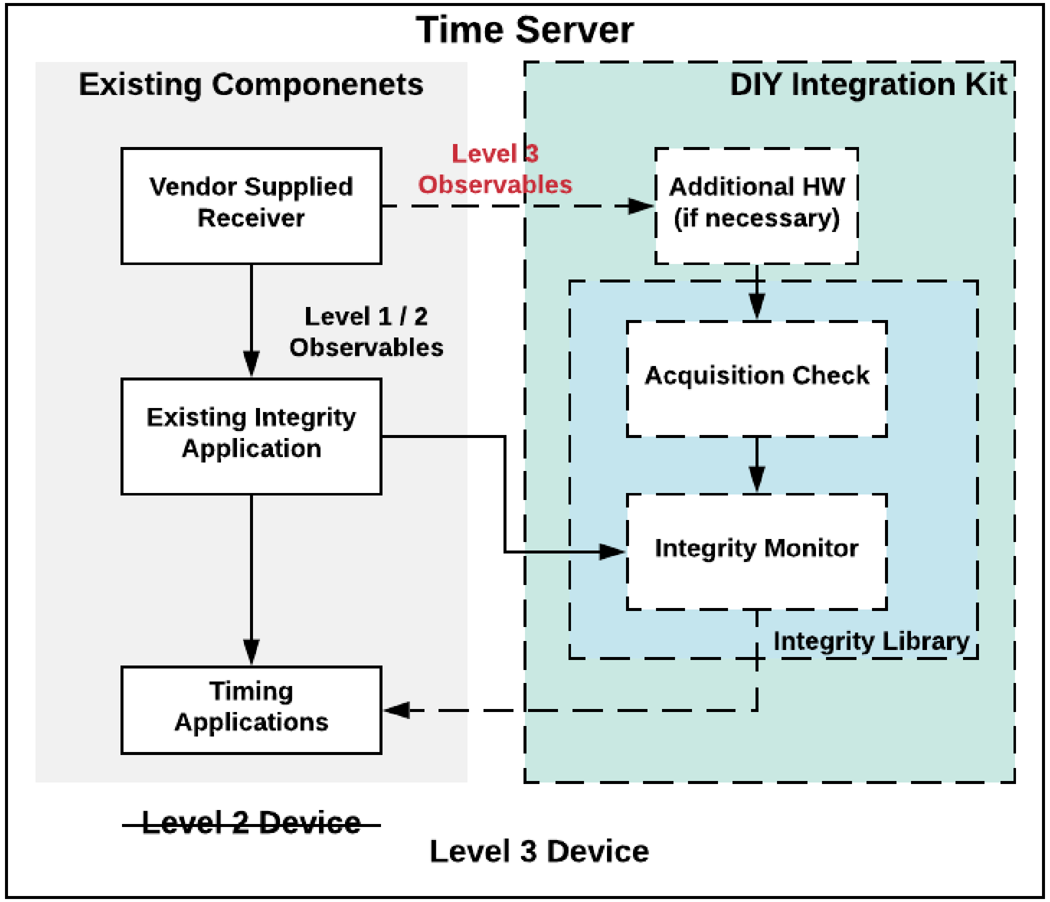
Position-Velocity Consistency Check
- Compares a pseudo-velocity from position to actual velocity measurement

Range-Position Check (Multi-Node)
- Checks positions from multiple receivers to known distances between the antennas

*As currently defined by DHS S&T / HSSEDI Resilient PNT Conformance Framework working group

Available Resources Forthcoming to the Community

- Integrity open-architecture reference implementation to be available as a software library from DHS S&T
  - Reference system for system integrators
  - Fill gaps in current offerings (i.e. adding software capability to go from a Level 1 to 2, for example)
  - Modular framework allows SI's to add their own flavor to spoofing mitigation
- Adaptation of the demonstration platform into a DIY kit available to the community
  - Not intended to be a competing product with current industry offerings
  - Best solutions will come from system integrator products
  - Targeted to end-users who need something quickly with no current market offerings meeting requirements
  - Could also be assembled as a reference system for Resilient PNT Conformance guidelines from DHS / HSSEDI



Homeland Security
Science and Technology

HSSEDI
Homeland Security Systems Engineering & Development Institute™

WORKSHOP ON SYNCHRONIZATION AND TIMING SYSTEMS

Timing Services Based on European GNSS Technologies

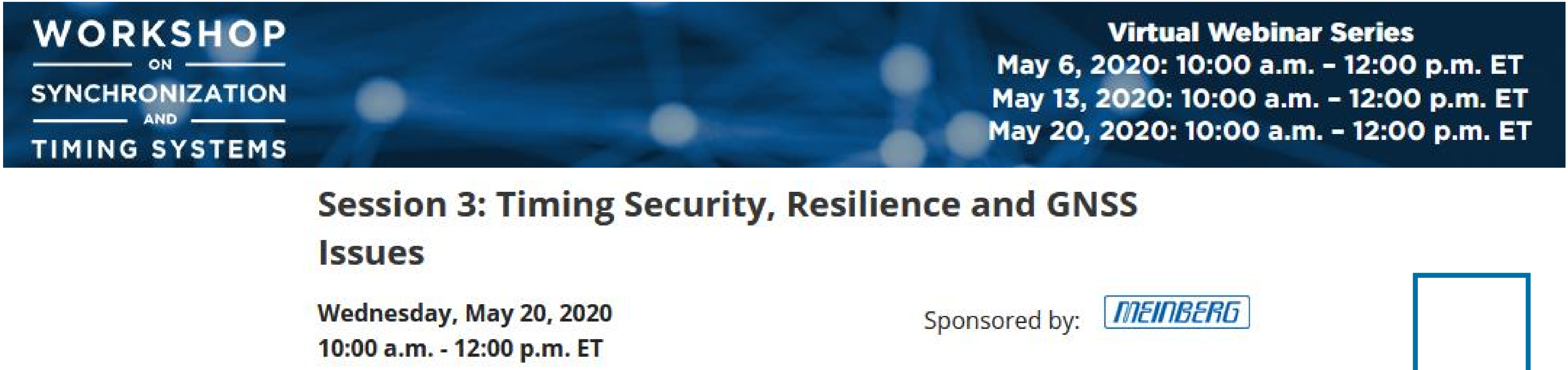
Andreas Bauch
Research Scientist
Physikalisch-Technische Bundesanstalt

Sponsored by: MEINBERG

Session 3: Timing Security, Resilience and GNSS Issues
May 20, 2020

Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

Timing Services Based on European GNSS


WORKSHOP ON SYNCHRONIZATION AND TIMING SYSTEMS

Virtual Webinar Series
May 6, 2020: 10:00 a.m. – 12:00 p.m. ET
May 13, 2020: 10:00 a.m. – 12:00 p.m. ET
May 20, 2020: 10:00 a.m. – 12:00 p.m. ET

Session 3: Timing Security, Resilience and GNSS Issues

Wednesday, May 20, 2020
10:00 a.m. - 12:00 p.m. ET

Sponsored by: MEINBERG

Andreas Bauch, WG Time Dissemination

Timing Services Based on European GNSS

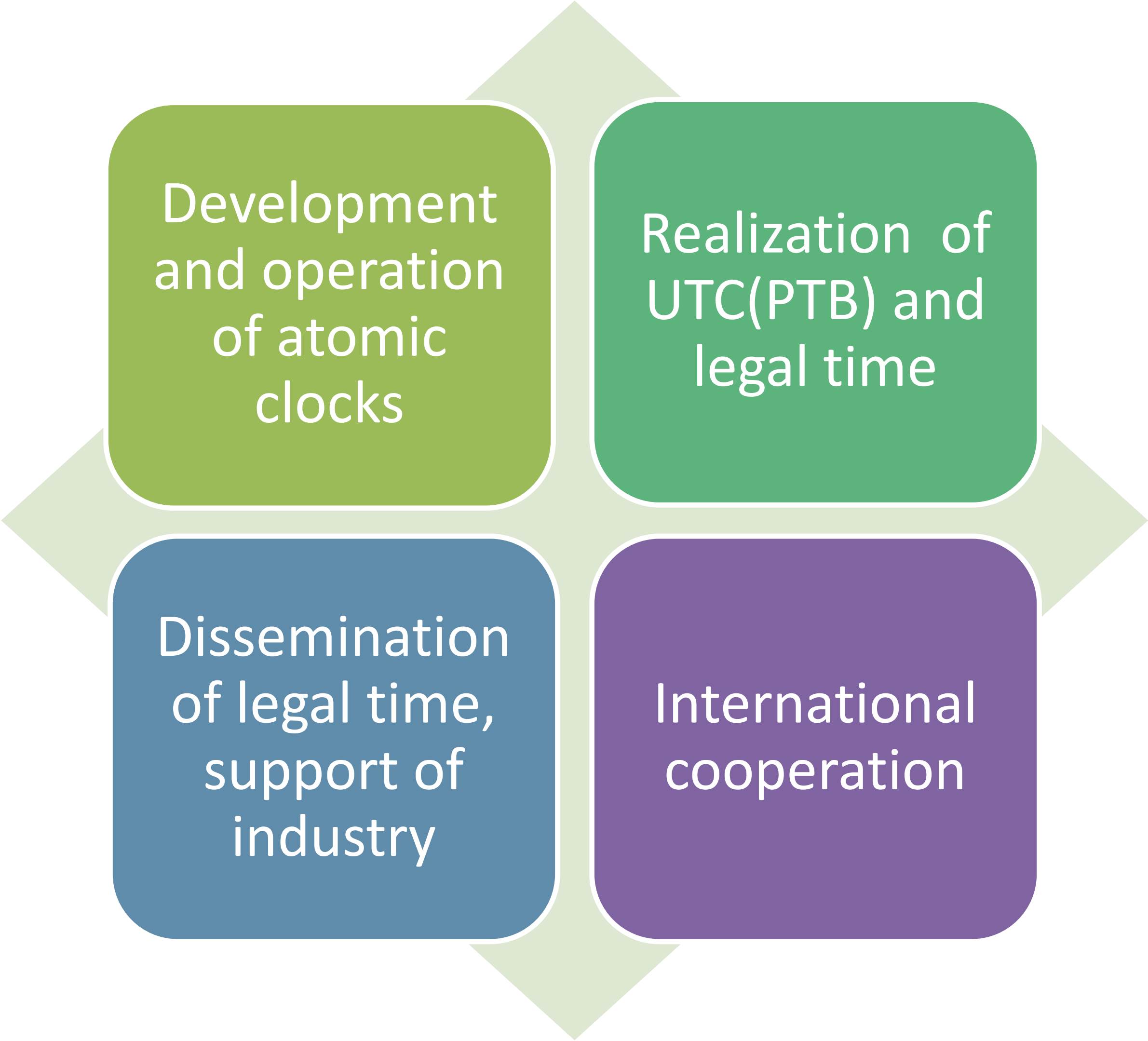
- Introduction
- Motivation
- EU project EGALITE
- Conclusions

Andreas Bauch (*1957)
Physicist, PhD

In PTB since 1983, today Head, Time Dissemination WG; Involved in Galileo projects with ESA, EU, GSA since 2002

PTB: its role and its involvement in T&F

- National Metrology Institute, since 1887
- Headquarter in Braunschweig, roots in Berlin where a second site still exists.
- Federal Ministry for Economy and Energy
- 1850 staff, 180 Mio. € budget



Development and operation of atomic clocks

Realization of UTC(PTB) and legal time

Dissemination of legal time, support of industry

International cooperation

Motivation

Many applications require assured >*access*< to accurate >*time*<

?? time unit (frequency), 1PPS epoch or Time-of-Day, ??

for making measurements or for date/time stamping

traceable to international or/and legal standards.

GNSS reception is predominant in many fields, but is it

assured ?

accurate ?

sufficient to obtain traceability ?

Motivation

Many applications require assured >*access*< to accurate >*time*<

GNSS reception is predominant in many fields, but is it
assured ? (safe, secured, trustworthy,…) is not my topic

Motivation

Many applications require assured >*access*< to accurate >*time*<

GNSS reception is predominant in many fields, but is it

accurate ? revolutionized time-keeping decades ago, still „technically“ better than many user requirements

Motivation

Many applications require assured >*access*< to accurate >*time*<

GNSS reception is predominant in many fields, but is it

sufficient to obtain traceability ?

This is where rules of metrology come into play.

Motivation

Traceability is relevant for both, making measurements and for time/date stamping, defined in the VIM* as

„property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations ((comparisons)), each contributing to the measurement uncertainty."

Each of the highlighted words would deserve a detailed discussion.

In short: The metrological community feels confident that reception and processing of GNSS signals alone does not provide traceability as defined above (Matsakis et al.*, Piester et al.*).

Motivation

Traceability is relevant for both, making measurements and for time/date stamping, defined in the VIM* as

„property of a measurement result whereby the resu lated to a reference through a documented unbroken chain of calibrations ((comparison tributing to the measurement uncertainty."

* References given on last slide

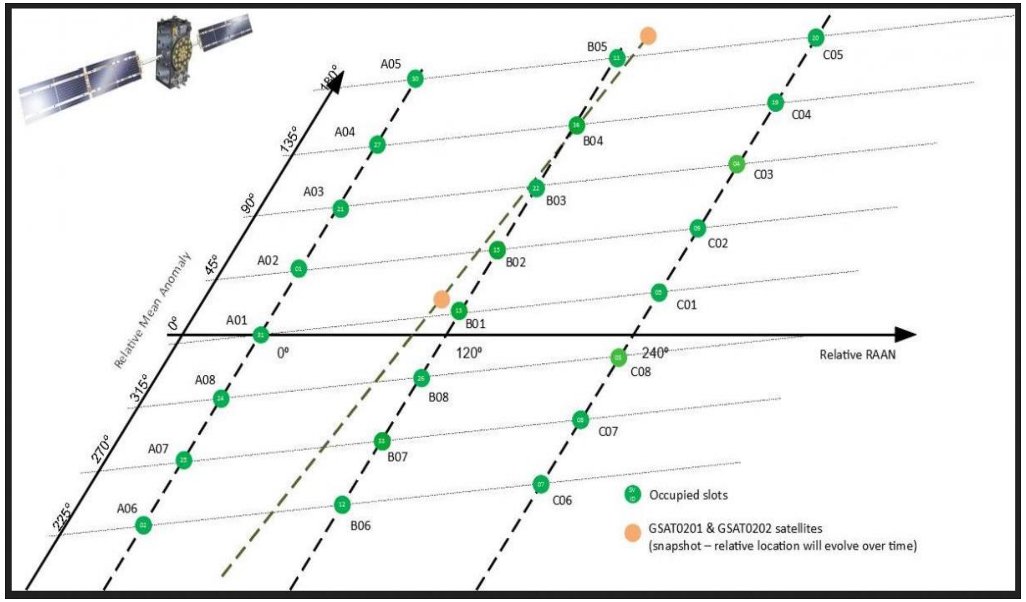
Each of the highlighted words would deserve a detailed discussion.

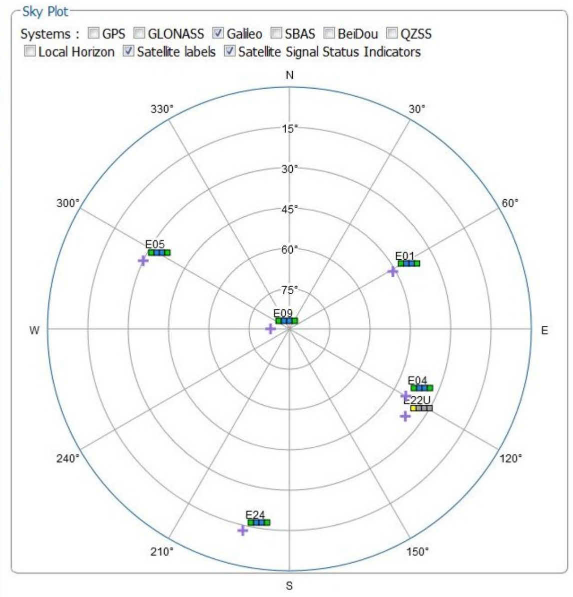
In short: The metrological community feels confident that reception and processing of GNSS signals alone does not provide traceability (Matsakis et al.*, Piester et al.*)

The use of European GNSS

Galileo – the European GNSS

- Initial Services officially announced December 2016
- Minimum Performance Level (MPL) according to OS Service Definition Document* (OS SDD 2019)
- EU and GSA interested in the optimal exploitation of the Galileo services for European users




Sky Plot

Systems : □ GPS □ GLONASS ☑ Galileo □ SBAS □ BeiDou □ QZSS

□ Local Horizon ☑ Satellite labels ☑ Satellite Signal Status Indicators

EU project EGALITE

EGNOS and Galileo Timing Service Extension and Consolidation

Funding by EC under H2020 framework program
Studied the feasibility of dedicated **Timing Services** based on **Galileo**

gmv INNOVATING SOLUTIONS

PTB

Royal Observatory of Belgium

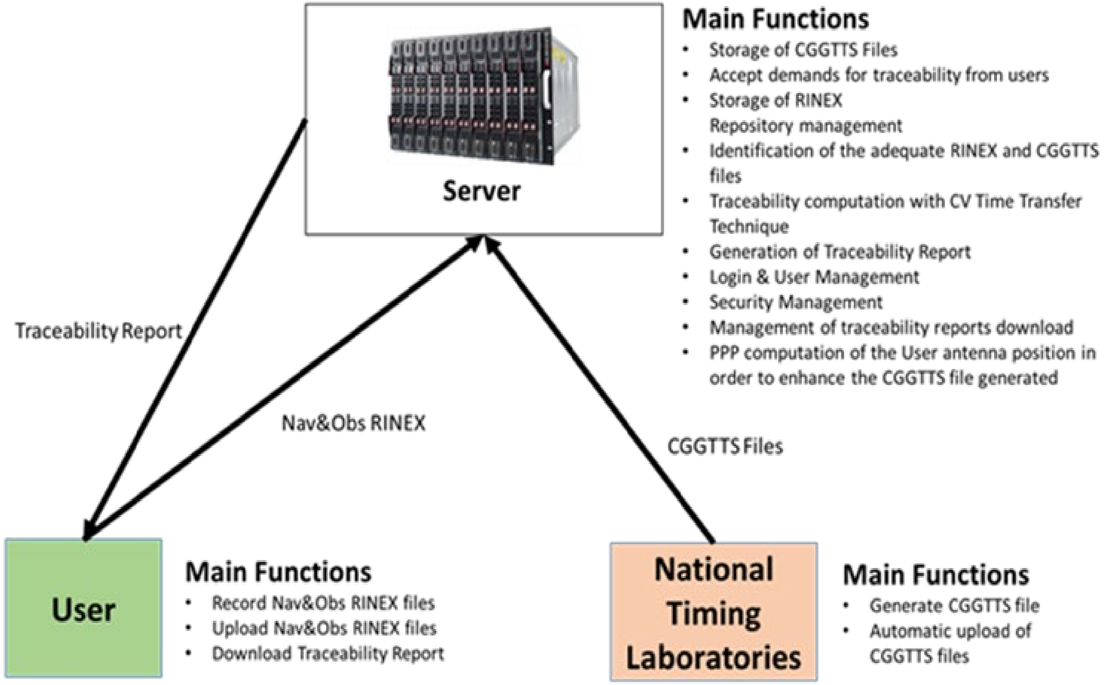
Valdani Vicari & Associati
ECONOMICS & POLICY

EU project EGALITE

Timing Services Based on European GNSS

* **proposal 1**: Service to obtain legal traceability

- ➢ CGGTTS files provided periodically by the NMIs in EU in an automatic way.
- ➢ GNSS raw data (in RINEX format) provided by the users of the Service.
- ➢ Traceability reports would be disseminated to the users and stored in the Server.



Main Functions
- Storage of CGGTTS Files
- Accept demands for traceability from users
- Storage of RINEX Repository management
- Identification of the adequate RINEX and CGGTTS files
- Traceability computation with CV Time Transfer Technique
- Generation of Traceability Report
- Login & User Management
- Security Management
- Management of traceability reports download
- PPP computation of the User antenna position in order to enhance the CGGTTS file generated

Main Functions
- Record Nav&Obs RINEX files
- Upload Nav&Obs RINEX files
- Download Traceability Report

Main Functions
- Generate CGGTTS file
- Automatic upload of CGGTTS files

- ➢ The service is proposed for both GPS and Galileo users with low cost timing receivers with either Dual or Single Frequency equipment
- ➢ Similar to service offered by NIST .

- ➢ No decision for its implementation in the short term

EU project EGALITE

Second proposed Timing Service:

- Based on **Timing Integrity Monitoring Stations** Measurements processed by a Timing Service Processing Facility which would disseminate **timing flags** to the users in the Galileo Signal-In-Space for indicating Use/Not Use Galileo satellites for timing applications
- Additional measures at receiver level are proposed such as **T-RAIM**, **Holdover**, and calibration, etc.

➢ TS would provide **end-to-end committed performances** to the users; Timing receivers to be developed according to dedicated standard.

EU project EGALITE

Result of questionaire 2018/2019 among EU members:

- In all European Union de facto time is obeyed as UTC, UTC+1h, UTC+2h or UTC+3h, respectively, including daylight saving time.
- In some countries, legal time is defined but
  - no institute is given the task to realize it,
  - no institute has a legal mandate to disseminate legal time.

- Practically all European institutes that pursue a T+F-activity disseminate time-of-day information (i. e. UTC) via the public Internet using the protocol NTP.

- Technical means of dissemination are not mentioned in any legal document, in particular GNSS (or GPS) is not mentioned anywhere.

EU project EGALITE

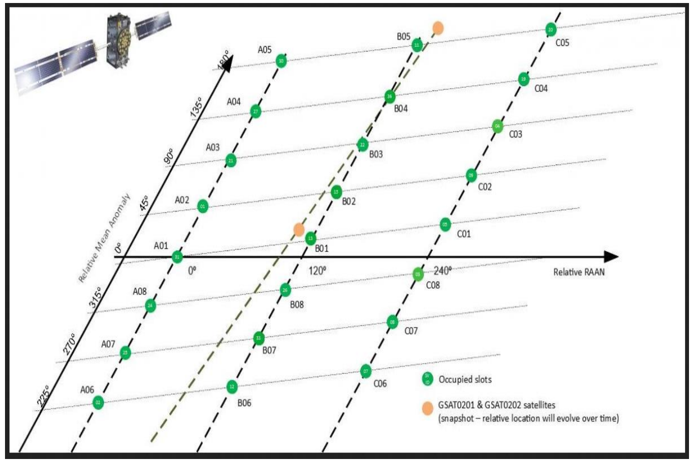
Result of questionaire 2018/2019 among EU members:

- Reception of GPS is used in countless applications for access to (legal) time - irrespective of existing laws:
- i. e. TOD in UTC through Week Number, Seconds of Week, Leap Second count.

  Galileo is “known”, but not yet widely used.
- EGNOS is of minor relevance in the T+F community.

The use of European GNSS

It is widely accepted not to use GNSS system times, but the predictions
GST – UTC (for Galileo) or GPStime – UTC(USNO),
which are broadcast in the respective navigation messages.



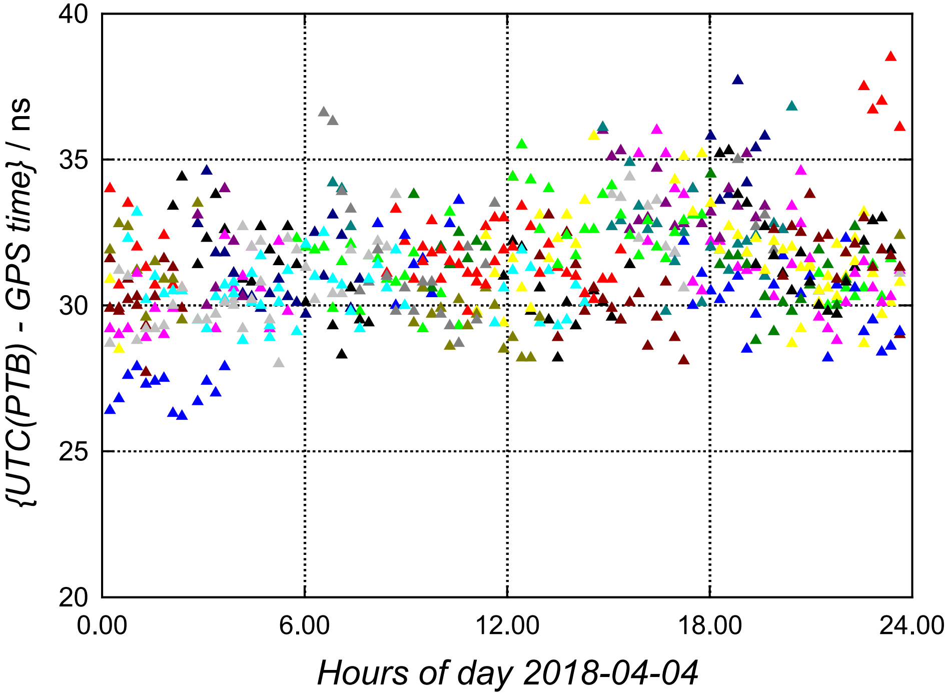
But

OS SDD Table 11 provides MPL for GST – UTC prediction

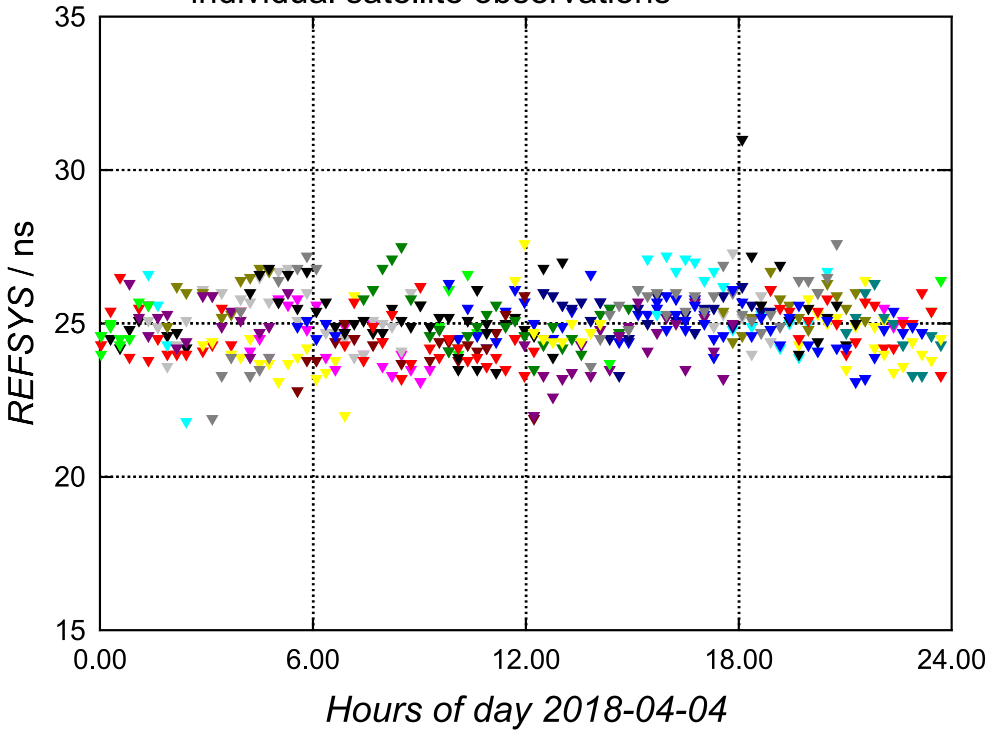
- ❖ Missing traceability: how is GST constructed, how is the prediction made?
- OS SDD Table 18 implicitly fixes MPL for clock model SV-GST
  to an almost negligible value (??)
- ❖ Missing traceability: algorithm? description?
- Proposals made to improve documentation for facilitating traceability
- Work to be continued in CCTF Task force on GNSS traceability, starting 2020

The use of European GNSS…
brings advantages!

GPS observation with receiver PT13 at PTB
individual satellites observations



Galileo observation with receiver PT13 at PTB
individual satellite observations



Better clock and orbit predicition,
Improved „NeQuick“ ionosphere model*
for single frequency users..

Timing Services Based on European GNSS

Conclusions regarding professional applications of (legal) time:

a) Make a clear distinction between

- ♦ Time interval / frequency (unit of time)
- ♦ mutual synchronization within a network / system
- ♦ synchronization with respect to UTC
- ♦ Time of Day (TOD) according to legal time

b) Clearly differentiate between

- ♦ legal prescription (as German TeleKommunikationsGesetz)
- ♦ prescription due to EU regulations (like MIFID / RTS25)
- ♦ technical requirements in critical infrastructure applications

Timing Services Based on European GNSS

Conclusions regarding professional applications of (legal) time:

- There are ways to make measurement results traceable in the sense of the VIM:
- Recommendation to retrieve and analyze GNSS signal monitoring results from NMIs or other resources.
  Example: PTB public data repository and Time Service Bulletin*
- Recommendation to get signal delays in the receiver calibrated whenever epoch (accurate time synchronization) matters.

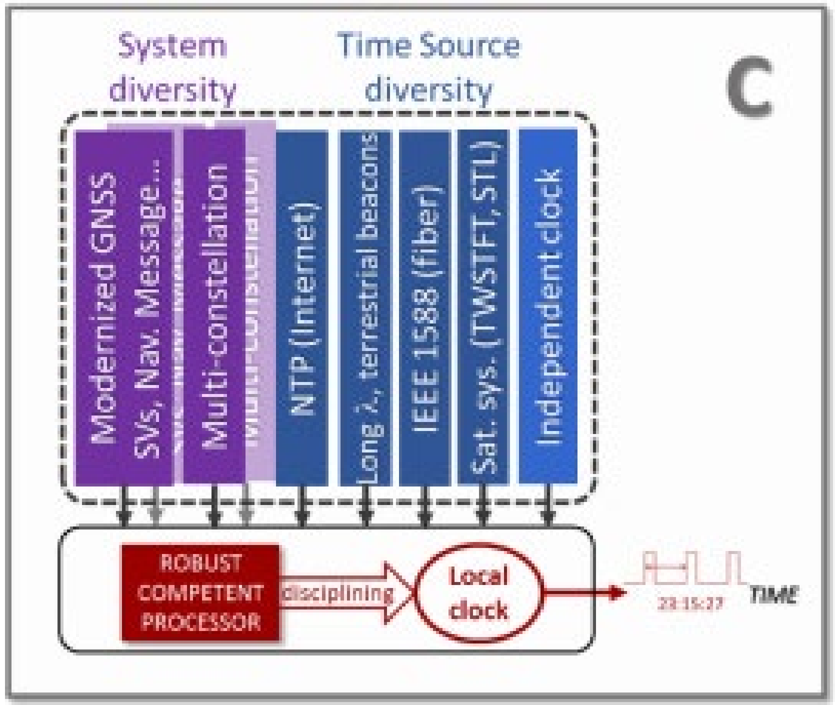
Timing Services Based on European GNSS

Conclusions regarding professional applications of (legal) time:

Final Recommendations:

- No <u>single</u> source of timing should be recommended for use in critical infrastructures.
- Promote use of redundant timing information, delivered via diverse routes, i.e.
- Integrate
  - fiber-based signals via public or private network (NTP, PTP, WR),
  - radio-signals, good clocks for hold-over

  in exacting timing systems.



Schematics of the competent processor, source NIST

Thank you for the opportunity to share my ideas with you.

Feel free to contact me at	andreas.bauch@ptb.de
See our website at	www.ptb.de/time

PTB Timing Services Based on European GNSS

List of references

Joint Committee for Guides in Metrology, “International vocabulary of metrology – Basic and general concepts and associated terms (VIM), 3rd Edition”, JCGM 200:2012, JCGM, 2012.

D. Matsakis, J. Levine, and M. A. Lombardi, “Metrological and legal traceability of time signals “, Proc. 2018 ION PTTI, Reston, Virginia, pp. 59-71

D. Piester et al., „Disciplined Oscillators for Traceable Frequency and Time in Metrology and Financial Sectors”, Navigation, vol. 66, 2019, pp. 661-671.

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European GNSS (Galileo) Open Service Service Definition Document (OS SDD) 05/2019

D. Piester et al., “PTB’s Time and Frequency Services 2018 – 2019”, Proc. 2020 ION PTTI, San Diego, CA

J. Fidalgo et al., “Proposal for the Definition of a European GNSS Timing Service”, Proc. ION 2019

European GNSS (Galileo) Open Service: Ionospheric Correction Algorithm for Galileo Single Frequency Users, European Commission, 2015

Links:

https://www.gsc-europa.eu/system-service-status/orbital-and-technical-parameters
ftp://ftp.ptb.de/pub/time/GNSS

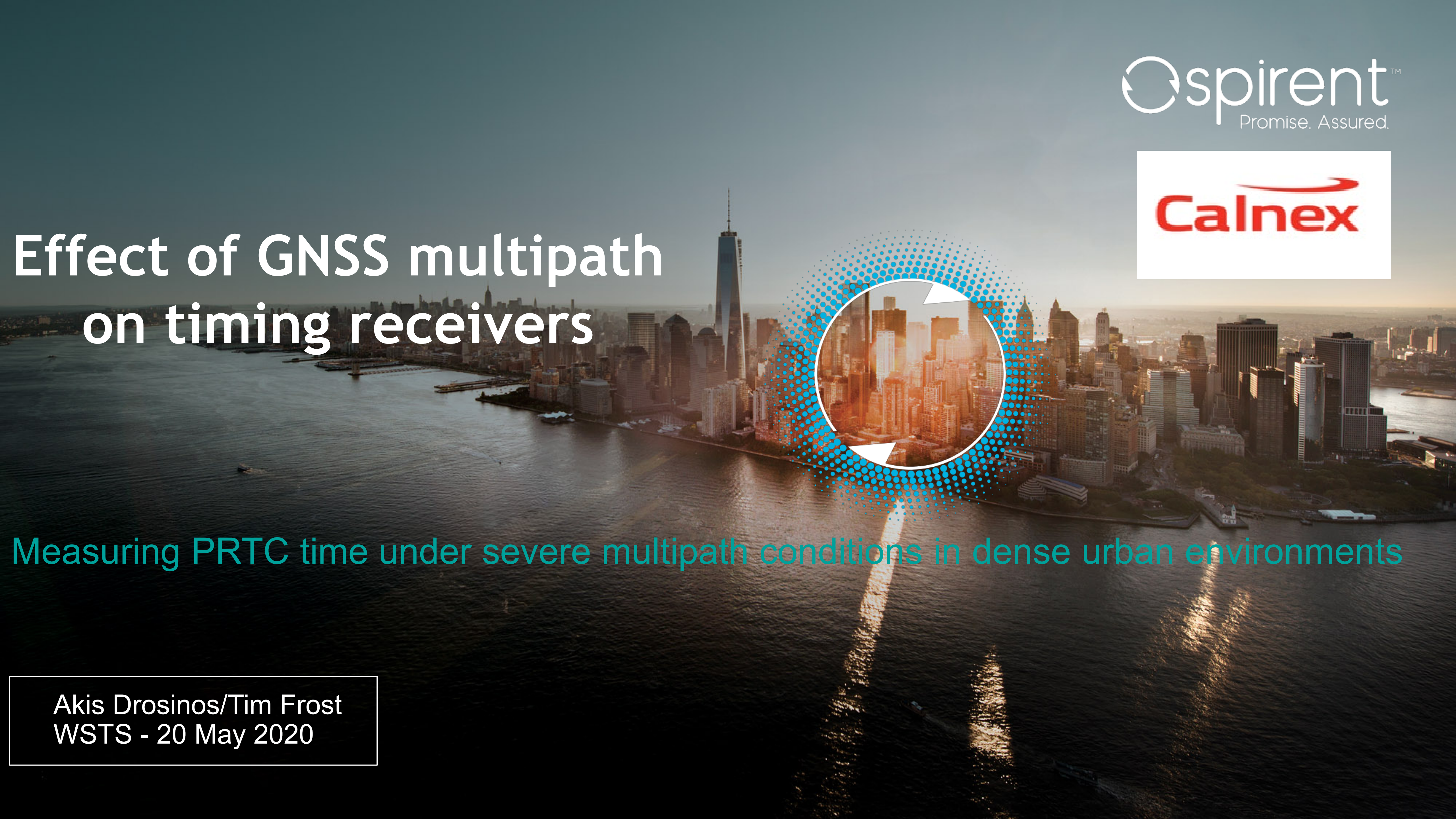
WORKSHOP ON SYNCHRONIZATION AND TIMING SYSTEMS

Effect of GNSS Multipath on Timing Receivers

Akis Droninos
Member of the Technical Staff
Spirent Communications

Sponsored by: MEINBERG

Session 3: Timing Security, Resilience and GNSS Issues
May 20, 2020



Spirent
Promise. Assured.

Calnex

Effect of GNSS multipath on timing receivers

Measuring PRTC time under severe multipath conditions in dense urban environments

Akis Drosinos/Tim Frost
WSTS - 20 May 2020

Session objectives

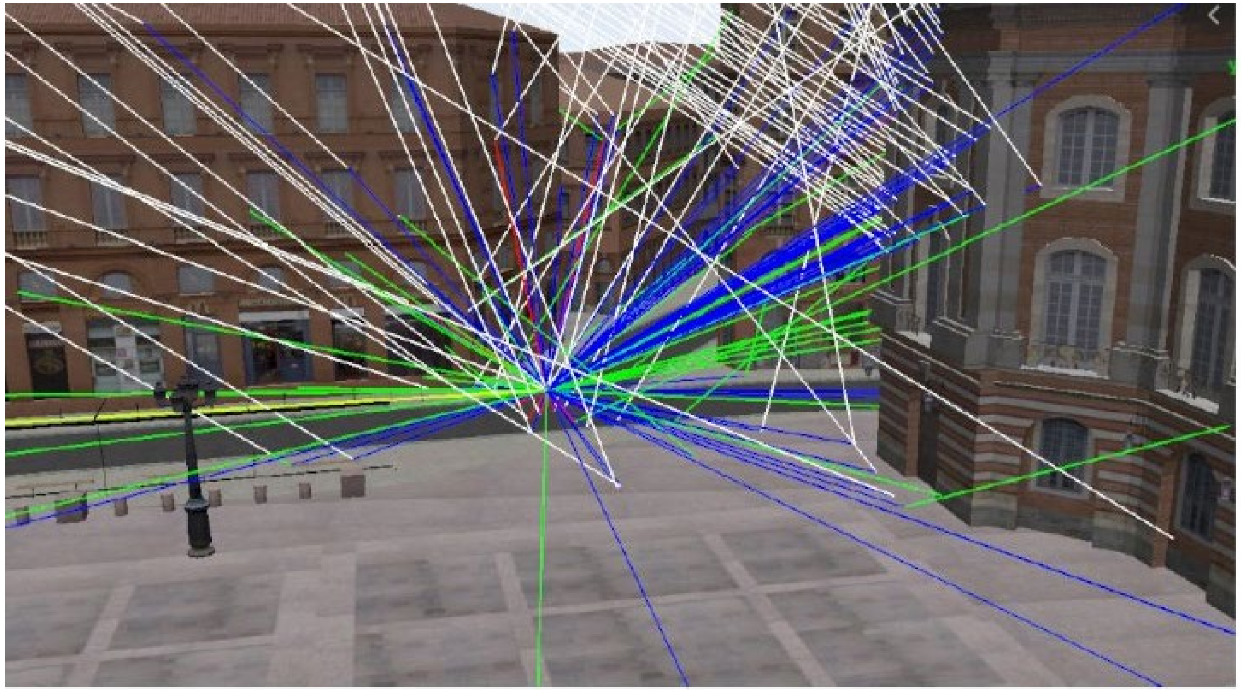
1. Talking you through the set-up that was used to conduct the measurements.
2. Presenting the experimental results of the effects multipath has on timing receivers in dense urban environments.
3. Discussing about the importance of introducing new testing methods to measure such effects.

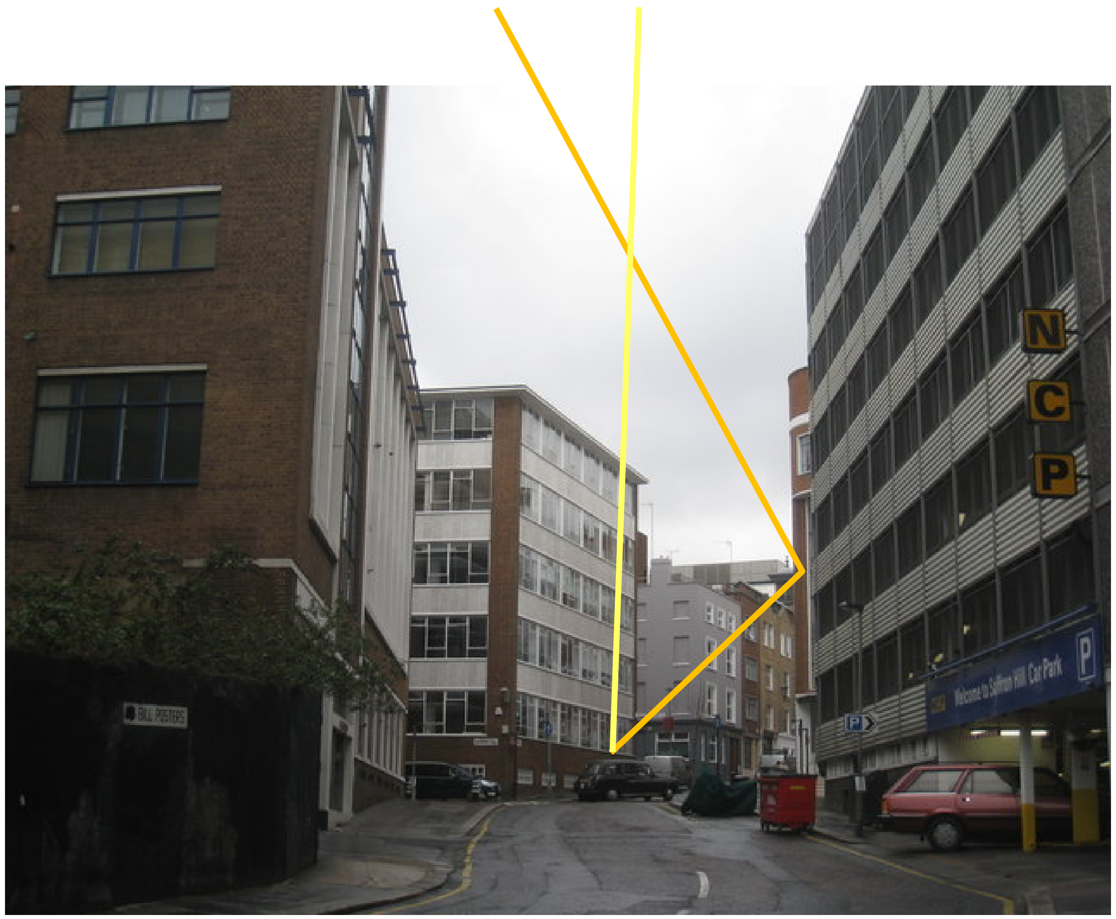
Introduction

- Sometimes the GNSS-based PRTC’s might be installed in areas where there is not a clear view of the sky, e.g. in dense urban environments.
- Multipath will degrade the performance of the timing accuracy of the GNSS-based PRTC’s and therefore providing testing methods in order to “measure” this error is of utmost importance.

Multipath 1/2

Urban canyon environments





Multipath 2/2

Geometry & characteristics

- It depends solely on the environment around the antenna and is therefore very difficult to be modelled.
  - A constructive multipath interference results in an increase in the C/N0, while a destructive interference results in a decrease in the C/N0. [1]
  - Moreover, multipath interference might be constructive on one frequency and destructive on another. [1]
- In our tests, we considered GPS L1 and GLONASS L1 due to frequency limitations on the PRTC.

Time error measurement tests set-up 1/4

- Our set-up was based on Figures I.7 and I.8 of Appendix I in the G.8272/Y.1367 Recommendation.
- However, since those set-ups didn't take into account non-ideal GNSS conditions, we introduced a 3D ray tracing software in order to simulate a realistic multipath environment.
- All runs were ~1 day long, static, and before the measurements, the DUT was always in “Position-Fix” mode, locked to GNSS.

Time error measurement tests set-up 2/4

- The atmospheric conditions, in the simulator, were normal and there were no other forms of interference present.
- Satellite clock or track errors were not applied either.
- The measured values, from the Packet and Timing Monitor device, where the:
  - 1 PPS absolute time error
  - 2-way time error (PTP measurement)

Time error measurement tests set-up 3/4

- For our tests we used the following equipment:
  - a GNSS signal generator with enough GNSS channels to simulate the multipath environment.
  - a GNSS-based PRTC/T-GM supporting PTP and 1 PPS, capable of tracking GPS L1 & GLONASS L1 frequencies.
  - a 3D ray tracing software.
  - a Packet Timing Monitor.

Time error measurement tests set-up 4/4

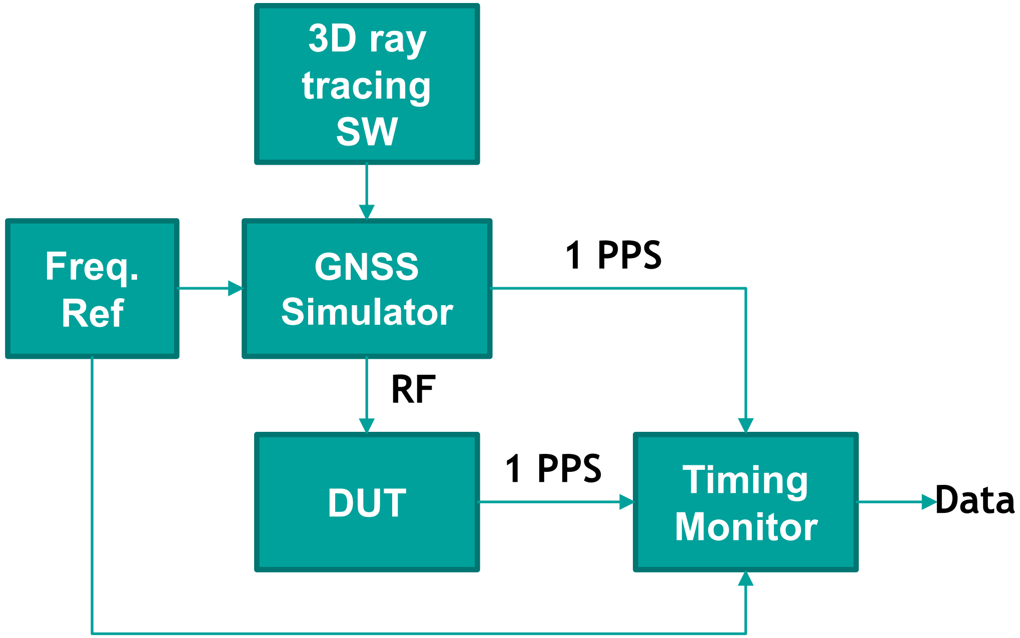


Figure 1: 1 PPS measurement set-up

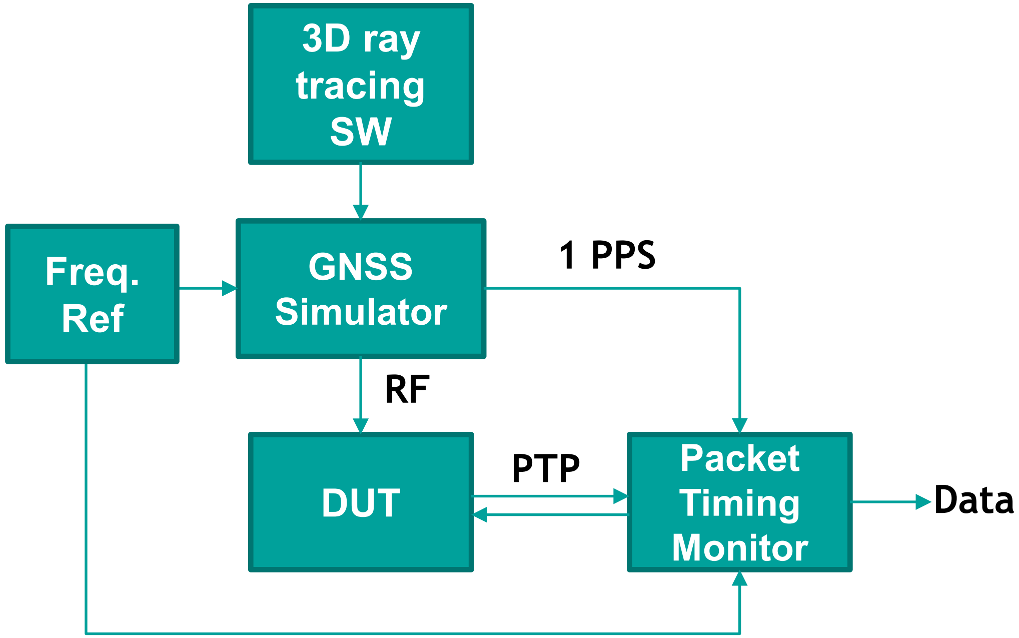


Figure 2. PTP measurement set-up

Simulated Scenes

- The dense urban environments, for which we ran our experimental tests, are:
    1. San Francisco, California
    2. Manhattan, New York
    3. Shanghai, China

San Francisco 1/3

3D scene

- The white lines represent the direct signals
- The blue lines represent the refracted signals
- The red lines represent the reflected signals

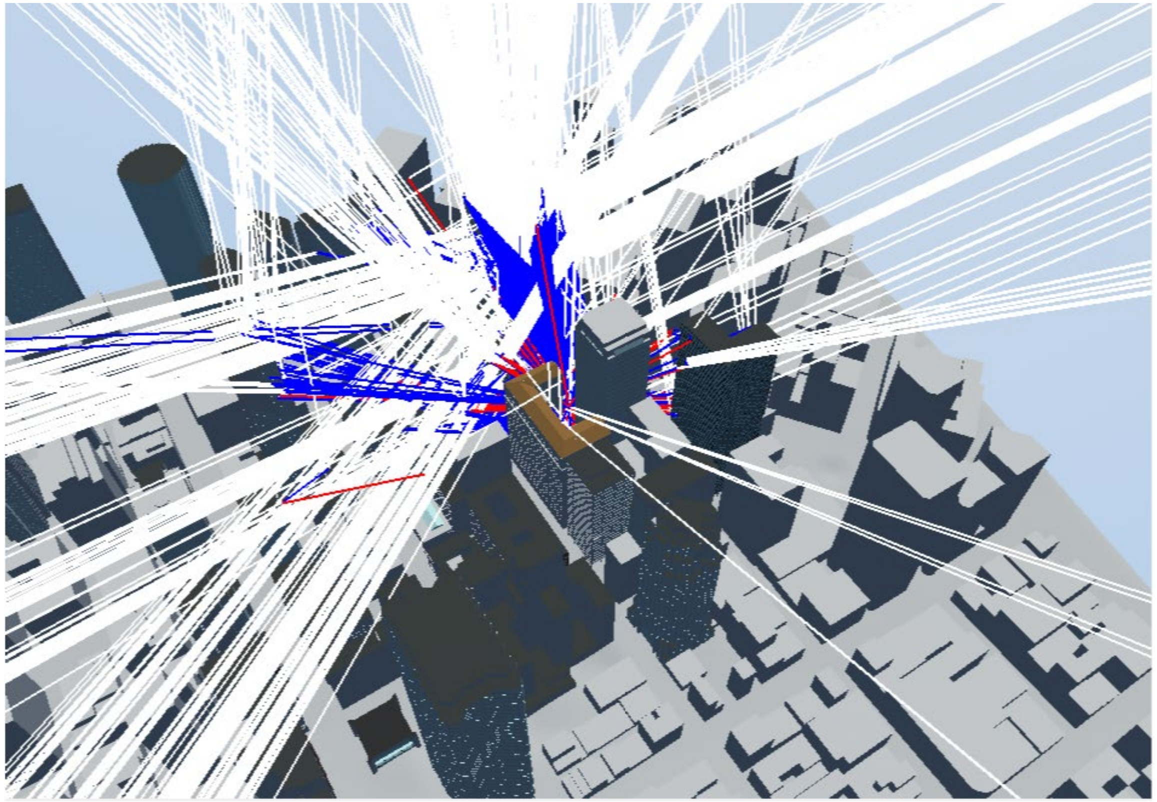


Figure 3: San Francisco multipath environment

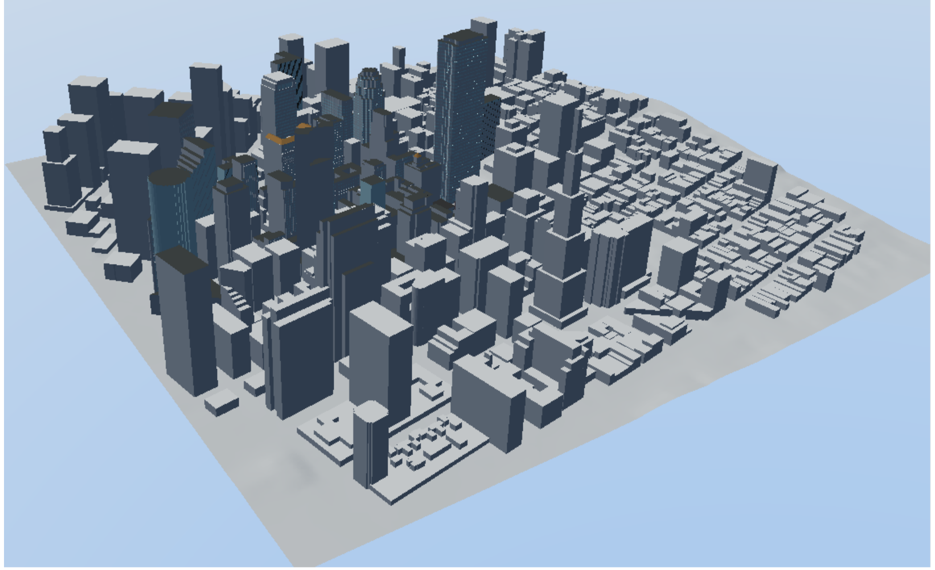


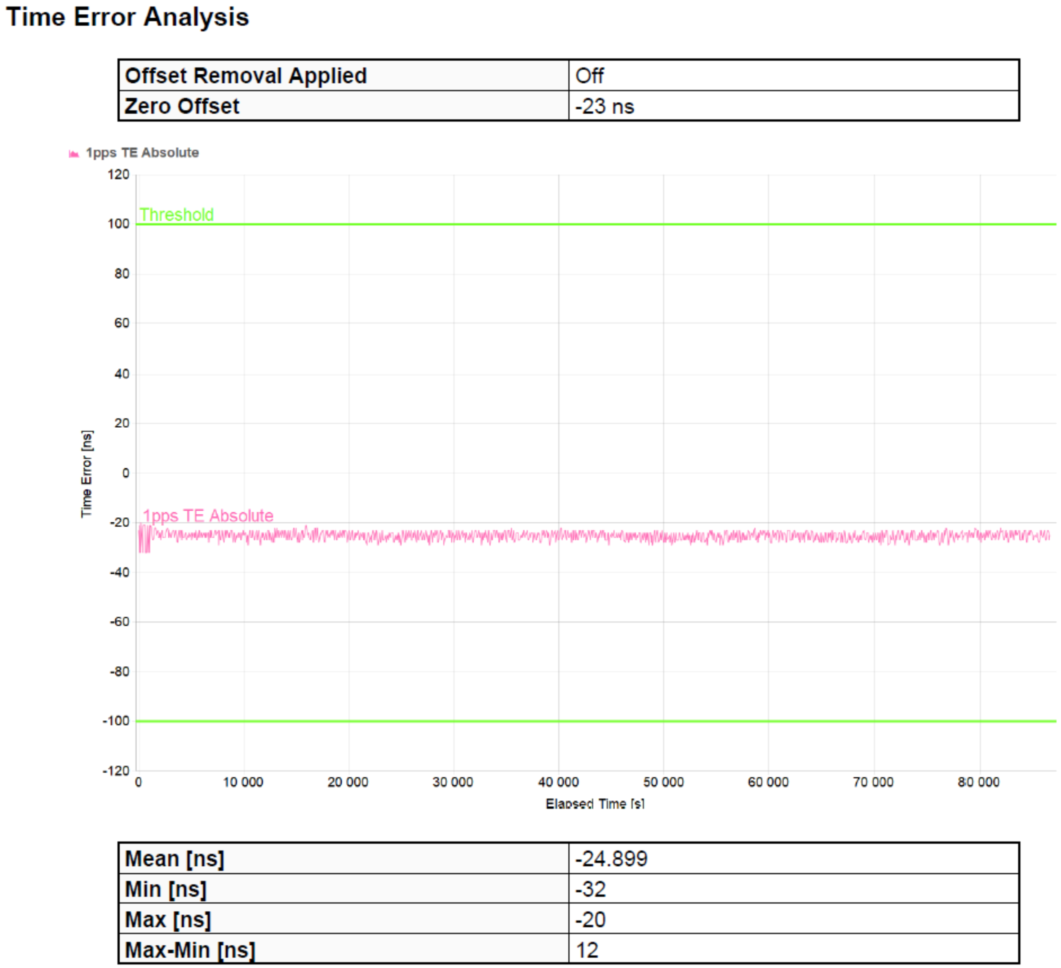
Figure 4: San Francisco 3D scene

San Francisco 2/3

Open sky conditions

spirent Promise. Assured.

Calnex

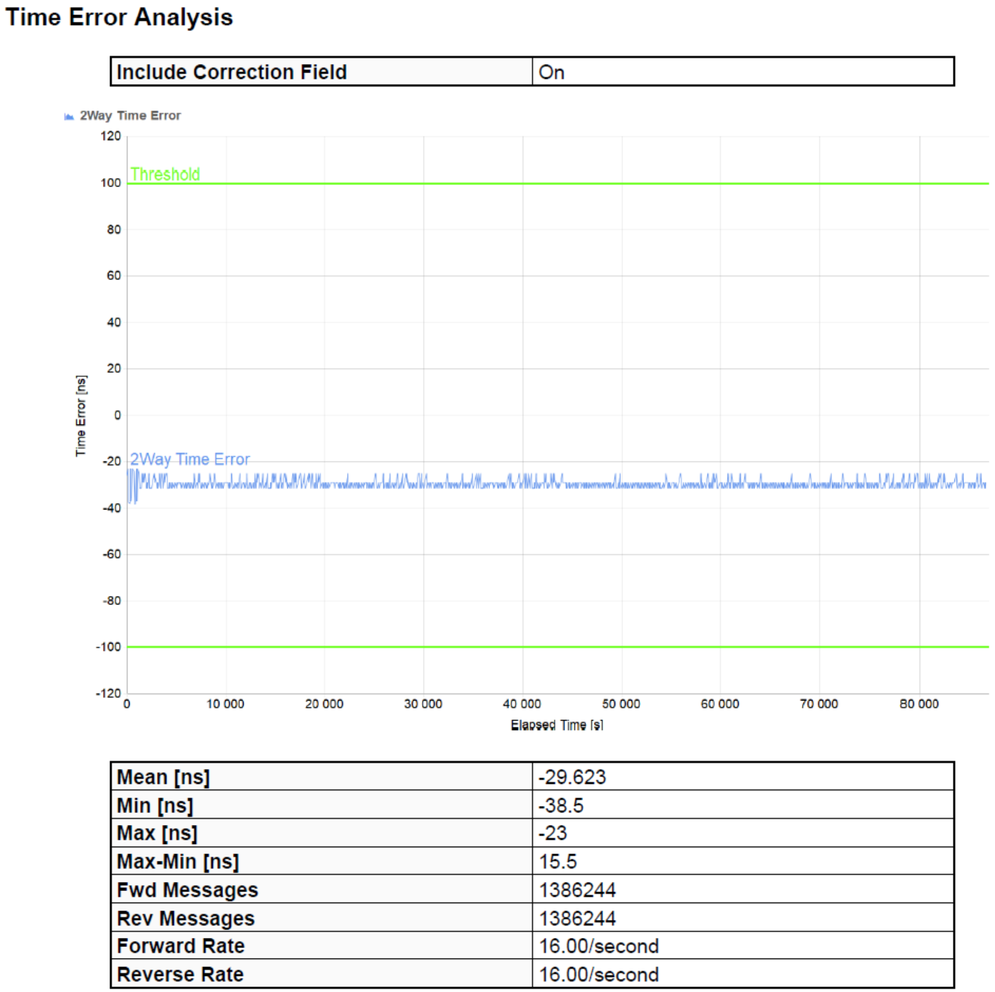


Time Error Analysis

Offset Removal Applied	Off
Zero Offset	-23 ns

Mean [ns]	-24.899
Min [ns]	-32
Max [ns]	-20
Max-Min [ns]	12

Figure 7. 1 PPS absolute time error under open-sky conditions



Time Error Analysis

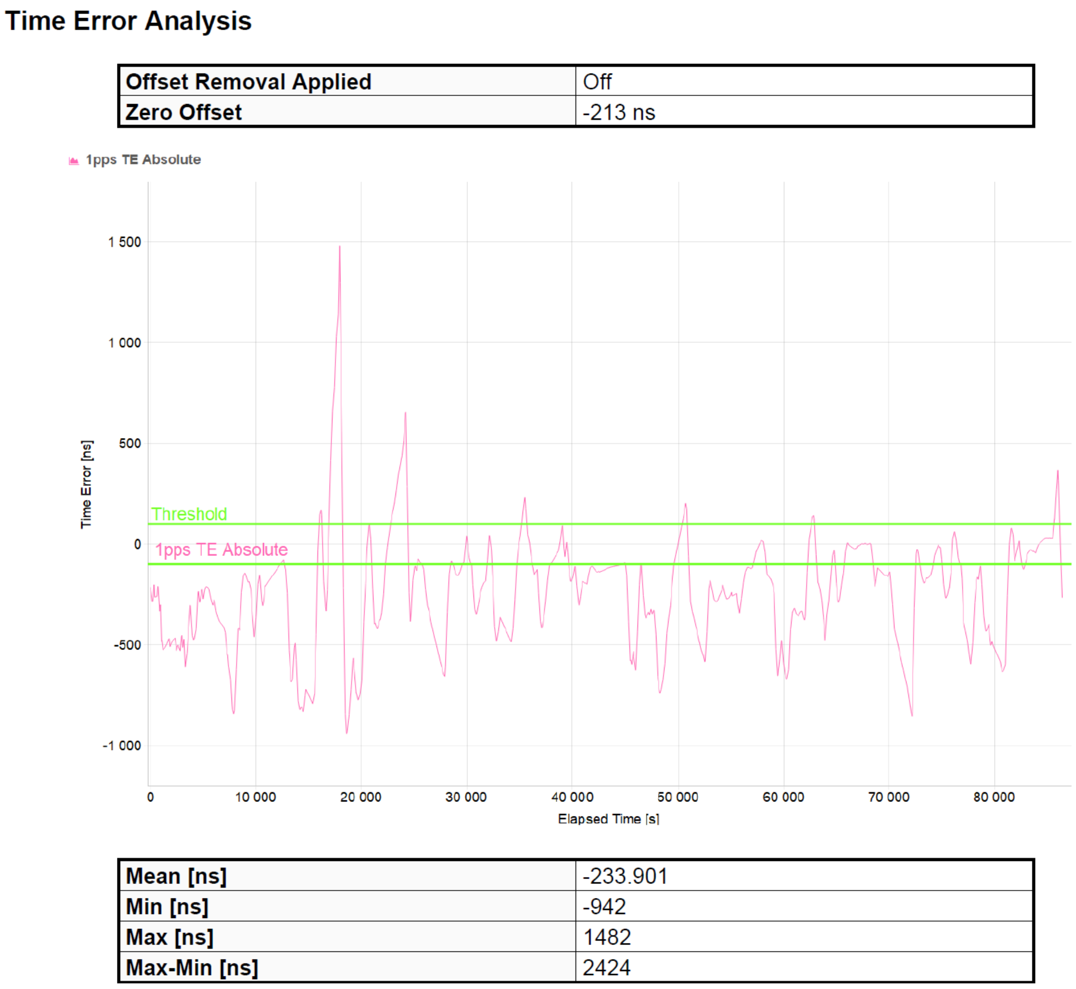
Include Correction Field	On

Mean [ns]	-29.623
Min [ns]	-38.5
Max [ns]	-23
Max-Min [ns]	15.5
Fwd Messages	1386244
Rev Messages	1386244
Forward Rate	16.00/second
Reverse Rate	16.00/second

Figure 8. 2-way time error under open-sky conditions

San Francisco 3/3

Multipath conditions

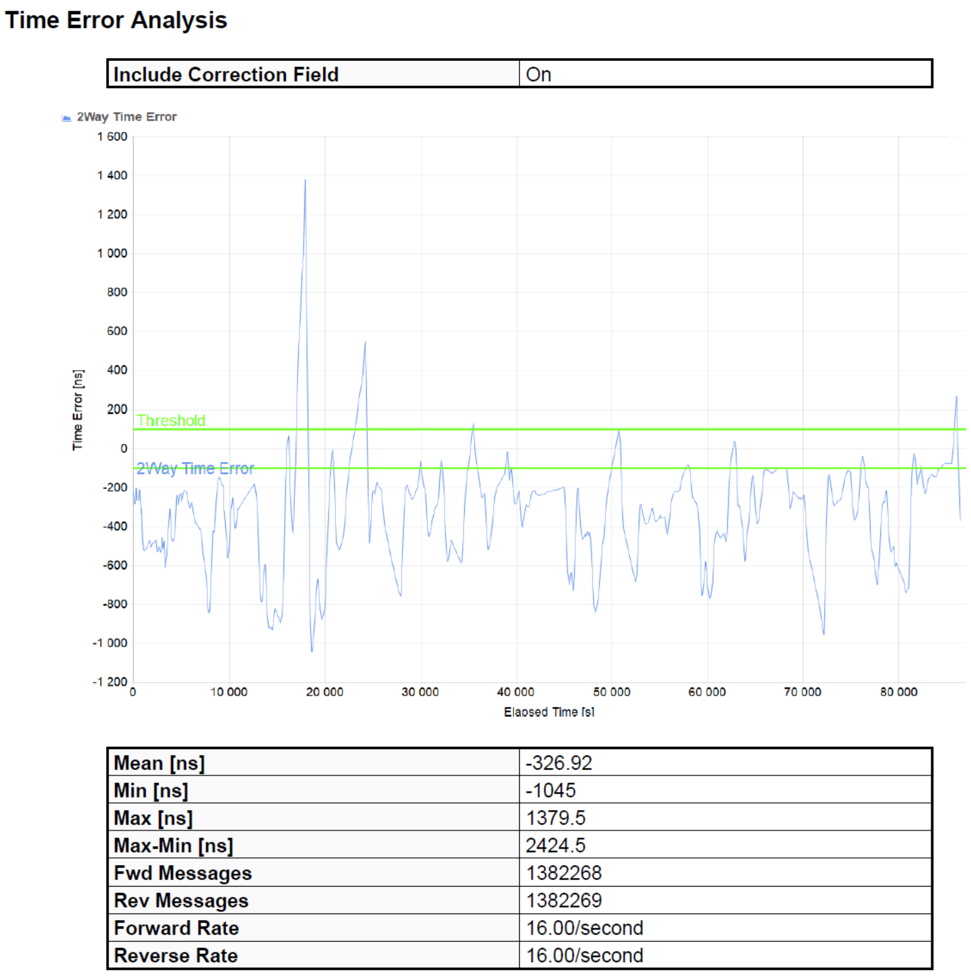


Time Error Analysis

Offset Removal Applied	Off
Zero Offset	-213 ns

Mean [ns]	-233.901
Min [ns]	-942
Max [ns]	1482
Max-Min [ns]	2424

Figure 5. 1 PPS absolute time error under multipath conditions



Time Error Analysis

Include Correction Field	On

Mean [ns]	-326.92
Min [ns]	-1045
Max [ns]	1379.5
Max-Min [ns]	2424.5
Fwd Messages	1382268
Rev Messages	1382269
Forward Rate	16.00/second
Reverse Rate	16.00/second

Figure 6. 2-way time error under multipath conditions

Manhattan 1/4

3D scene

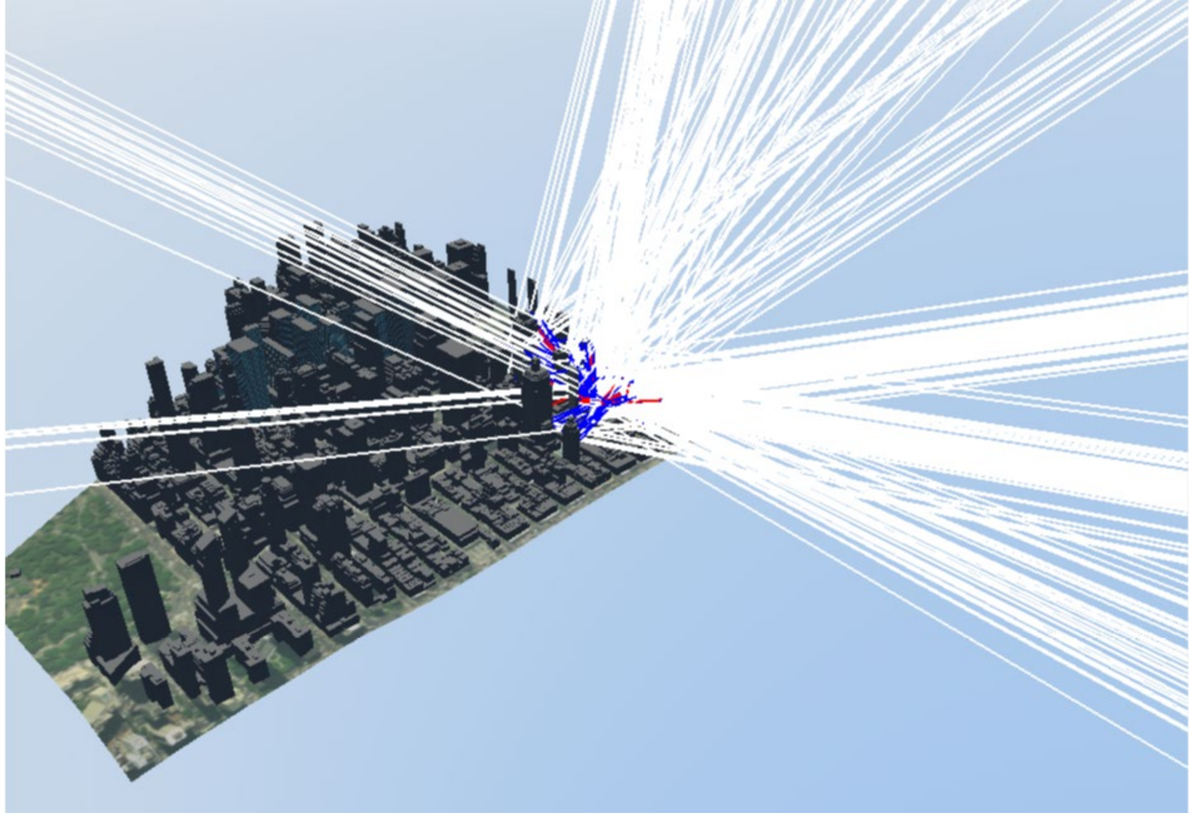


Figure 9: Manhattan multipath environment

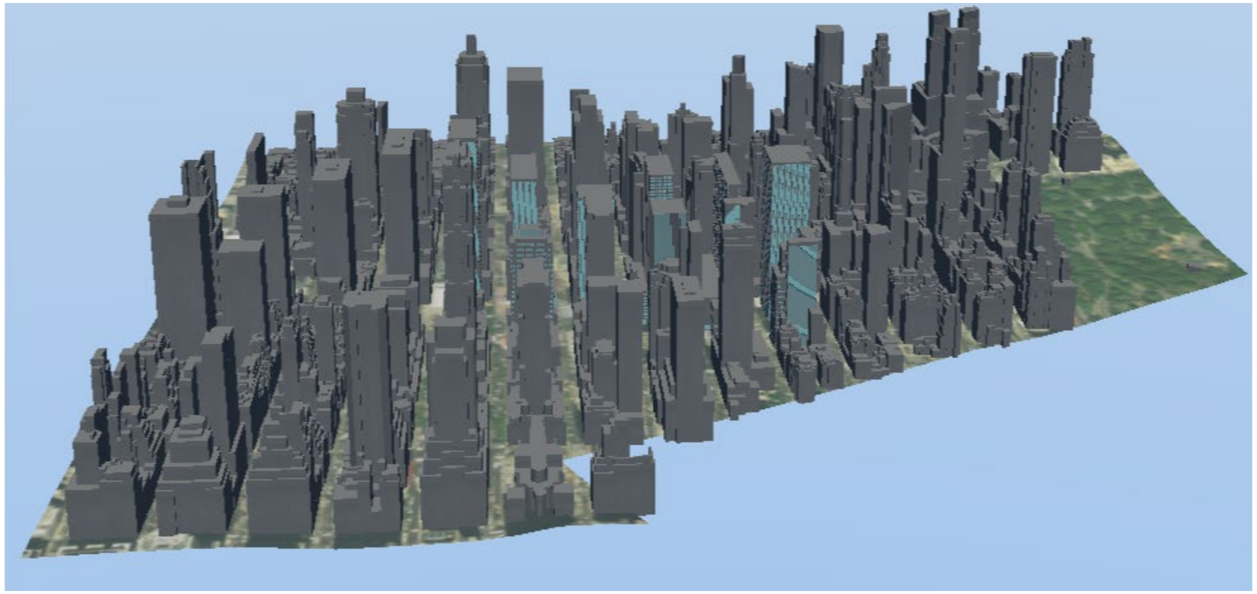


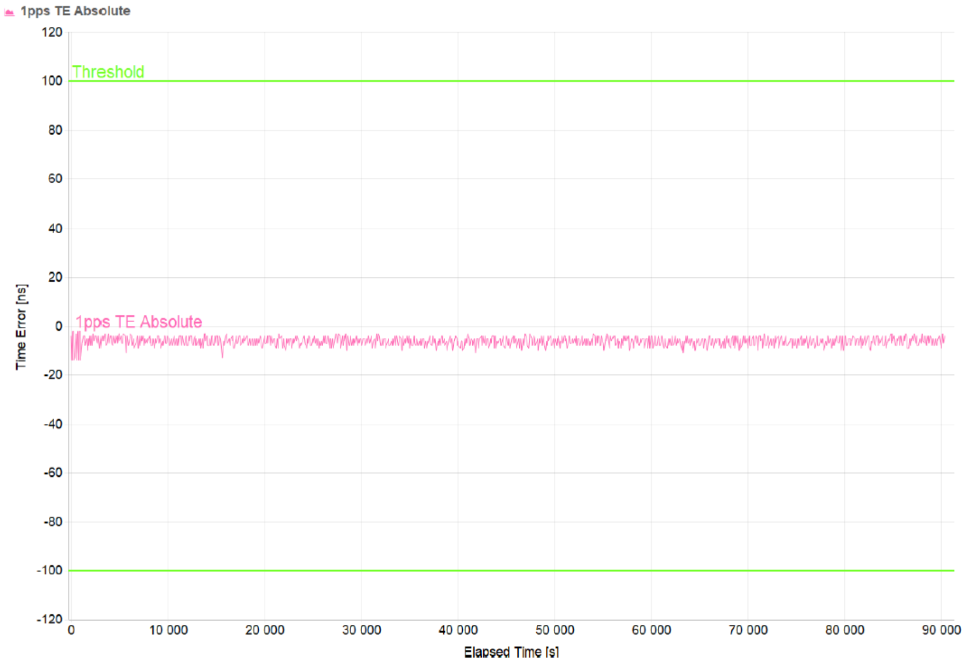
Figure 10: Manhattan 3D scene

Manhattan 2/4

Open sky conditions

Time Error Analysis

Offset Removal Applied	Off
Zero Offset	-4 ns

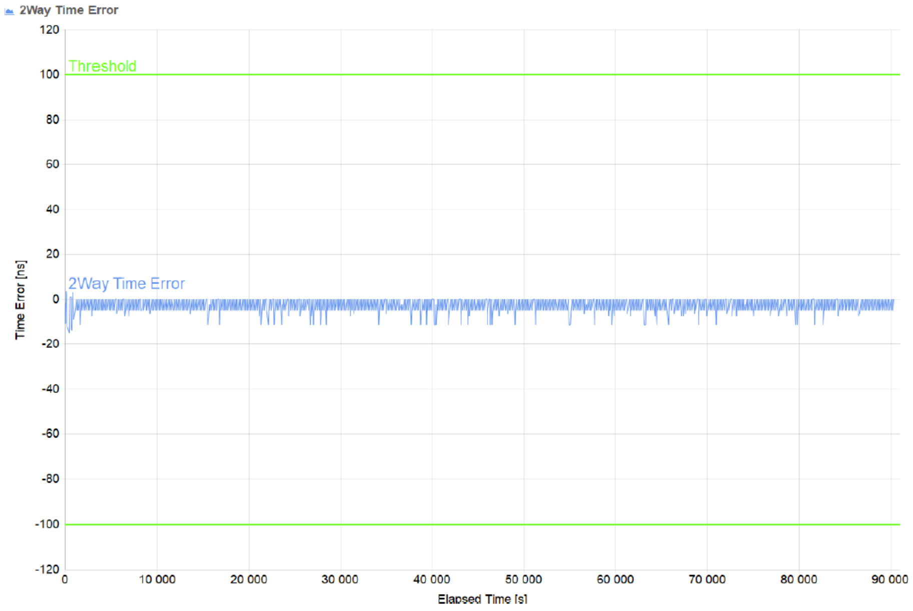


Mean [ns]	-6.442
Min [ns]	-14
Max [ns]	-2
Max-Min [ns]	12

Figure 13. 1 PPS absolute time error under open-sky conditions

Time Error Analysis

Include Correction Field	On



Mean [ns]	-1.233
Min [ns]	-15
Max [ns]	3.5
Max-Min [ns]	18.5
Fwd Messages	1444967
Rev Messages	1444954
Forward Rate	16.00/second
Reverse Rate	16.00/second

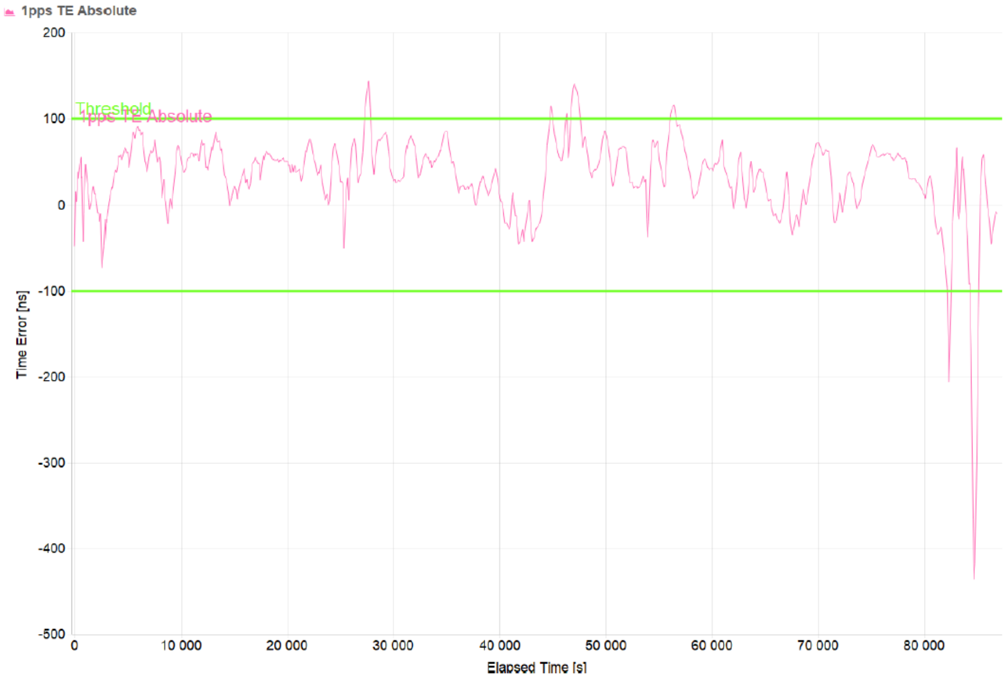
Figure 14. 2-way time error under open-sky conditions

Manhattan 3/4

Multipath conditions

Time Error Analysis

Offset Removal Applied	Off
Zero Offset	-48 ns

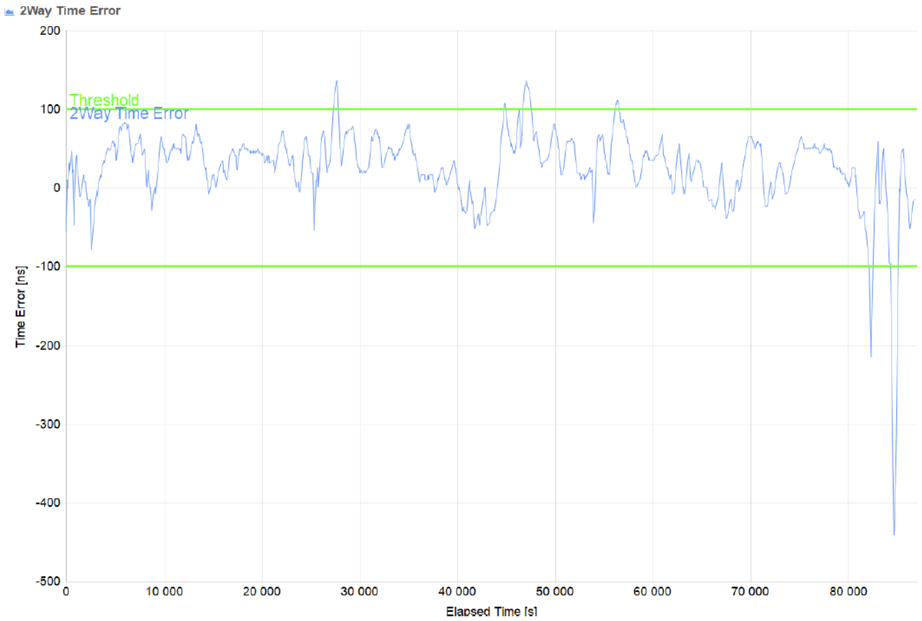


Mean [ns]	32.345
Min [ns]	-436
Max [ns]	144
Max-Min [ns]	580

Figure 11. 1 PPS absolute time error under multipath conditions

Time Error Analysis

Include Correction Field	On

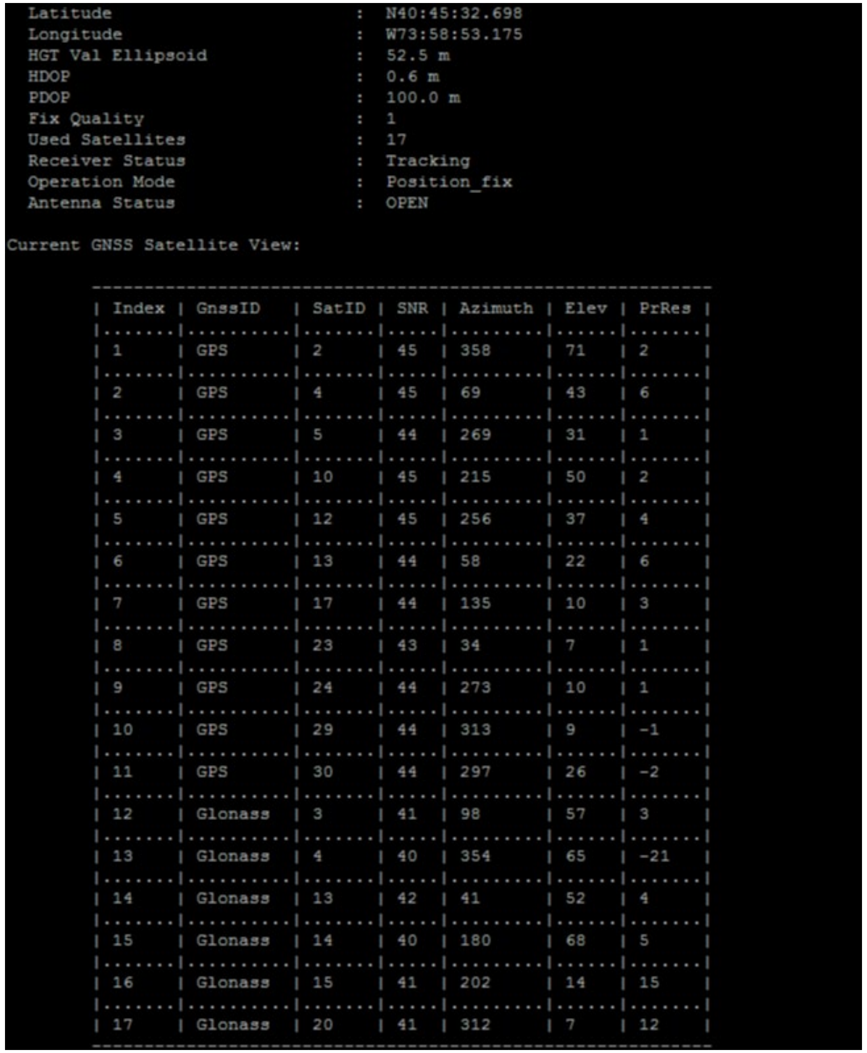


Mean [ns]	26.224
Min [ns]	-441.5
Max [ns]	136.5
Max-Min [ns]	578
Fwd Messages	1389047
Rev Messages	1389030
Forward Rate	16.00/second
Reverse Rate	16.00/second

Figure 12. 2-way time error under multipath conditions

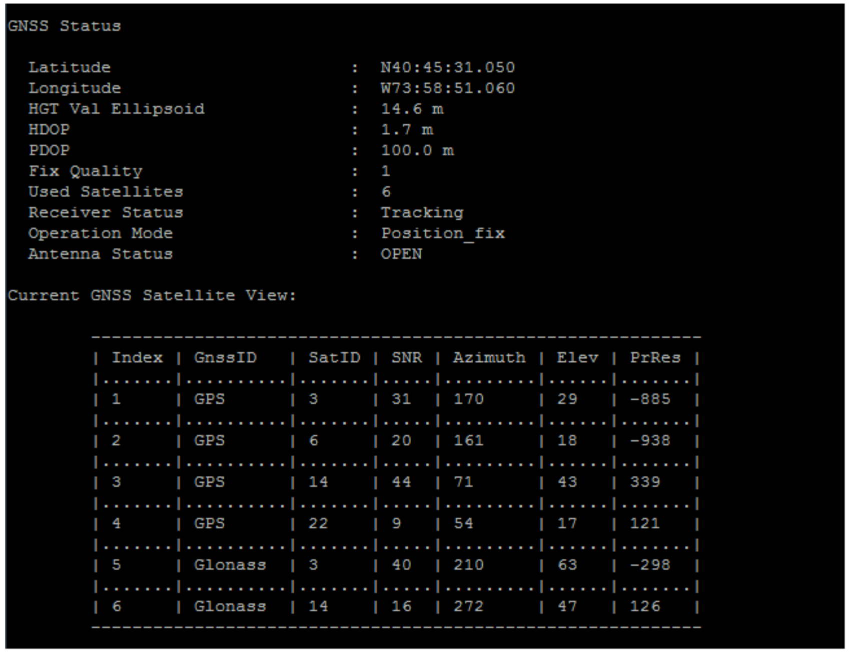
Manhattan 4/4

GNSS status of the DUT



```
  Latitude                          :  N40:45:32.698
  Longitude                         :  W73:58:53.175
  HGT Val Ellipsoid                 :  52.5 m
  HDOP                              :  0.6 m
  PDOP                              :  100.0 m
  Fix Quality                       :  1
  Used Satellites                   :  17
  Receiver Status                   :  Tracking
  Operation Mode                    :  Position_fix
  Antenna Status                    :  OPEN

Current GNSS Satellite View:

        ------------------------------------------------------------
        | Index | GnssID    | SatID | SNR | Azimuth  | Elev | PrRes |
        |.......|...........|.......|.....|..........|......|.......|
        | 1     | GPS       | 2     | 45  | 358      | 71   | 2     |
        |.......|...........|.......|.....|..........|......|.......|
        | 2     | GPS       | 4     | 45  | 69       | 43   | 6     |
        |.......|...........|.......|.....|..........|......|.......|
        | 3     | GPS       | 5     | 44  | 269      | 31   | 1     |
        |.......|...........|.......|.....|..........|......|.......|
        | 4     | GPS       | 10    | 45  | 215      | 50   | 2     |
        |.......|...........|.......|.....|..........|......|.......|
        | 5     | GPS       | 12    | 45  | 256      | 37   | 4     |
        |.......|...........|.......|.....|..........|......|.......|
        | 6     | GPS       | 13    | 44  | 58       | 22   | 6     |
        |.......|...........|.......|.....|..........|......|.......|
        | 7     | GPS       | 17    | 44  | 135      | 10   | 3     |
        |.......|...........|.......|.....|..........|......|.......|
        | 8     | GPS       | 23    | 43  | 34       | 7    | 1     |
        |.......|...........|.......|.....|..........|......|.......|
        | 9     | GPS       | 24    | 44  | 273      | 10   | 1     |
        |.......|...........|.......|.....|..........|......|.......|
        | 10    | GPS       | 29    | 44  | 313      | 9    | -1    |
        |.......|...........|.......|.....|..........|......|.......|
        | 11    | GPS       | 30    | 44  | 297      | 26   | -2    |
        |.......|...........|.......|.....|..........|......|.......|
        | 12    | Glonass   | 3     | 41  | 98       | 57   | 3     |
        |.......|...........|.......|.....|..........|......|.......|
        | 13    | Glonass   | 4     | 40  | 354      | 65   | -21   |
        |.......|...........|.......|.....|..........|......|.......|
        | 14    | Glonass   | 13    | 42  | 41       | 52   | 4     |
        |.......|...........|.......|.....|..........|......|.......|
        | 15    | Glonass   | 14    | 40  | 180      | 68   | 5     |
        |.......|...........|.......|.....|..........|......|.......|
        | 16    | Glonass   | 15    | 41  | 202      | 14   | 15    |
        |.......|...........|.......|.....|..........|......|.......|
        | 17    | Glonass   | 20    | 41  | 312      | 7    | 12    |
        ------------------------------------------------------------
```

Figure 15. GNSS status of DUT under open sky conditions



```
GNSS Status

  Latitude                          :  N40:45:31.050
  Longitude                         :  W73:58:51.060
  HGT Val Ellipsoid                 :  14.6 m
  HDOP                              :  1.7 m
  PDOP                              :  100.0 m
  Fix Quality                       :  1
  Used Satellites                   :  6
  Receiver Status                   :  Tracking
  Operation Mode                    :  Position_fix
  Antenna Status                    :  OPEN

Current GNSS Satellite View:

        ------------------------------------------------------------
        | Index | GnssID    | SatID | SNR | Azimuth  | Elev | PrRes |
        |.......|...........|.......|.....|..........|......|.......|
        | 1     | GPS       | 3     | 31  | 170      | 29   | -885  |
        |.......|...........|.......|.....|..........|......|.......|
        | 2     | GPS       | 6     | 20  | 161      | 18   | -938  |
        |.......|...........|.......|.....|..........|......|.......|
        | 3     | GPS       | 14    | 44  | 71       | 43   | 339   |
        |.......|...........|.......|.....|..........|......|.......|
        | 4     | GPS       | 22    | 9   | 54       | 17   | 121   |
        |.......|...........|.......|.....|..........|......|.......|
        | 5     | Glonass   | 3     | 40  | 210      | 63   | -298  |
        |.......|...........|.......|.....|..........|......|.......|
        | 6     | Glonass   | 14    | 16  | 272      | 47   | 126   |
        ------------------------------------------------------------
```

Figure 16. GNSS status of DUT under multipath conditions

- There is a big difference in the ellipsoidal height, the pseudorange residuals and in the satellites that were used from the receiver.
- Also, the CN0 values are much smaller in Figure 16.

Shanghai 1/4

3D scene

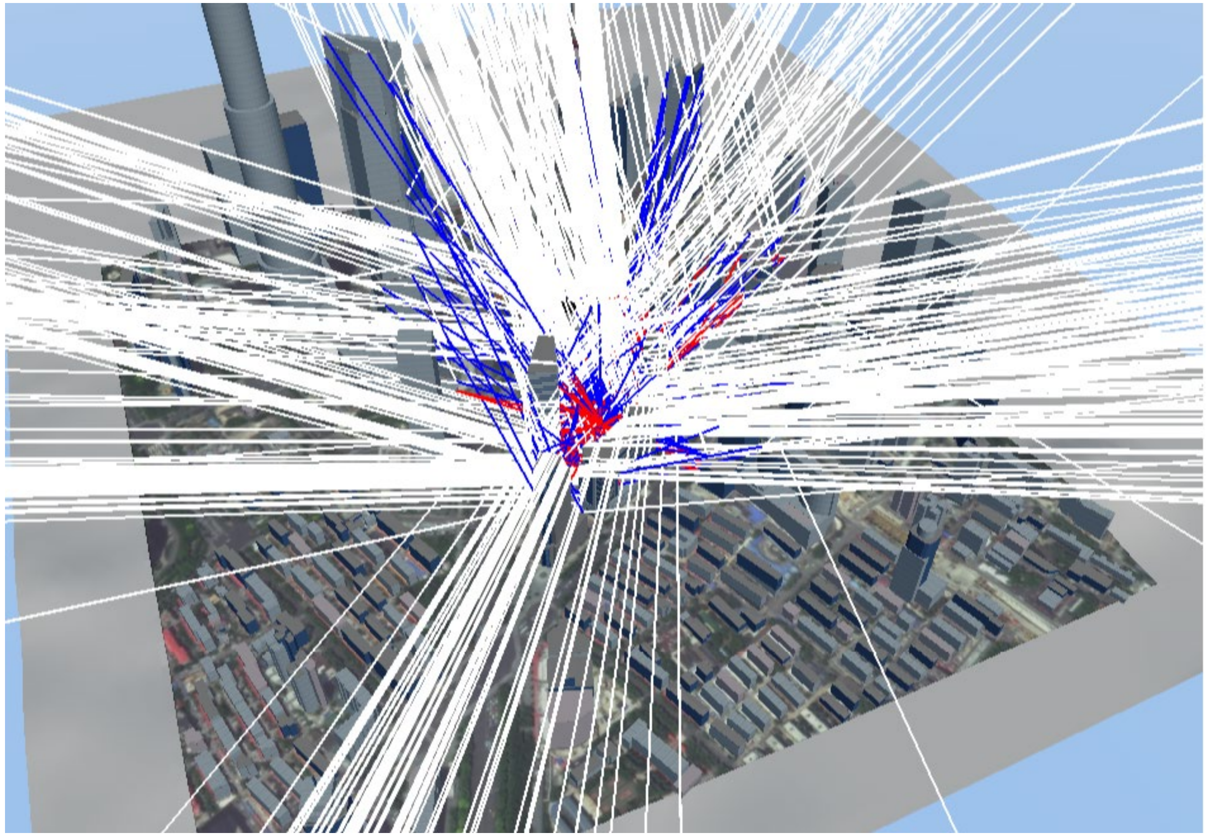


Figure 17: Shanghai multipath environment

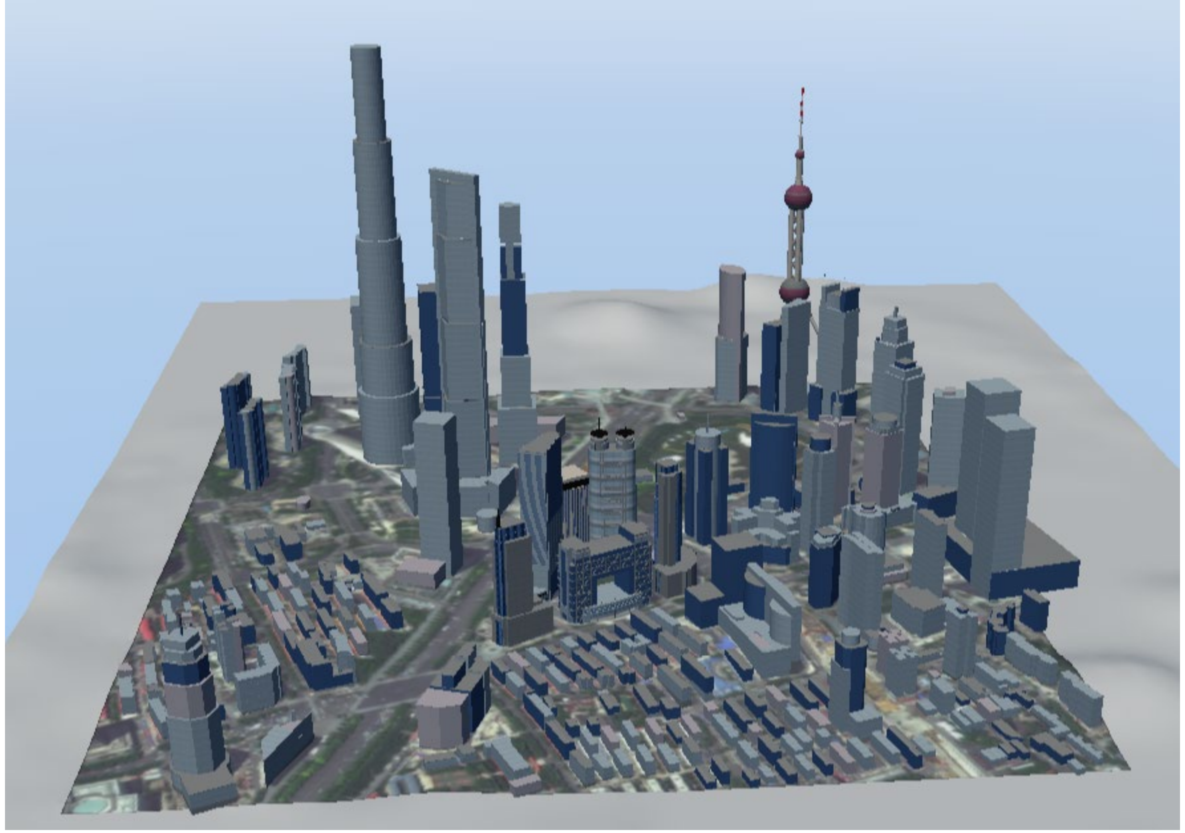


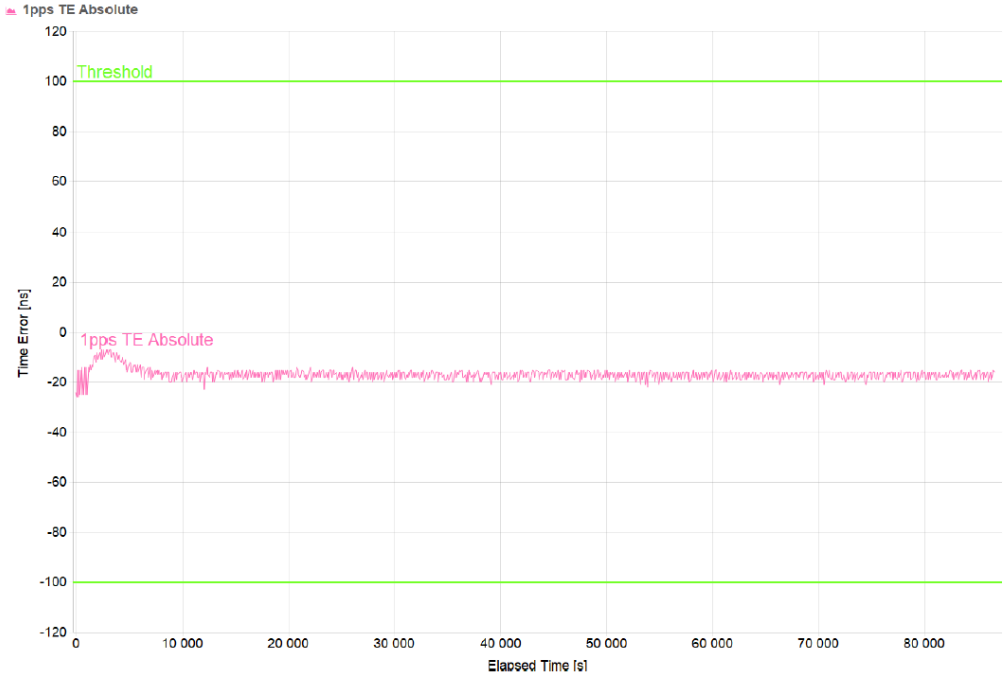
Figure 18: Shanghai 3D scene

Shanghai 2/4

Open sky conditions

Time Error Analysis

Offset Removal Applied	Off
Zero Offset	-24 ns

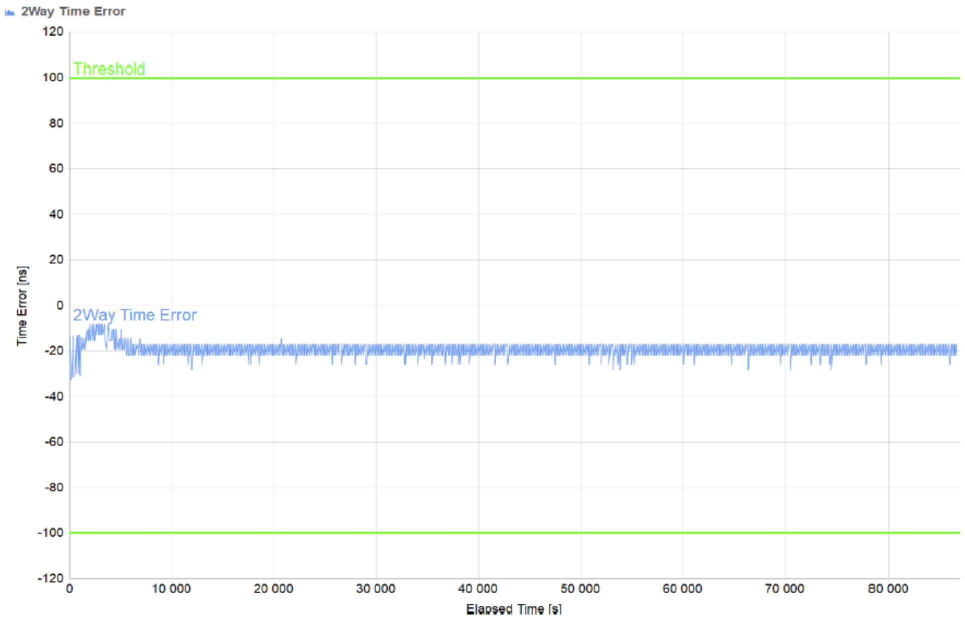


Mean [ns]	-16.784
Min [ns]	-26
Max [ns]	-7
Max-Min [ns]	19

Figure 20. 1 PPS absolute time error under open-sky conditions

Time Error Analysis

Include Correction Field	On

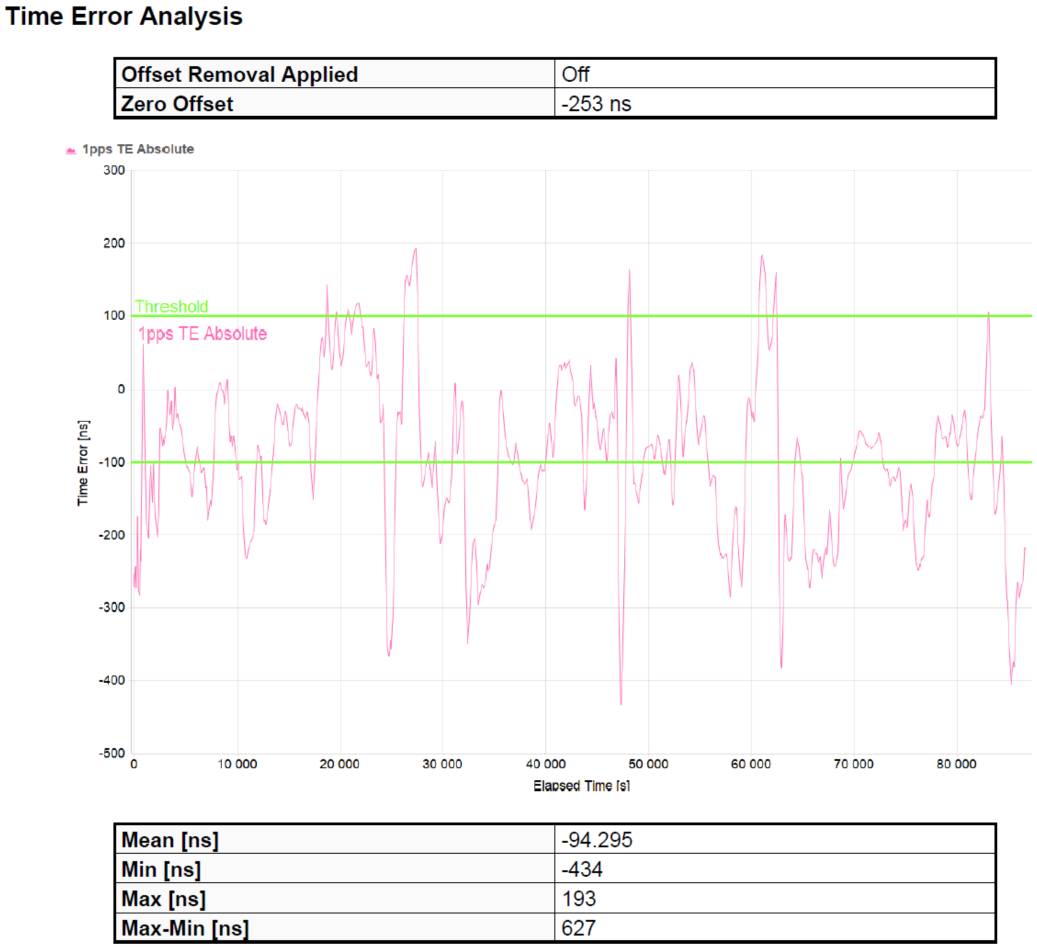


Mean [ns]	-20.565
Min [ns]	-33
Max [ns]	-8
Max-Min [ns]	25
Fwd Messages	1385223
Rev Messages	1385223
Forward Rate	16.00/second
Reverse Rate	16.00/second

Figure 21. 2-way time error under open-sky conditions

Shanghai 3/4

Multipath conditions



Time Error Analysis

Offset Removal Applied	Off
Zero Offset	-253 ns

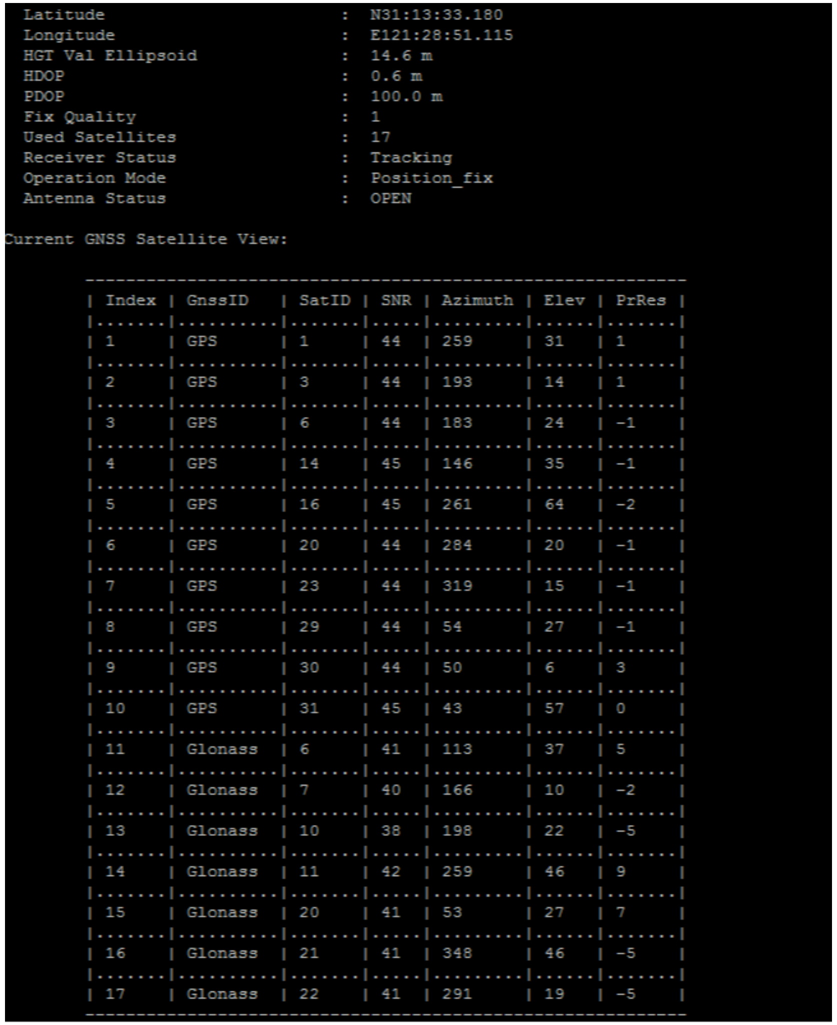
Mean [ns]	-94.295
Min [ns]	-434
Max [ns]	193
Max-Min [ns]	627

Figure 19. 1 PPS absolute time error under multipath conditions

- Unfortunately, there was no valid PTP measurement for this scene. Something must have gone wrong.
- The 1 PPS time error has an absolute mean value of 94.3 ns, but it deviated a lot with a maximum value of +193 ns and a minimum of – 434 ns.
- The measurements for the open sky conditions are within the PRTC-A and B limits.

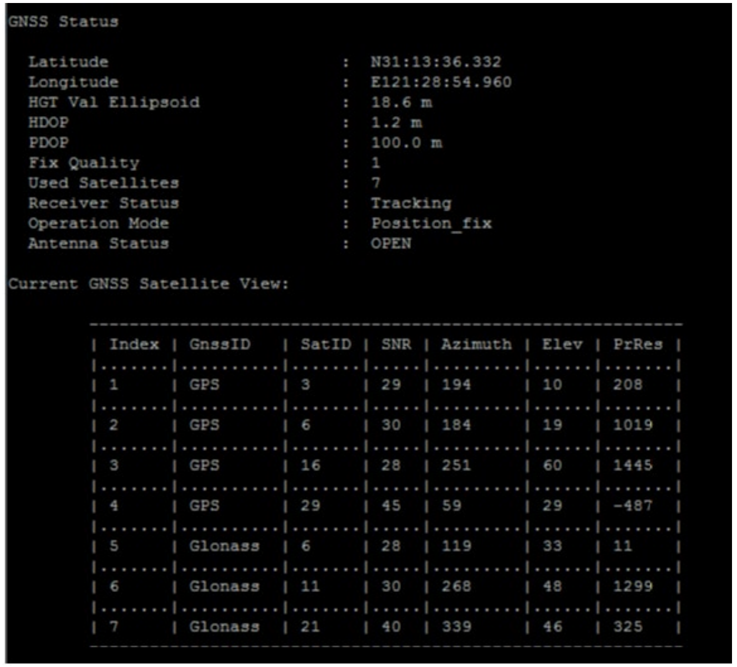
Shanghai 4/4

GNSS status of the DUT



```
  Latitude                          :  N31:13:33.180
  Longitude                         :  E121:28:51.115
  HGT Val Ellipsoid                 :  14.6 m
  HDOP                              :  0.6 m
  PDOP                              :  100.0 m
  Fix Quality                       :  1
  Used Satellites                   :  17
  Receiver Status                   :  Tracking
  Operation Mode                    :  Position_fix
  Antenna Status                    :  OPEN

Current GNSS Satellite View:

        -----------------------------------------------------------
        | Index | GnssID     | SatID | SNR | Azimuth  | Elev | PrRes  |
        |.......|...........|.......|.....|.........|......|.......|
        | 1     | GPS        | 1     | 44  | 259      | 31   | 1      |
        |.......|...........|.......|.....|.........|......|.......|
        | 2     | GPS        | 3     | 44  | 193      | 14   | 1      |
        |.......|...........|.......|.....|.........|......|.......|
        | 3     | GPS        | 6     | 44  | 183      | 24   | -1     |
        |.......|...........|.......|.....|.........|......|.......|
        | 4     | GPS        | 14    | 45  | 146      | 35   | -1     |
        |.......|...........|.......|.....|.........|......|.......|
        | 5     | GPS        | 16    | 45  | 261      | 64   | -2     |
        |.......|...........|.......|.....|.........|......|.......|
        | 6     | GPS        | 20    | 44  | 284      | 20   | -1     |
        |.......|...........|.......|.....|.........|......|.......|
        | 7     | GPS        | 23    | 44  | 319      | 15   | -1     |
        |.......|...........|.......|.....|.........|......|.......|
        | 8     | GPS        | 29    | 44  | 54       | 27   | -1     |
        |.......|...........|.......|.....|.........|......|.......|
        | 9     | GPS        | 30    | 44  | 50       | 6    | 3      |
        |.......|...........|.......|.....|.........|......|.......|
        | 10    | GPS        | 31    | 45  | 43       | 57   | 0      |
        |.......|...........|.......|.....|.........|......|.......|
        | 11    | Glonass    | 6     | 41  | 113      | 37   | 5      |
        |.......|...........|.......|.....|.........|......|.......|
        | 12    | Glonass    | 7     | 40  | 166      | 10   | -2     |
        |.......|...........|.......|.....|.........|......|.......|
        | 13    | Glonass    | 10    | 38  | 198      | 22   | -5     |
        |.......|...........|.......|.....|.........|......|.......|
        | 14    | Glonass    | 11    | 42  | 259      | 46   | 9      |
        |.......|...........|.......|.....|.........|......|.......|
        | 15    | Glonass    | 20    | 41  | 53       | 27   | 7      |
        |.......|...........|.......|.....|.........|......|.......|
        | 16    | Glonass    | 21    | 41  | 348      | 46   | -5     |
        |.......|...........|.......|.....|.........|......|.......|
        | 17    | Glonass    | 22    | 41  | 291      | 19   | -5     |
        -----------------------------------------------------------
```

Figure 22. GNSS status of DUT under open sky conditions



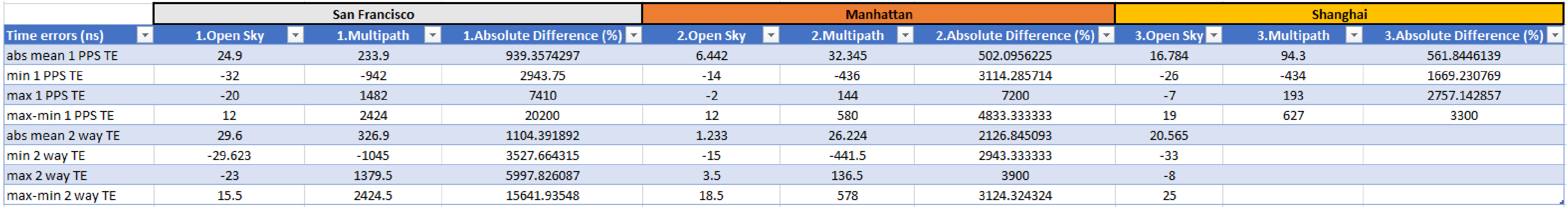
```
GNSS Status

  Latitude                          :  N31:13:36.332
  Longitude                         :  E121:28:54.960
  HGT Val Ellipsoid                 :  18.6 m
  HDOP                              :  1.2 m
  PDOP                              :  100.0 m
  Fix Quality                       :  1
  Used Satellites                   :  7
  Receiver Status                   :  Tracking
  Operation Mode                    :  Position_fix
  Antenna Status                    :  OPEN

Current GNSS Satellite View:

        -----------------------------------------------------------
        | Index | GnssID     | SatID | SNR | Azimuth  | Elev | PrRes  |
        |.......|...........|.......|.....|.........|......|.......|
        | 1     | GPS        | 3     | 29  | 194      | 10   | 208    |
        |.......|...........|.......|.....|.........|......|.......|
        | 2     | GPS        | 6     | 30  | 184      | 19   | 1019   |
        |.......|...........|.......|.....|.........|......|.......|
        | 3     | GPS        | 16    | 28  | 251      | 60   | 1445   |
        |.......|...........|.......|.....|.........|......|.......|
        | 4     | GPS        | 29    | 45  | 59       | 29   | -487   |
        |.......|...........|.......|.....|.........|......|.......|
        | 5     | Glonass    | 6     | 28  | 119      | 33   | 11     |
        |.......|...........|.......|.....|.........|......|.......|
        | 6     | Glonass    | 11    | 30  | 268      | 48   | 1299   |
        |.......|...........|.......|.....|.........|......|.......|
        | 7     | Glonass    | 21    | 40  | 339      | 46   | 325    |
        -----------------------------------------------------------
```

Figure 23. GNSS status of DUT under multipath conditions

- The ellipsoidal height didn’t show large differences, but the pseudorange residuals were much larger in the multipath environment than the values in the open sky conditions.
- Also, the used satellites were much less under multipath conditions.
- The CN0 was a lot lower in the multipath run, when compared to the values in the open sky conditions.

Conclusions

- Time recovery is crucial in telecom applications and as we see in Table 1 below, multipath will degrade the performance of the timing accuracy of the GNSS-based PRTC's. Thus, being able to simulate this effect, and introduce new **testing methods**, will save companies time and money.



	San Francisco			Manhattan			Shanghai		
Time errors (ns)	1.Open Sky	1.Multipath	1.Absolute Difference (%)	2.Open Sky	2.Multipath	2.Absolute Difference (%)	3.Open Sky	3.Multipath	3.Absolute Difference (%)
abs mean 1 PPS TE	24.9	233.9	939.3574297	6.442	32.345	502.0956225	16.784	94.3	561.8446139
min 1 PPS TE	-32	-942	2943.75	-14	-436	3114.285714	-26	-434	1669.230769
max 1 PPS TE	-20	1482	7410	-2	144	7200	-7	193	2757.142857
max-min 1 PPS TE	12	2424	20200	12	580	4833.333333	19	627	3300
abs mean 2 way TE	29.6	326.9	1104.391892	1.233	26.224	2126.845093	20.565		
min 2 way TE	-29.623	-1045	3527.664315	-15	-441.5	2943.333333	-33		
max 2 way TE	-23	1379.5	5997.826087	3.5	136.5	3900	-8		
max-min 2 way TE	15.5	2424.5	15641.93548	18.5	578	3124.324324	25		

Table 1: Quantitative analysis of the results

Future Work

- Our future work on multipath measurements aims to the following:
  - Measurements from live multipath environments and comparison to the simulated results.
  - Measurements with L2 and L5 frequencies for GPS, GLONASS and Galileo.

References

- Paul D. Groves, Ziyi Jiang, Morten Rudi and Philip Strode, *A Portfolio Approach to NLOS and Multipath Mitigation in Dense Urban Areas*, University College London, Unite Kingdom [1] - https://discovery.ucl.ac.uk/id/eprint/1394968/1/ION_GNSS13_B6_2_Groves_et_al_1_0%20%28NLOS%29.pdf
- ITU-T G.8272/Y.1367, *Timing characteristics of primary reference time clocks* [2] – https://www.itu.int/rec/T-REC-G.8272/en
- Hannah, Bruce M. *Modelling and simulation of GPS multipath propagation. Diss. Queensland University of Technology, 2001. [3]* - https://eprints.qut.edu.au/15782/1/Bruce_Hannah_Thesis.pdf

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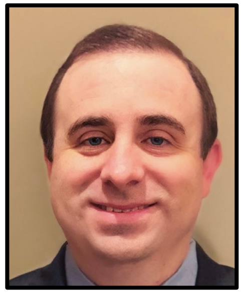

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