Today’s PTA Agenda

- 10:30 to 11:30 PTA Overview
- 11:30 to 12:30 Lunch
- 12:30 to 1:45 Protect, with Board Discussion
- 1:45 to 2:00 Break
- 2:00 to 3:15 Toughen, with Board Discussion
- 3:15 to 3:30 Break
- 3:30 to 4:45 Augment, with Board Discussion
- 4:45 to 5:00 PTA Summary
- 5:00 to 6:00 Board Deliberations
- 6:00 Adjourn

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SPACE-BASED POSITIONING
NAVIGATION & TIMING
NATIONAL ADVISORY BOARD

Augmenting GPS for Critical Infrastructure

24 April 2024

Background on Augmenting GPS

- Augment: Provision of GPS enhancements* as well as provision and use of alternate sources of PNT that complement, back up, or replace (partly or entirely) use of GPS
- GPS augmentations can be used to obtain situational awareness—whether GPS receiver is providing incorrect position, velocity, time
- Different classes of alternate PNT sources:
  - Standalone: clocks and Inertial Navigation Systems
  - Using information from natural phenomena: terrain, Earth magnetic field, celestial
  - Using generated information like GNSS, eLoran, ATSC 3.0 BPS
- GPS is widely used as an inexpensive and accurate source of time
  - There are many alternate sources of timing
- GPS is also widely used for positioning and navigation
  - Finding alternate sources of positioning and navigation is more challenging

*See next slide

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GPS Enhancements

- Enhancements help receivers improve (e.g., accuracy, integrity, robustness) their processing of GPS signals
- Many enhancements are available:
  - Satellite-Based Augmentation Systems, especially the U.S.'s WAAS
  - Commercial differential services and Real-Time Kinematic
  - High accuracy information for Precise Point Positioning
  - Receiver enhancements such as Controlled Reception Pattern Antennas (CRPAs) and inertial aiding
- Proposed GPS High Accuracy and Robustness Service endorsed by PNTAB
  - Could be extended to "Enhancement Server" that securely provides wide range of information

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Context for This Work

- DoT efforts on Complementary PNT
- NIST development of foundational PNT profile
- IEEE P1952: Standard for Resilient Positioning, Navigation and Timing (PNT) User Equipment
- Does not address civil aviation, which is being separately addressed by the FAA

We are not developing a process, standard, framework, or architecture; we seek alternative PNT sources to augment GPS in the *near-term*

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Evaluating Alternate PNT Sources—Having PNT Is Not Binary

- **Functions**
  - Positioning
  - Navigation
  - Timing
- **Measurement accuracy**
  - In service region with PNT infrastructure deployed
  - When a use case has varying measurement accuracy needs, the most stringent is reported
- **Operating region**
  - Satisfy service region of use case
- **Availability and continuity—is augmentation there for needed duration in service region**
  - Augmentations can introduce new attack surfaces and vulnerabilities
  - Toughness of PNT infrastructure and user device
  - Account for augmentation dependencies (power, GNSS, Internet, etc.)
- **Operating conditions and limitations**
  - Operate in conditions needed for use case
- **Infrastructure cost to Government**
  - High (>$1000M initial, $100M annual)
  - Moderate (>$100M initial, $10M annual)
  - Low (<$100M initial, <$10M annual)
- **Acceptable user device cost, size, weight, and power (CSWaP)**
  - Includes purchasing, installing, sustaining, replacing
  - User device CSWaP matches use case needs
- **Operational maturity—speed to deploy**
  - Mature: PNT infrastructure fielded, user devices available
  - Evolving: PNT infrastructure readily fielded (<3 years), user devices readily produced
  - Immature: Needs significant deployment of PNT infrastructure and/or development of user devices

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Evaluating Availability and Continuity

- Alternate source must meet use case needs for time duration that GPS is not useful
- Three possible causes for GPS not being useful:
  - User device failure
    - Owner/operator must assess this risk and plan to address it; not considered further
  - Interference or spoofing prevents operation of user device
    - User assesses risk of occurrence with U.S. Government guidance
    - Assume U.S. Government commits to maximum 3 days to detect and remove source
  - GPS fails to provide useful signals from satellites—natural, accidental, or malevolent cause
    - ESG: "determining the likelihood that GPS infrastructure (GPS Ground Segment, GPS Space Segment, and GPS user equipment) could fail for any reason is very challenging. The possibility of threats could change more quickly than the ability to react to them."
    - Assume rate of common mode GPS failure less than 1 in 10 years, having maximum duration of 3 days
      - More pessimistic than specified in GPS Performance Standard

Pending further guidance, alternative PNT sources need to meet user needs for up to 3 days

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Evaluating Availability and Continuity

- Alternate source must meet use case needs for time duration that GPS is not useful
- Three possible causes for GPS not being useful:
  - User device failure
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  - GPS fails to provide useful signals from satellites—natural, accidental, or malevolent cause
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    - Assume rate of common mode GPS failure less than 1 in 10 years, having maximum duration of 3 days
      - More pessimistic than specified in GPS Performance Standard

Risk Depends upon Actions and Information from U.S. Government

Pending further guidance, alternative PNT sources need to meet user needs for up to 3 days

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Meaning of the Evaluation Colors

- Details in backup slides contain evaluation of each candidate alternate PNT source in the context of each use case:
  - Blue: better than needed
  - Green: meets what is needed in almost all situations
  - Yellow: unknown or marginal in many situations
  - Red: does not meet what's needed in many situations
- Use test results: EU's Joint Research Center and DoT's FY18 CPNT Report
- All assessments labeled draft for now
- Overall score for each alternate source and for each use case is the lowest color
  - Example for an alternate source

Use Case	Criteria							Overall Score
	Accuracy	Avail. & Cont.	Operat. Region	Conditions	Cost to Gov.	CSWaP	Op. Maturity	
Use Case 1	Y	G	G	G	B	B	B	Y
Use Case 2	R	G	G	G	B	B	B	R
Use Case 3	G	G	G	G	B	B	B	G

Letters in cells denote colors for those with color vision deficiency

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Examining Alternate PNT Sources

- Alternate Positioning and Navigation Sources GPS for Critical Infrastructure
  - Lead: Scott Burgett
  - Contributors: John Betz, Renato Filjar, Tom Powell, Logan Scott

- Alternate Time Transfer and Timing Sources for Critical Infrastructure
  - Lead: Pat Diamond
  - Contributors: John Betz, Vahid Madani, Logan Scott

- Augmentation Summary

- Details

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Representative Critical Infrastructure Positioning and Navigation Use Cases (1 of 2)

Use Case	Measurement Accuracy	Service Region	Operating Conditions	Acceptable CSWaP*
Positive Train Control	2D 1 m (2DRMS)	Entire U.S.	All Earth Surface	High
Precision Agriculture, Other Commercial	±1 cm H, ±1.5 cm V	Entire U.S.	All Earth Surface	Moderate
Driving: Route Navigation	2D 3 m (2DRMS)	Entire U.S.	All Earth Surface	Low
Driving: Lane Navigation	2D 1 m (2DRMS)	Entire U.S.	All Earth Surface	Low
Driving: Autonomous Vehicles	2D 0.1 m (2DRMS)	Entire U.S.	All Earth Surface	Moderate
Space Launch	3D 5 m RMS, 0.1 m/s per axis	Worldwide to GEO	All Earth Surface and Space	Moderate
Space Operations	3D 1 m (95%) at LEO	LEO to GEO	Space	Moderate

*CSWaP: Cost, Size, Weight, and Power

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Reference: Canonical Use Cases for Critical Infrastructure (gps.gov)

Representative Critical Infrastructure Positioning and Navigation Use Cases (2 of 2)

Use Case	Measurement Accuracy	Service Region	Operating Conditions	Acceptable CSWaP*
Maritime: Ocean/ Seas	2D 185 m (2DRMS)	Worldwide	All Earth Surface	High
Maritime: Harbors	2D 8 m (2DRMS)	Harbors in U.S.	All Earth Surface	High
Maritime: Inland Waterways	2D 2 m (2DRMS)	Entire U.S.	All Earth Surface	Moderate
UAS En Route	2D 1 m (2DRMS)	Entire U.S.	Airborne	Moderate
UAS Sensing	± 1 cm H, ± 1.5 cm V	Entire U.S.	Airborne	Low
Emergency 911	2D 50 m (for 40% of wireless calls)	Entire U.S.	All Earth Surface and Space	Low
Automated Facilities	± 1 cm H, ± 1.5 cm V	Ports and other locations	All Earth Surface	Moderate

*CSWaP: Cost, Size, Weight, and Power

Reference: [Canonical Use Cases for Critical Infrastructure (gps.gov)]

Alternate Positioning and Navigation Sources Evaluated

- Cellular
- Galileo
- Locata
- Satelles Satellite Time and Location (STL)
- NextNav
- eLoran
- PhasorLab
- TRX
- Skyhook
- Inertial
- Wi-Fi (802.11 az)
- Wi-Fi RSSI
- Visual Positioning
- Visual Odometry
- Magnetic Anomaly Navigation (Magnav)
- Automated Celestial

Listed in No Particular Order

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Example of Evaluating Alternate PN Source: Galileo

Use Case	Criteria							Overall Score
	Accuracy	Avail. & Cont.	Operat. Region	Conditions	Cost to Gov.	User CSWaP	Op. Maturity	
Positive Train Control	G	Y	G	G	B	B	B	Y
Precision Agriculture, etc.	R / G (RTK)	Y	G	G	B	B	B	Y (RTK)
Driving: Route Navigation	G	Y	G	G	B	B	B	Y
Driving: Lane Navigation	R / G (RTK)	Y	G	G	B	B	B	Y (RTK)
Driving: Autonomous Vehicles	R	Y	G	G	B	B	B	R
Space Launch	G	Y	G	G	B	B	B	Y
Space Operations	G	Y	G	G	B	B	B	Y
Maritime: Oceans/Sea	B	Y	G	G	B	B	B	Y
Maritime: Harbors	G	[illegible]	G	G	B	B	B	Y
Maritime: Inland Waterways	G	Y	G	G	B	B	B	Y
UAS: En Route	G	Y	G	G	B	B	B	Y
UAS: Sensing	R / G (RTK)	Y	G	G	B	B	B	Y (RTK)
Emergency 911	B	Y	G	G	B	B	B	Y
Automated Facilities	R / G (RTK)	Y	G	G	B	B	B	Y (RTK)

Positioning and Navigation Alternate Source Scorecard

Tech-nology	Use Case													
	Pos. Train Control	Preci-sion	Drive: Route	Drive: Lane	Drive: Auto	Space Launch	Space Ops.	Mari-time Ocean	Mari-time Harbor	Mari-time Inland	U[illegible]n Rou[illegible]	UAS Sense	E911	Auto. Fac.
Cellular	Y	R	Y	Y	R	R	R	R	Y	R	R	R	G	R
Galileo	Y	Y/RTK	Y	Y/RTK	R	Y	Y	Y	[illegible]	Y	Y	[illegible]	Y	Y/RTK
Locata	R	Y	R	R	R	R	R	R	Y	[illegible]	R	[illegible]	R	Y
Satelles	R	R	R	R	R	R	R	[illegible]	R	R	R	R	Y	R
NextNav	R	R	R	R	R	R	R	R	R	R	R	R	R	R
eLoran	R	R	R	R	R	R	R	R	[illegible]	[illegible]	R	R	R	R
PhasorLab	R	R	R	R	[illegible]	R	R	R	R	R	R	R	R	R
TRX	R	R	R	R	R	R	R	[illegible]	R	R	R	R	R	R
Skyhook	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Inertial	R	R	[illegible]	R	[illegible]	R	R	R	R	R	R	R	R	R
WiFi (802.11az)	R	R	R	R	[illegible]	[illegible]	R	R	Y	Y	R	R	R	R
WiFi (RSSI)	R	R	R	R	[illegible]	R	R	R	R	R	R	R	R	R
Vision Aiding P	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Vision Aiding O	R	R	R	[illegible]	R	R	R	R	R	R	R	R	R	R
Magnav	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Auto. Celest.	R	R	R	R	R	R	R	R	R	R	R	R	R	R

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Explanation of Positioning and Navigation Scoring (1 of 4)

- Absence of verified user device toughness limits most maximum scores to yellow
- Few technologies meet the use case needs for both accuracy over 3 days and service region
- Galileo would score green in many use cases if:
  - User devices verified to be tough
  - U.S. Government promptly removes significant sources of interference
  - RTK used where highest accuracy needed
- Locata relies upon engineered placement of multiple “Locatalites”
  - TRL 9, used in numerous operational automated environments
  - Performance in dense multipath relies on “soccer ball” sized V-Ray antenna
  - Would require very large number of Locatalites for large operating regions
- Satelles lacks accuracy except possibly for Maritime: Oceans/Seas and E911
  - Lacking data on accuracy with short hold times and dynamic positioning
  - User device CSWaP may not be compatible with E911

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Explanation of Positioning and Navigation Scoring (2 of 4)

- NextNav is a terrestrial beaconing solution
  - Accuracy is not sufficient for most applications
  - High TRL and low CSWaP
  - Would require a very large number of beacons for large service regions
  - Three day continuity requires high CSWaP clocks in master beacons
- eLoran assessed as operationally immature: time required for site preparation, acquisition and installation of transmitters, cybersecure master control station and software, connectivity between transmitters and master control station and reference stations
  - Even then, accuracy and user device CSWaP limited to Maritime: Harbors and Inland
- PhasorLab uses dense mesh network of cooperative devices for relative navigation
  - Performance highly influenced by network density and multipath
  - Not suited for large service regions with sparse cooperative devices
- TRX is a mobile dismount solution not designed for most use cases
  - Intended for keeping track of personnel in GPS contested areas

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Explanation of Positioning and Navigation Scoring (3 of 4)

- Skyhook uses WiFi signals of opportunity and a map of these signals to create a high TRL, low user CSWaP, Round Trip Timing (RTT) solution
  - Accuracy not sufficient for most applications
  - Signals of opportunity inconsistent and non-existent in remote areas; depend on power and Internet availability
- Inertial drift does not provide needed accuracy over three days
- WiFi (802.11az) uses fine timing measurement accurate to about 2 meters or better
  - Does not cover large and remote service regions
  - Dependent on power and Internet
- WiFi (RSSI) measures received signal strength (RSSI) from several Access Points to Determine Position
  - Does not cover large and remote service regions
  - Dependent on power and Internet

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Explanation of Positioning and Navigation Scoring (4 of 4)

- Magnav assessed as operationally immature: sensors, platform calibration, map availability
- Visual aids positioning limited by weather, nighttime, availability of maps for entire service regions
- Visual aids odometry limited by weather and nighttime; unable to sustain accuracy over three days
- Automated Celestial limited by weather and user device CSWaP

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- Details

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Representative Critical Infrastructure Timing Use Cases

Use Case	Measurement Accuracy	Service Region	Operating Conditions	Acceptable CSWaP*
Cellular Base Station: Intercell Interference	± 1 μs	Entire U.S.	All Earth Surface	Moderate
Cellular Base Station: Carrier Aggregation	± 0.13 μs	Entire U.S.	All Earth Surface	Moderate
Phasor Measurement Unit	± 1 μs	Entire U.S.	All Earth Surface	Low
Financial Trading	± 50 ms (US), ± 1 μs (EU)	Urban Areas	All Earth Surface	High

*CSWaP: Cost, Size, Weight, and Power

Reference: Canonical Use Cases for Critical Infrastructure (gps.gov)

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Time Transfer vs. Time Source

- A **Time Source** Is a Clock
  - Can Maintain Time Once Disciplined
  - examples: Cesium Standard Clock, My Wristwatch

- A **Time Transfer System Can Convey** Time from One Location To Another
  - Absolute Accuracy Depends On the Time Source
  - examples: Locata, TWSTFT

- **Some Systems Combine These Functions**
  - examples: Iridium (Satelles), ATSC 3.0 BPS, Galileo, GPS

Alternate Time Transfer and Timing Sources Evaluated

Both Time Source and Time Transfer

- ATSC 3.0 BPS
- TWSTFT
- PTP (IEEE 1588)/Fiber with integrated clock
- Cesium Clock
- Rubidium Clock
- Chip Scale Atomic Clock
- Oven Compensated Crystal Oscillator (OCXO)
- Cellular
- NTP/Fiber with integrated clock
- Galileo
- Satelles Satellite Time and Location (STL)
- eLoran
- Locata
- NextNav
- PhasorLabs

Listed in No Particular Order

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Timing Transfer Method & Source Alternate Scorecard

Technology	Use Case			
	Cellular Base Station: Intercell Interference	Cellular Base Station: Carrier Aggregation	Phasor Measurement Unit	Financial Trading
ATSC 3.0 BPS	Y	Y	Y	Y
TWSTFT	R	R	R	R
PTP/Fiber	R	R	[illegible]	R
Cesium Clock	R	R	R	G
Rubidium Clock	B	R	G	G
Chip Scale Atomic Clock	R	R	[illegible]	R
OCXO	[illegible]	R	R	R
Cellular	R	R	R	R
NTP/Fiber	R	[illegible]	R	R
Galileo	[illegible]	Y	Y	Y
Satelles	[illegible]	Y	Y	Y
eLoran	[illegible]	R	R	R
Locata	R	R	R	Y
NextNav	R	R	R	Y
PhasorLab	R	R	R	Y

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Explanation of Timing Scoring

- **ATSC 3.0 BPS** scores very well
  - ATSC 3.0 now covers 80+% of CONUS and will reach 100% coverage by end of 2025.
    - Also, in various other countries
  - Traceable to UTC (Boulder NIST & Gaithersburg NIST)
  - Mesh Network for Inherent Ensembling and Redundancy
  - ATSC 3.0 BPS receiver chips are expected to be 8x8mm and under $10
  - Receiver toughness unknown

- **TWSTFT – Two Way Satellite Time and Frequency Transfer** is a very common mechanism used to transfer time between BIPM (UTC Source) and NIST and USNO.
    - While well understood and widely used is impractical for Timing Augmentation for GPS due to Satellite transponder expense, large earth stations and Capitol cost of Satellite Modems.
    - Not compatible with portable devices.

Explanation of Timing Scoring

- **PTP (IEEE 1588-2019) over Fiber** is impractical for use as Timing Augmentation for GPS
  - While PTP is a layer 2/3 time transfer protocol, its performance depends on the determinism in the symmetry of the paths between PTP nodes.
  - PTP equipment tends to be expensive and is not compatible with portable devices.

- **Atomic Clocks** are generally very expensive (e.g. $84,000 for a 5071A) and only used at the root of a timing tree.
  - Requires periodic synchronization to UTC using a technique called common view (TWSTFT).
  - While highly precise (<10 nsec) are impractical for large scale deployment as a timing augmentation for GPS.

- **Cellular (5G)** using 3GPP release 17 and 18 have the promise of transferring UTC via RF.
  - Not yet deployed in consumer networks.
  - The observable precision is TBD.
  - Reliability not proven for critical infrastructure use.

Explanation of Timing Scoring

- **NTP (Secure Network Time Protocol) over Fiber** is impractical to use as a timing augmentation for GPS.
  - Like PTP NTP is a layer 3 time transfer protocol.
  - NTP unlike PTP does not use unicast/multicast node to node addressing rather uses a datagram IP mechanism for communication.
  - Widely used over the internet, PC's get time from diverse NTP servers.
  - Typical precision is on the order of milliseconds.

- **Galileo** dual frequency signals approved for use in U.S.
  - Receiver toughness unknown

- **Iridium (Satelles)** is an operational LEO constellation of 66 satellites.
  - Traceable to UTC Time (NIST Boulder)
  - NIST testing has shown Iridium to be able to achieve 50nsec relative to UTC
  - Receiver toughness unknown

Explanation of Timing Scoring

- **Locata**
  - Demonstrated High Precision Time Transfer in JRC Testing
  - 1.7 nsec time transfer accuracy (ext. source) over 105 km distance
  - TRL 9

- **eLoran**
  - Lacking operational maturity in U.S.—infrastructure would take more than 3 years to deploy
  - Ability to serve entire U.S. (all 50 states and territories) uncertain
  - <100 nsec Accuracy Standalone

- **NextNav**
  - Demonstrated High Precision Time Transfer (~ 20 nsec) in DoT Testing
  - Network of beacons operating in the 902-928 MHz band

- **PhasorLabs**
  - Demonstrated High Precision Time Transfer (~ 20 nsec) in DoT Testing
  - Dynamic Mesh Network requiring high density
  - Operates in 2.4 GHz ISM Band
  - Assessed as TRL 6/7

Examining Alternate PNT Sources

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- Augmentation Summary

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Augmentation Assessment Foundations

- These assessments rely on aspects outside of user control:
  - U.S. Government ability to remove significant interference sources within three days
  - Negligible likelihood that GPS outages from natural, accidental, malevolent causes would last more than three days
- Need verification that alternative PNT sources are Toughened
  - Any infrastructure needed for the alternative source
  - User devices

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Augment Recommendations—for PNTAB Deliberation

- Those proposing alternative PNT sources should apply the criteria and use cases to assess these sources, documenting their utility for critical infrastructure
- DoT and DHS apply results and methodology in parallel efforts:
  - Implement HARS, investigate more sophisticated “enhancement servers”
  - Focus on turning Galileo use green for near-term pragmatic alternate PNT source:
    - Need dual-frequency, dual-system GPS/Galileo user devices known to be Tough
    - U.S. Government promptly removes significant sources of interference
  - Use methodology to prioritize and focus longer-term efforts on alternate sources
    - Which satisfy criteria for most important use cases—widespread or niche
    - Which have fundamental limitations, even if operationally matured
    - Which limitations can be mitigated through investment
    - Explore integration/fusion of multiple positioning and navigation sources selected to meet use case needs

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- 12:30 to 1:45 Protect, with Board Discussion
- 1:45 to 2:00 Break
- 2:00 to 3:15 Toughen, with Board Discussion
- 3:15 to 3:30 Break
- 3:30 to 4:45 Augment, with Board Discussion
- 4:45 to 5:00 PTA Summary
- 5:00 to 6:00 Board Deliberations
- 6:00 Adjourn

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Examining Alternate PNT Sources

DETAILS, NOT PRESENTED

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Use of Foreign Satnav Signals

- DA-11-498A1_Rcd.pdf (fcc.gov) prohibits non-Federal use of foreign satnav signals without a waiver
- FCC-18-158A1_Rcd.pdf waives prohibition of non-Federal use of Galileo E1 and E5 signals
  - Does not include Galileo E6 signal that broadcasts Galileo’s High Accuracy Service (HAS)
- Service regions of QZSS and NavIC do not include continental U.S.

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Evaluating Alternate PN Source: Galileo

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Conditions	Cost to Gov.	User CSWaP	Op. Maturity
Positive Train Control	G	Y	G	G	[illegible]	B	B
Precision Agriculture, etc.	R / G (RTK)	Y	G	G	B	B	B
Driving: Route Navigation	G	Y	G	G	B	B	B
Driving: Lane Navigation	R / G (RTK)	Y	G	[illegible]	B	B	B
Driving: Autonomous Vehicles	R	Y	G	G	B	B	B
Space Launch	G	Y	G	G	B	B	B
Space Operations	[illegible]	Y	G	G	B	B	B
Maritime: Oceans/S[illegible]	B	Y	G	G	B	B	B
Maritime: Harbors	G	Y	G	G	B	B	B
Maritime: Inland Waterways	G	Y	G	G	B	B	B
UAS: En Route	G	Y	G	G	B	B	B
UAS: Sensing	R / G (RTK)	Y	G	G	B	B	B
Emergency 911	B	Y	G	G	B	B	B
Automated Facilities	R / G (RTK)	Y	G	G	B	B	B

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Evaluating Alternate PN Source: eLoran

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Conditions	Cost [illegible] Gov.	User CSWaP	Op. Maturity
Positive Train Control	R	Y	R	G	Y	G	R
Precision Agriculture, etc.	R	Y	R	[illegible]	Y	G	R
Driving: Route Navigation	R	Y	R	G	Y	G	R
Driving: Lane Navigation	R	Y	R	G	Y	G	R
Driving: Autonomous Vehicles	R	Y	R	[illegible]	Y	G	R
Space Launch	R	Y	R	G	Y	G	R
Space Operations	R	Y	R	G	Y	G	R
Maritime: Oceans/Seas	[illegible]	[illegible]	[illegible]	G	Y	B	R
Maritime: Harbors	[illegible] / G	Y	Y	G	Y	B	R
Maritime: Inland Waterways	[illegible] / G	Y	Y	G	Y	B	R
UAS: En Route	[illegible]	Y	Y	G	Y	Y	R
UAS: Sensing	R	Y	Y	G	Y	Y	R
Emergency 911	G	Y	R	G	Y	R	R
Automated Facilities	R	Y	Y	G	Y	G	R

Evaluating Alternate PN Source: Satelles Satellite Time and Location

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Conditions	Cost to Gov.	User CSWaP	Op. Maturity
Positive Train Control	R	Y	G	G	B	B	B
Precision Agriculture, etc.	R	Y	G	G	B	B	B
Driving: Route Navigation	R	Y	G	G	B	B	B
Driving: Lane Navigation	R	Y	G	G	B	B	B
Driving: Autonomous Vehicles	R	[illegible]	G	G	B	B	B
Space Launch	R	Y	R	G	B	B	B
Space Operations	R	[illegible]	R	G	B	B	B
Maritime: Oceans/Seas	Y	Y	G	G	B	B	B
Maritime: Harbors	R	Y	G	G	B	B	B
Maritime: Inland Waterways	R	Y	G	G	B	B	B
UAS: En Route	R	Y	G	G	B	Y	B
UAS: Sensing	R	Y	G	G	B	Y	B
Emergency 911	Y	Y	G	G	B	Y	B
Automated Facilities	R	Y	G	G	B	B	B

Evaluating Alternate PN Source: Inertial

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Conditions	Cost to Gov.	CSWaP	Op. Maturity
Positive Train Control	G	R	G	G	B	R	B
Precision Agriculture, etc.	G	R	G	G	B	R	B
Driving: Route Navigation	G	R	G	G	B	R	B
Driving: Lane Navigation	G	R	G	G	B	R	B
Driving: Autonomous Vehicles	G	R	G	G	B	R	B
Space Launch	G	R	G	G	B	Y	B
Space Operations	G	R	G	G	B	R	B
Maritime: Oceans/Seas	Y	R	G	G	B	Y	B
Maritime: Harbors	G	R	G	G	B	Y	B
Maritime: Inland Waterways	G	R	G	G	B	Y	B
UAS: En Route	G	R	G	G	B	R	B
UAS: Sensing	G	R	G	G	B	R	B
Emergency 911	G	R	G	G	B	R	B
Automated Facilities	G	R	G	G	B	R	B

Evaluating Alternate PN Source: Magnav

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Conditions	Cost to Gov.	CSWaP	Op. Maturity
Positive Train Control	R	Y	G	G	Y	Y	R
Precision Agriculture, etc.	R	Y	G	G	Y	Y	R
Driving: Route Navigation	R	Y	G	G	Y	Y	R
Driving: Lane Navigation	R	Y	G	G	Y	Y	R
Driving: Autonomous Vehicles	R	[illegible]	G	G	Y	Y	R
Space Launch	R	Y	R	G	Y	Y	R
Space Operations	R	[illegible]	R	G	Y	Y	R
Maritime: Oceans/Seas	Y	Y	Y	G	Y	Y	R
Maritime: Harbors	R	Y	G	G	Y	Y	R
Maritime: Inland Waterways	R	Y	G	G	Y	Y	R
UAS: En Route	R	Y	G	G	Y	Y	R
UAS: Sensing	R	Y	G	G	Y	Y	R
Emergency 911	R	Y	G	G	Y	Y	R
Automated Facilities	R	Y	G	G	Y	Y	R

Evaluating Alternate PN Source: NextNav

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Conditions	Cost to [illegible]	CSWaP	Op. Maturity
Positive Train Control	R	R	G	G	R	G	Y
Precision Agriculture, etc.	R	R	G	[illegible]	R	G	Y
Driving: Route Navigation	R	Y	G	G	R	[illegible]	Y
Driving: Lane Navigation	R	Y	G	G	R	G	Y
Driving: Autonomous Vehicles	R	Y	G	G	R	G	Y
Space Launch	R	[illegible]	R	[illegible]	R	G	Y
Space Operations	R	R	R	R	R	G	Y
Maritime: Oceans/Seas	B	R	R	R	R	G	Y
Maritime: Harbors	[illegible]	[illegible]	Y	G	R	G	Y
Maritime: Inland Waterways	R	Y	Y	G	R	G	Y
UAS: En Route	R	[illegible]	Y	G	R	G	Y
UAS: Sensing	R	Y	Y	G	R	G	Y
Emergency 911	G	R	G	G	R	G	Y
Automated Facilities	[illegible]	Y	G	G	R	G	Y

PTA

Evaluating Alternate PN Source: TRX

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Conditions	Cost to C[illegible]	CSWaP	Op. Maturity
Positive Train Control	R	R	G	G	R	G	Y
Precision Agriculture, etc.	R	R	G	[illegible]	R	G	Y
Driving: Route Navigation	R	R	G	G	R	[illegible]	Y
Driving: Lane Navigation	R	R	G	G	R	G	Y
Driving: Autonomous Vehicles	R	R	G	G	R	G	Y
Space Launch	R	[illegible]	R	[illegible]	R	G	Y
Space Operations	R	R	R	R	R	G	Y
Maritime: Oceans/Seas	R	R	R	R	R	G	Y
Maritime: Harbors	[illegible]	[illegible]	Y	G	R	G	Y
Maritime: Inland Waterways	R	[illegible]	G	G	R	G	Y
UAS: En Route	R	R	R	G	R	G	Y
UAS: Sensing	R	R	R	G	R	G	Y
Emergency 911	G	R	G	G	R	G	Y
Automated Facilities	[illegible]	R	G	G	R	G	Y

Evaluating Alternate PN Source: Skyhook

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Conditions	Cost to O[illegible]	CSWaP	Op. Maturity
Positive Train Control	R	R	G	G	Y	G	R
Precision Agriculture, etc.	R	R	G	G	Y	G	R
Driving: Route Navigation	G	Y	G	G	Y	G	R
Driving: Lane Navigation	R	Y	G	G	Y	G	R
Driving: Autonomous Vehicles	R	Y	G	G	Y	G	R
Space Launch	R	R	R	R	Y	G	R
Space Operations	R	R	R	R	Y	G	R
Maritime: Oceans/Seas	B	R	R	R	Y	G	R
Maritime: Harbors	[illegible]	Y	Y	G	Y	G	Y
Maritime: Inland Waterways	Y	[illegible]	Y	G	Y	G	R
UAS: En Route	R	Y	Y	G	Y	G	R
UAS: Sensing	R	Y	Y	G	Y	G	R
Emergency 911	G	R	G	G	Y	G	R
Automated Facilities	R	Y	G	G	Y	G	Y

PTA

Evaluating Alternate PN Source: Cellular (4G/5G)

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Conditions	Cost to [illegible]	CSWaP	Op. Maturity
Positive Train Control	Y	Y	Y	G	Y	G	R
Precision Agriculture, etc.	R	G	G	[illegible]	G	G	R
Driving: Route Navigation	G	G	Y	G	G	[illegible]	G
Driving: Lane Navigation	Y	G	G	G	G	G	Y
Driving: Autonomous Vehicles	R	Y	G	G	G	G	R
Space Launch	R	[illegible]	R	[illegible]	R	G	R
Space Operations	R	R	R	R	R	G	R
Maritime: Oceans/Seas	Y? (NTN)	Y?(NTN)	Y?(NTN)	Y?(NTN)	G	G	R
Maritime: Harbors	[illegible]	[illegible]	[illegible]	G	G	G	Y
Maritime: Inland Waterways	G	[illegible]	G	G	G	G	R
UAS: En Route	Y	Y	Y?	Y	G	G	R
UAS: Sensing	R	G	G	G	G	G	R
Emergency 911	G	G	G	G	G	G	G
Automated Facilities	[illegible]	G	G	G	G	G	Y

PTA

Evaluating Alternate PN Source: WiFi (802.11az)

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Conditions	Cost to Gov.	C[illegible]WaP	Op. Maturity
Positive Train Control	Y	R	Y	G	Y	G	Y
Precision Agriculture, etc.	R	R	Y	G	Y	G	Y
Driving: Route Navigation	Y	Y	R	G	G	G	Y
Driving: Lane Navigation	Y	Y	R	G	[illegible]	G	Y
Driving: Autonomous Vehicles	R	Y	R	G	[illegible]	G	Y
Space Launch	R	R	R	R	R	G	R
Space Operations	R	R	R	R	R	G	R
Maritime: Oceans/Seas	B	R	R	R	Y	G	Y
Maritime: Harbors	G	Y	[illegible]	G	Y	G	Y
Maritime: Inland Waterways	[illegible]	Y	Y	G	Y	G	Y
UAS: En Route	[illegible]	[illegible]	R	G	Y	G	Y
UAS: Sensing	R	Y	R	G	G	G	Y
Emergency 911	B	[illegible]	Y	G	G	G	Y
Automated Facilities	R	Y	G	G	G	G	Y

PTA

Evaluating Alternate PN Source: WiFi (RSSI)

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Conditions	Cost to O[illegible]	CSWaP	Op. Maturity
Positive Train Control	R	Y	G	G	Y	G	G
Precision Agriculture, etc.	R	Y	G	G	Y	G	G
Driving: Route Navigation	R	Y	G	G	Y	G	G
Driving: Lane Navigation	R	Y	G	G	Y	G	G
Driving: Autonomous Vehicles	R	Y	G	G	Y	G	G
Space Launch	R	R	R	R	Y	G	R
Space Operations	R	R	R	R	Y	G	R
Maritime: Oceans/Seas	B	R	R	R	Y	G	R
Maritime: Harbors	[illegible]	[illegible]	[illegible]	G	Y	G	G
Maritime: Inland Waterways	R	[illegible]	Y	G	Y	G	G
UAS: En Route	R	Y	Y	G	Y	G	G
UAS: Sensing	R	Y	Y	G	Y	G	G
Emergency 911	G	Y	G	G	Y	G	G
Automated Facilities	R	G	G	G	Y	G	G

PTA

Evaluating Alternate PN Source: Locata

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Conditions	Cost to [illegible]	CSWaP	Op. Maturity
Positive Train Control	B	Y	Y	G	R	G	Y
Precision Agriculture, etc.	G	Y	G	[illegible]	Y	G	Y
Driving: Route Navigation	B	Y	G	G	R	[illegible]	Y
Driving: Lane Navigation	B	Y	G	G	R	Y	Y
Driving: Autonomous Vehicles	B	Y	G	G	R	Y	Y
Space Launch	B	[illegible]	R	[illegible]	R	R	R
Space Operations	B	R	R	R	R	R	R
Maritime: Oceans/Seas	B	R	R	R	R	G	Y
Maritime: Harbors	[illegible]	[illegible]	[illegible]	G	Y	G	Y
Maritime: Inland Waterways	B	[illegible]	G	G	R	G	Y
UAS: En Route	B	Y	G	G	R	Y	Y
UAS: Sensing	G	G	G	G	G	Y	Y
Emergency 911	B	Y	G	G	R	G	Y
Automated Facilities	[illegible]	Y	G	G	G	G	G

Evaluating Alternate PN Source: PhasorLab

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Conditions	Cost to ...	CSWaP	Op. Maturity
Positive Train Control	R	Y	G	G	R	G	Y
Precision Agriculture, etc.	R	Y	G	[illegible]	Y	G	Y
Driving: Route Navigation	R	Y	G	G	R	[illegible]	Y
Driving: Lane Navigation	R	Y	G	G	R	G	Y
Driving: Autonomous Vehicles	R	Y	G	G	R	G	Y
Space Launch	R	[illegible]	R	[illegible]	R	G	R
Space Operations	R	R	R	R	R	G	R
Maritime: Oceans/Seas	B	R	R	R	R	G	Y
Maritime: Harbors	[illegible]	[illegible]	[illegible]	G	Y	G	Y
Maritime: Inland Waterways	R	[illegible]	G	G	R	G	Y
UAS: En Route	R	Y	G	G	R	G	Y
UAS: Sensing	R	Y	G	G	G	G	Y
Emergency 911	G	Y	G	G	R	G	Y
Automated Facilities	[illegible]	G	G	G	G	G	Y

PTA

Evaluating Alternate PN Source: Visual Aids Positioning

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Conditions	Cost to [illegible]	CSWaP	Op. Maturity
Positive Train Control	Y	R	R	R	R	R	R
Precision Agriculture, etc.	R	R	R	[illegible]	R	R	R
Driving: Route Navigation	B	R	R	R	R	[illegible]	R
Driving: Lane Navigation	Y	R	R	R	R	R	R
Driving: Autonomous Vehicles	R	R	R	R	R	R	R
Space Launch	B	[illegible]	R	[illegible]	R	R	R
Space Operations	Y	R	R	R	R	R	R
Maritime: Oceans/Seas	B	R	R	R	R	R	R
Maritime: Harbors	[illegible]	[illegible]	[illegible]	R	R	R	R
Maritime: Inland Waterways	G	[illegible]	R	R	R	R	R
UAS: En Route	Y	R	R	R	R	R	R
UAS: Sensing	R	R	R	R	R	R	R
Emergency 911	B	R	R	R	R	R	R
Automated Facilities	[illegible]	R	R	R	R	R	R

PTA

Evaluating Alternate PN Source: Visual Aids Odomotry

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Conditions	Cost to [illegible]	CSWaP	Op. Maturity
Positive Train Control	R	R	R	R	R	R	R
Precision Agriculture, etc.	R	R	R	[illegible]	R	R	R
Driving: Route Navigation	R	R	R	R	R	[illegible]	R
Driving: Lane Navigation	R	R	R	R	R	R	R
Driving: Autonomous Vehicles	R	R	R	R	R	R	R
Space Launch	R	[illegible]	R	[illegible]	R	R	R
Space Operations	R	R	R	R	R	R	R
Maritime: Oceans/Seas	R	R	R	R	R	R	R
Maritime: Harbors	[illegible]	[illegible]	[illegible]	R	R	R	R
Maritime: Inland Waterways	R	[illegible]	R	R	R	R	R
UAS: En Route	R	R	R	R	R	R	R
UAS: Sensing	R	R	R	R	R	R	R
Emergency 911	R	R	R	R	R	R	R
Automated Facilities	[illegible]	R	R	R	R	R	R

Evaluating Alternate PN Source: Auto Celestial

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Conditions	Cost to [illegible]	CSWaP	Op. Maturity
Positive Train Control	R	R	R	R	Y	R	R
Precision Agriculture, etc.	R	R	R	[illegible]	Y	R	R
Driving: Route Navigation	R	R	R	R	Y	[illegible]	R
Driving: Lane Navigation	R	R	R	R	Y	R	R
Driving: Autonomous Vehicles	R	R	R	R	Y	R	R
Space Launch	R	[illegible]	R	[illegible]	Y	R	R
Space Operations	R	Y	G	G	Y	G	R
Maritime: Oceans/Seas	G	R	R	R	Y	Y	R
Maritime: Harbors	[illegible]	[illegible]	[illegible]	R	Y	Y	R
Maritime: Inland Waterways	R	[illegible]	R	R	Y	Y	R
UAS: En Route	R	R	R	R	Y	R	R
UAS: Sensing	R	R	R	R	Y	R	R
Emergency 911	R	R	R	R	Y	R	R
Automated Facilities	[illegible]	R	R	R	Y	R	R

Evaluating Alternate Timing Transfer & Time Source Method: ATSC 3.0 BPS

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Conditions	Cost to Gov.	CSWaP	Op. Maturity
Cellular Base Station: Intercell Interference*	G	Y	G	G	G	G	G
Cellular Base Station: Carrier Aggregation	G	Y	G	G	G	G	G
Phasor Measurement Unit	G	Y	G	G	G	G	Y
Financial Trading	G	Y	G	G	G	G	Y

- ATSC 3.0 BPS is a time transfer method disciplined to UTC Time
- Internationally accepted standard for NextGen television transmission.
- Currently in field trials and performance of between 5 & 25nS indicates its capability to satisfy any Critical Infrastructure timing requirements.
- The DOT Complementary PNT action plan activities include adding ATSC 3.0 BPS as a viable timing transfer method.
- The Broadcasters are expected to implement this technology onto their already existing broadcast infrastructure at no cost to the Gov.
- At this reporting ATSC 3.0 is deployed in 78% of CONUS and is expected to be 100% by end of 2025.

Evaluating Alternate Timing Transfer Method: TWSTFT

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Con[illegible]ons	Cost [illegible] Gov.	CSWaP	Op. Maturity
Cellular Base Station: Intercell Interference*	G	G	G	G	R	R	G
Cellular Base Station: Carrier Aggregation	G	G	G	[illegible]	R	R	G
Phasor Measurement Unit	G	G	G	G	R	R	G
Financial Trading	G	G	[illegible]	G	R	R	G

- TWSTFT is a tried-and-true method for frequency transfer via GEO satellite.
- TWSTFT is an expensive method of frequency transfer since end point requires its own satellite dish.
- TWSTFT is a transfer mechanism only and not a source of time or frequency.

Evaluating Alternate Time Transfer Method: PTP (IEEE 1588) / Fiber

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Con[illegible]ons	Cost [illegible] Gov.	CSWaP	Op. Maturity
Cellular Base Station: Intercell Interference*	R	R	G	G	Y	G	G
Cellular Base Station: Carrier Aggregation	R	R	G	[illegible]	Y	G	G
Phasor Measurement Unit	R	G	G	G	Y	G	G
Financial Trading	R	Y	[illegible]	G	Y	G	G

- PTP 1588 is expensive when fully realized
- Can be very accurate BUT accuracy is mostly a function of the network over which the protocol operates.
- Security concerns over wide area, public networks vis. man in the middle attacks

Evaluating Alternate Timing Source: Cesium Clock

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Conditions	Cost to Gov.	CSWaP	Op. Maturity
Cellular Base Station: Intercell Interference*	B	B	R	B	Y	R	B
Cellular Base Station: Carrier Aggregation	B	B	R	B	Y	R	B
Phasor Measurement Unit	B	B	R	B	Y	R	B
Financial Trading	B	B	B	B	G	G	B

- Cesium Clock is a time standard so accuracy is adequate for all Critical Infrastructure uses.
- Cesium Clock is a stand-alone single location device.
- Cesium Clock is very expensive (e.g. $84,000 for a 5071A) making wide usage distribution impractical.
- Limited Deployments with Moderate Maintenance and Life Cycle Cost Properties

PTA

Evaluating Alternate Timing Source: Rubidium Clock

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Oper. Region	Conditions	Cost to Gov.	CSWaP	Op. Maturity
Cellular Base Station: Intercell Interference*	B	B	B	B	B	B	B
Cellular Base Station: Carrier Aggregation	R	B	B	B	B	B	B
Phasor Measurement Unit	B	B	B	B	B	G	B
Financial Trading	[illegible]	B	B	B	B	B	B

- Rubidium Clock is a time source sub system typically integrated into a larger piece of equipment like a receiver.
- Is a shorter-term time source in a standalone usage and needs to be disciplined to a high quality time source (e.g., GPS receiver) in order to achieve performance required by Critical Infrastructure applications.
- In Wide Use (e.g Energy) with Excellent Maintenance and Life Cycle Cost Properties

PTA

Evaluating Alternate Timing Source: Chip Scale Atomic Clock (CSAC)

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Conditions	Cost to Go	CSWaP	Op. Maturity
Cellular Base Station: Intercell Interference*	R	B	B	B	B	B	B
Cellular Base Station: Carrier Aggregation	R	B	B	[illegible]	B	B	B
Phasor Measurement Unit	R	B	B	B	B	B	B
Financial Trading	R	B	B	B	B	B	B

- Chip Scale Atomic Clock is made using Rubidium so its score is the same as the characteristics.
- More Rugged than Traditional Rubidium (e.g. LEO, Undersea Drilling, other Harsh Environments)

PTA

Evaluating Alternate Timing Source: OCXO

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Conditions	Cost & Gov.	CSWaP	Op. Maturity
Cellular Base Station: Intercell Interference*	R	B	B	B	B	B	B
Cellular Base Station: Carrier Aggregation	R	B	B	[illegible]	B	B	B
Phasor Measurement Unit	R	B	B	B	B	B	B
Financial Trading	R	B	[illegible]	B	B	B	B

- Oven Controlled Crystal Oscillators are inexpensive compared to atomic clocks and their performance is not good enough for stand alone use in any Critical Infrastructure applications

- Excellent Short Term Phase Noise Properties

Evaluating Alternate Time Transfer Source: Cellular (5G)

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Conditions	Cost & Gov.	CSWaP	Op. Maturity
Cellular Base Station: Intercell Interference*	G	B	G	G	R	G	G
Cellular Base Station: Carrier Aggregation	G	B	G	[illegible]	R	G	G
Phasor Measurement Unit	Y	Y	G	G	R	G	Y
Financial Trading	Y	Y	[illegible]	G	R	G	Y

- 3GPP standards body has established in 5G versions Release 17 and 18 “should” be capable of transferring their “time” [illegible] via RF.
  - As yet this has not been implemented commercially.
- The Mobile Wireless Operators would demand a premium to the government for use of their radios as time transfer methods for Critical Infrastructure applications.
- Wide variation in what is actually deployed depending on carrier. Not always practical for Critical Infrastructure

Evaluating Alternate Timing Transfer Method: NTP/Fiber

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Conditions	Cost & Gov.	CSWaP	Op. Maturity
Cellular Base Station: Intercell Interference*	R	R	G	G	Y	G	G
Cellular Base Station: Carrier Aggregation	R	R	G	[illegible]	Y	G	G
Phasor Measurement Unit	R	R	G	G	Y	G	G
Financial Trading	R	Y	[illegible]	G	Y	G	G

- Similar to PTP
- NTP Is not used for Phasor Measurement Units

Evaluating Alternate Timing Source & Time Transfer: Galileo

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Conditions	Cost to Gov.	CSWaP	Op. Maturity
Cellular Base Station: Intercell Interference*	B	Y	[illegible]	B	B	B	B
Cellular Base Station: Carrier Aggregation	B	Y	B	B	B	B	B
Phasor Measurement Unit	B	[illegible]	B	B	B	B	B
Financial Trading	[illegible]	Y	[illegible]	B	B	B	B

- Toughness of receivers unknown

- Has Civil Authentication Features (OSNMA / ACAS)

Evaluating Alternate Time Source & Time Transfer: Iridium (STL)

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Constellations	Cost & Gov.	CSWaP	Op. Maturity
Cellular Base Station: Intercell Interference*	B	Y	B	B	Y	G	B
Cellular Base Station: Carrier Aggregation	Y	Y	B	[illegible]	Y	G	B
Phasor Measurement Unit	B	Y	B	B	Y	G	B
Financial Trading	B	Y	[illegible]	B	Y	B	B

- NIST has certified this service as a Stratum1 time transfer method.
- Time Traceable to NIST UTC
- Toughness of receivers unknown

PTA

Evaluating Alternate Timing Source: eLoran

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Co[illegible]ons	Cost [illegible] Gov.	CSWaP	Op. Maturity
Cellular Base Station: Intercell Interference*	B	Y	R	G	Y	G	R
Cellular Base Station: Carrier Aggregation	B	Y	R	[illegible]	Y	G	R
Phasor Measurement Unit	B	Y	R	G	Y	G	R
Financial Trading	B	Y	[illegible]	G	Y	B	R

PTA

Evaluating Alternate Time Transfer: Locata

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Con[illegible]ons	Cost [illegible] Gov.	CSWaP	Op. Maturity
Cellular Base Station: Intercell Interference*	B	Y	R	G	Y	G	R
Cellular Base Station: Carrier Aggregation	B	Y	R	[illegible]	Y	G	R
Phasor Measurement Unit	B	Y	R	G	Y	G	R
Financial Trading	B	Y	[illegible]	G	G	B	G

- Demonstrated High Precision Time Transfer in JRC Testing
- 1.7 nsec time transfer accuracy (ext. source) over 105 km distance
- TRL 9

PTA

Evaluating Alternate Timing Transfer: NextNav

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Co[illegible]ons	Cost [illegible] Gov.	CSWaP	Op. Maturity
Cellular Base Station: Intercell Interference*	B	Y	R	G	Y	G	R
Cellular Base Station: Carrier Aggregation	B	Y	R	[illegible]	Y	G	R
Phasor Measurement Unit	B	Y	R	G	Y	G	R
Financial Trading	B	Y	[illegible]	G	G	B	G

- Demonstrated High Precision Time Transfer (~ 20 nsec) in DoT Testing
- Network [illegible] beacons operating in the 902-928 MHz band

PTA

Evaluating Alternate Time Transfer: PhasorLab

Use Case	Criteria						
	Accuracy	Avail. & Cont.	Operat. Region	Con[illegible]ons	Cost [illegible] Gov.	CSWaP	Op. Maturity
Cellular Base Station: Intercell Interference*	B	Y	R	G	Y	G	R
Cellular Base Station: Carrier Aggregation	B	Y	R	[illegible]	Y	G	R
Phasor Measurement Unit	B	Y	R	G	Y	G	R
Financial Trading	B	Y	[illegible]	G	G	B	G

- Demonstrated High[illegible]recisi[illegible]n Ti[illegible]ransf[illegible]r (~ 20 nsec) in DoT Testing
- Dynamic [illegible]esh [illegible]etw[illegible]k requi[illegible]g high density
- Operates [illegible] 2.4 GH[illegible] ISM Band
- Assessed as [illegible]RL 6/7