The Need for a Robust Precise Time and Frequency Alternative to Global Navigation Satellite Systems

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Summary
(Starting with the end in mind)

- Time is an important Global Navigation Satellite System (GNSS)* product, often overlooked
  - GNSS Time users greatly outnumber all other users
- GNSS is vulnerable; GNSS is vulnerable!
- There are robust alternatives – but there is a need to identify and incorporate them into operations that ensure safety and security and to mitigate significant economic impact
- Precise Time is particularly important to certain ground based and airborne "discriminating" users
- For many applications authentication is as important as accuracy
- Today's status quo may not/will not be an acceptable alternative in the future as GNSS services continue to proliferate and support more and more critical operations

*The Global Positioning System is the US' GNSS

The Definition of *Robust*

ro·bust, *adj,* [rō-ˈbəst, ˈrō-(ˌ)bəst]

a: strong and healthy; having or exhibiting strength or vigorous health.

b: (of an object) strongly formed or sturdy in construction.

c: (of a process, system, organization, etc.) able to withstand or overcome adverse conditions.

. . . so let's agree that *Robust* Precise Time and Frequency is the provision of precise time and frequency services that are ***strong, sturdy, and able to withstand or overcome adverse conditions***.

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What are Adverse Conditions?

- Interference
  - Intentional/Unintentional
  - Predictable/Unpredictable
  - Manmade/Environmental
  - Crude/Sophisticated (Jamming/Spoofing)
  - Widespread/Localized
- Dependent on the Position, Navigation, and Timing (PNT) System (both xmtr and rcvr)
  - High power/low power
  - Line-of-sight/ground wave
  - Designed robustly/Engineered for a sunny day
- Both suppliers and users of PNT services need to recognize the potential for real-world adverse conditions and plan design, and equip accordingly

The world is changing…The world has changed

Commercially Available GPS Jammer
(so called "Personal Privacy Device")

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… and a few more "Personal Privacy Devices"

$110 Ebay

$69
The Jammer
Store

$335 EBay

$40 GPS&GSM
www.chinavasion.com

$55 Ebay

$83 GPS&GSM
www.Tayx.co.uk

$152 Ebay

“Super HOT New Cigarette Case Cell Phone Jammer”

- **Features**
  Power supply: Rechargeable Li-battery
  Effective Radius: 5m
  Dimension: 90x50x15mm
  Energy Consumption: 33dbm
  Accessories: AC Adapter/Car Adapter

- **Specifications**
  Jamming Signal Frequency:
  * CDMA: 869-880MHZ
  * GSM: 925-960MHZ
  * DCS: 1805-1930MHZ
  * 3G: 2110-2170MHZ

~ $99

The Problem

- GNSS-provided precise time and frequency is not robust
- Many users are not aware of the importance of time/frequency in system operations and that they derive it from GNSS
- Time and Frequency supports many critical infrastructure applications

Critical Infrastructure/Key Resource Sector	Uses GPS Timing?	
	Yes	No
1. Communications Sector	X	
2. Emergency Services Sector	X	
3. Information Technology Sector	X	
4. Banking & Finance Sector	X	
5. Healthcare & Public Health Sector	X	
6. Energy/Electric Power and Oil & Natural Gas SubSector	X	
7. Nuclear Sector	X	
8. Dams Sector	X	
9. Chemical Sector	X	
10. Critical Manufacturing	X	
11. Defense Industrial Base Sectors	X	
12. Postal & Shipping Sector	X	
13. Transportation Sector	X	
14. Government Facilities Sector	X	
15. Commercial Facilities Sector	X	
16. National Monuments and Icons Sector		X
17. Agriculture and Food Sector		X
18. Water and Wastewater Sector		X

Summary
15 of the18
CIKR Sectors
have some
degree of
GPS timing usage

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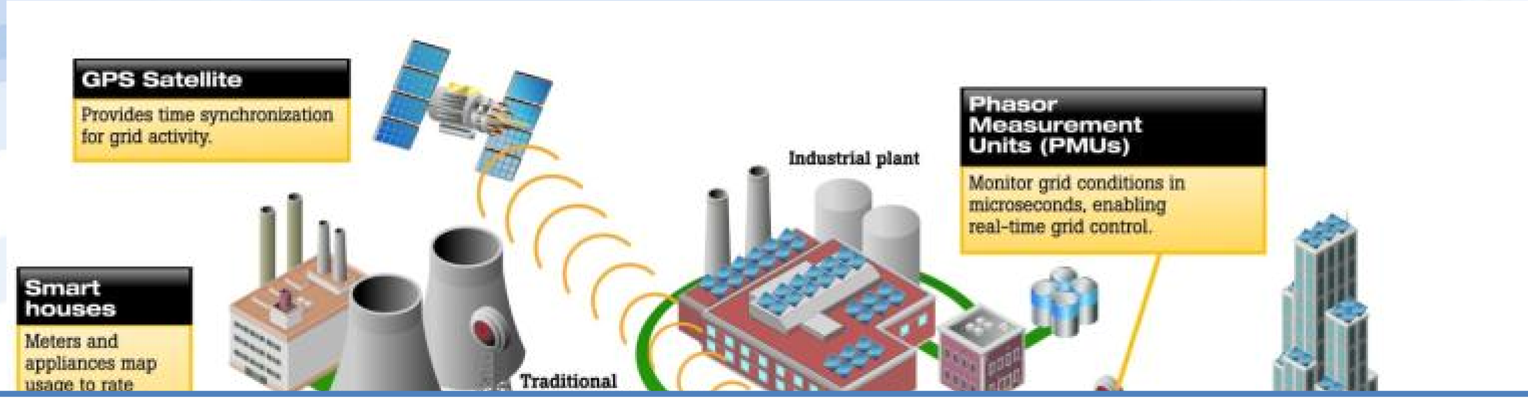
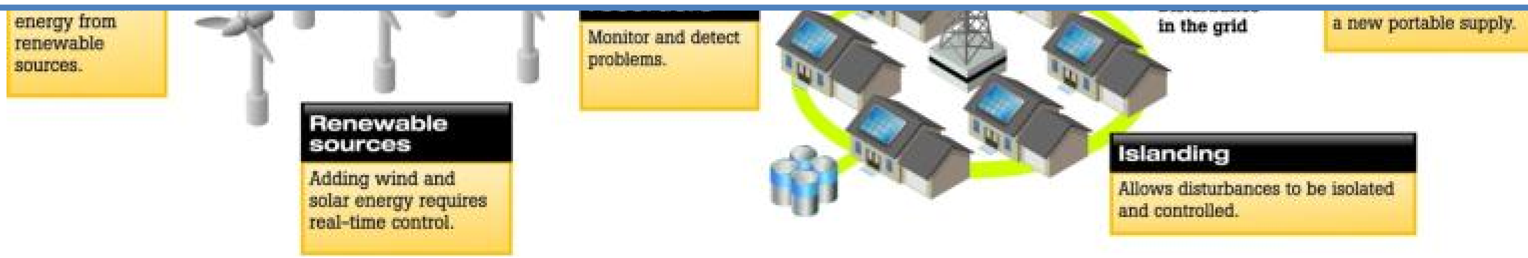


Power Grid Requirements

- *Minimum PMU requirement* for time synchronization = 26 µs;
  - Corresponds to a phase error of 0.57 º at the 60 Hz AC line frequency
  - Per *IEEE C37.118.2-2011* “Standard for Synchrophasor Data Transfer for Power Systems”
- The *<u>desired</u>* accuracy is 1 µs
  - Corresponds to a phase error of 0.022 °



Source: M. Lombardi, *“Microsecond Accuracy at Multiple Locations: Is it possible without GPS?,* IEEE Instrumentation and Measurement Magazine, October 2012

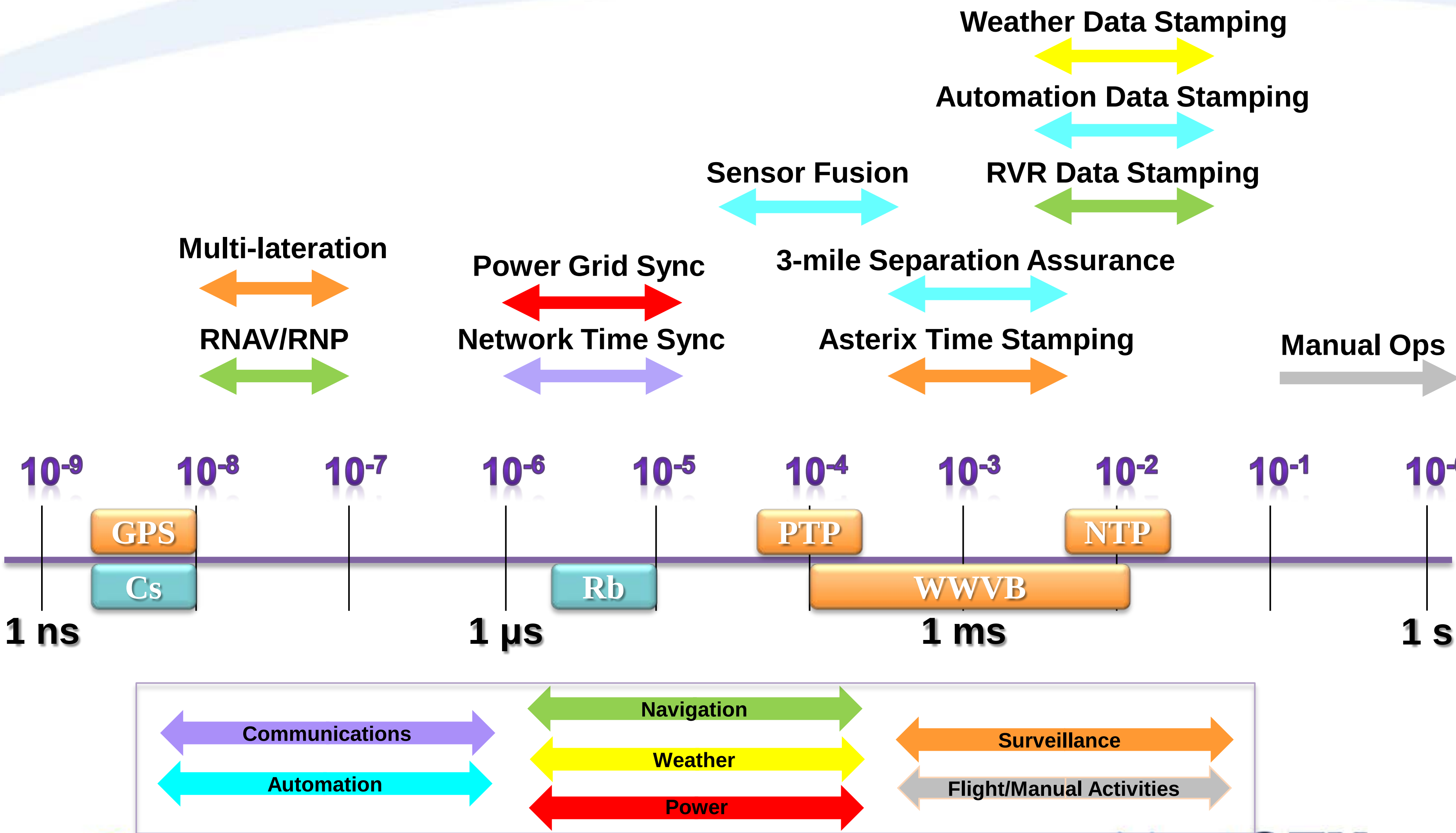
Why Alternate Position, Navigation, and Timing (PNT)?

- Homeland Security Presidential Directive-7 (HSPD-7) establishes a national policy to identify, prioritize, and protect ***critical infrastructure and services***.
  - Requires use of alternate means ("a back-up") if GPS services are being used for safety or security or to prevent significant economic impact
- FAA recognizes the need to maintain operations within the National Airspace System (NAS)
- Other Critical Infrastructure/Key Resource sectors also have real time and continuity of operations requirements
- <u>For many waiting for the source of the interference to be located and turned off is not an acceptable alternative.</u>

National Airspace System (NAS) Alternatives

- Today
  - The majority of aircraft flying in the NAS have non-GPS alternatives that ensure safety [e.g., Very High Frequency Ominidirectional Range(VOR), Instrument Landing System (ILS), etc.]
  - The FAA maintains a non-GNSS dependent ground based infrastructure
- Future
  - NAS capacity and efficiency improvements will rely on GNSS services
  - The FAA is exploring alternate position, navigation, and timing means to maintain safety and security and minimize economic impact in the event of a GNSS outage

National Airspace System Precise Time Requirements



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Sources of Time and Frequency

- **GPS**
  - 10 ns Time Accuracy
  - 1×10^{-13} Frequency Stability

- **WWVB**
  - 0.1 – 15 ms Time Accuracy
  - 1×10^{-10} - 1×10^{-12} Frequency Stability

- **ITS* (NTP)**
  - 10 ms Time Accuracy
  - 1×10^{-7} Frequency Stability

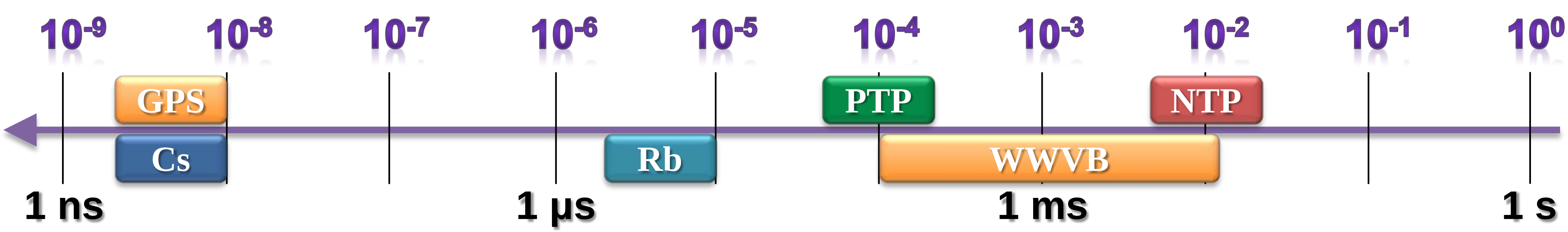
*Internet Time Service

- **ITS* (PTP)**
  - 0.1 ms Time Accuracy
  - 1×10^{-9} Frequency Stability

*Internet Time Service

- **Cesium (Cs) Clock**
  - 10 ns Time Accuracy
  - Cannot Recover Time independently
  - 1×10^{-13} Frequency Stability

- **Rubidium (Rb) Clock**
  - 10 µs Time Accuracy
  - Cannot Recover Time Independently
  - 5×10^{-11} Frequency Stability



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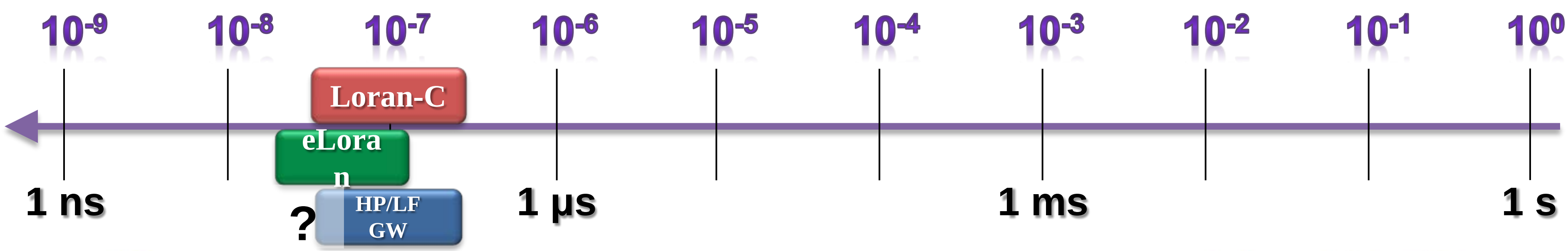
Sources of Time and Frequency

- **Loran-C**
  - 100 ns Time Accuracy
  - 1 x 10^{-11} Frequency Stability

- **eLoran**
  - 50 ns Time Accuracy
  - 1 x 10^{-11} Frequency Stability

- **Future HP/LF Groundwave??**
  - ?? ns
  - 1 x 10^{-11} Frequency Stability



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Today's Alternate Time and Frequency Sources

- Temperature Controlled Crystal Oscillators (TCXO)
- Network Time Protocol (NTP)
- Oven Controlled Crystal Oscillators (OCXO)
- Rubidium Clocks (Rb)
- Cesium Clocks (Cs)

Increasing Precision

Source	Frequency Accuracy	Time Uncertainty at One Day
TCXO	1×10^{-6}	86.4 ms
NTP	1×10^{-6} - 1×10^{-8}	86.4 ms - 864µs
OCXO	1×10^{-7} - 1×10^{-10}	8.6ms – 8.6µs
Rb	5×10^{-9} - 5×10^{-12}	432µs – 432ns
Cs	1×10^{-13}	10 ns
GPS	1×10^{-13}	10 ns

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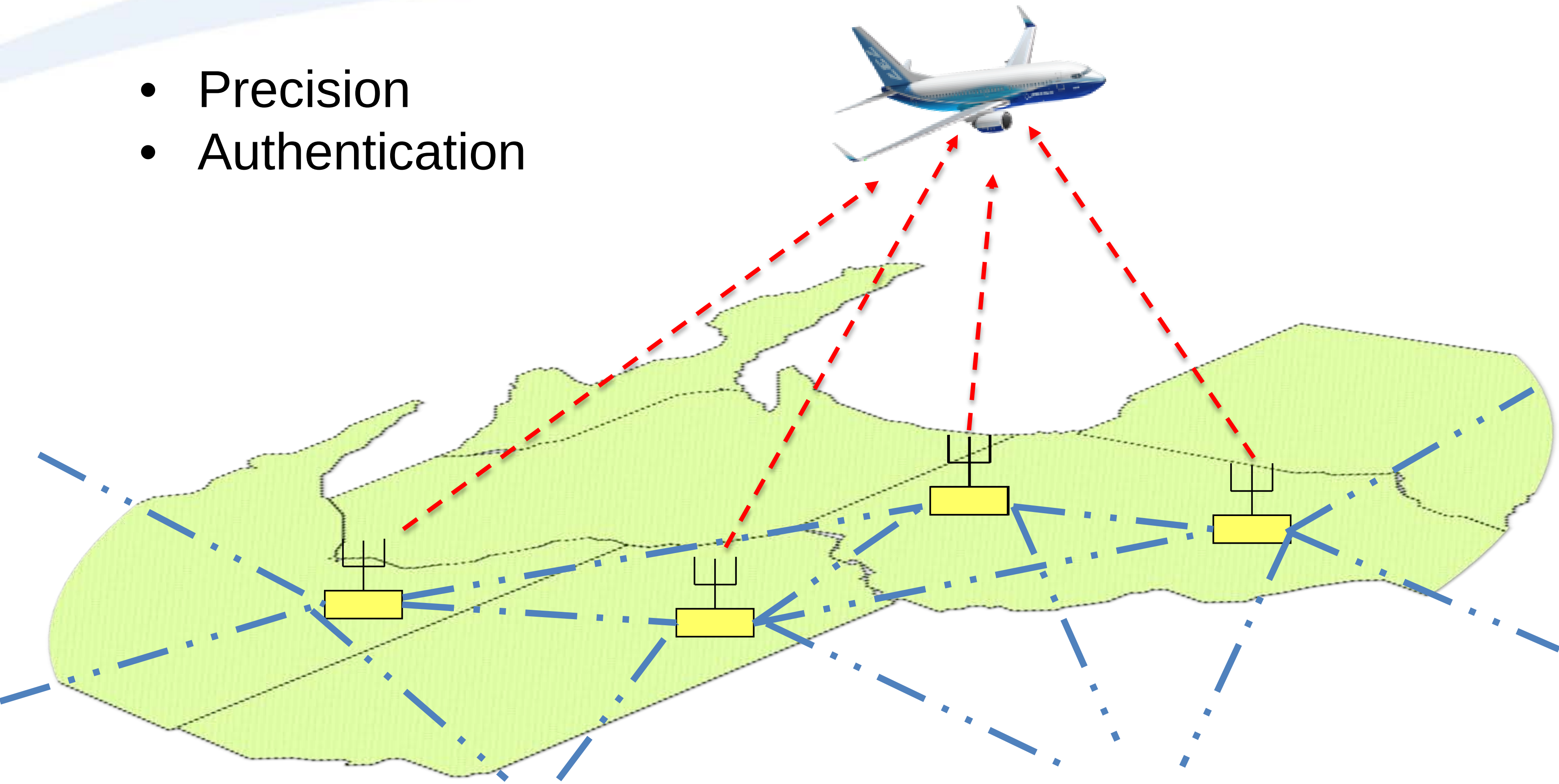
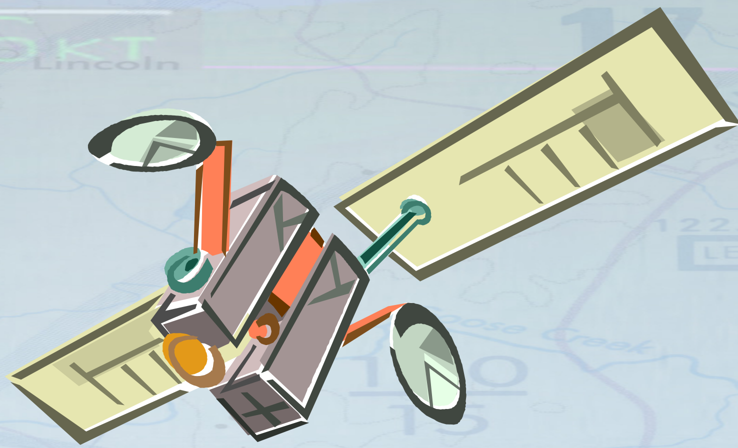
The Challenge of Robust Time Transfer

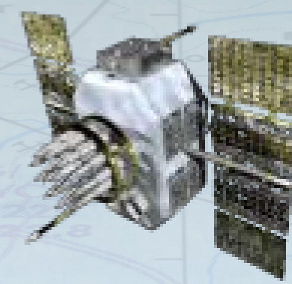
- Precision
- Authentication

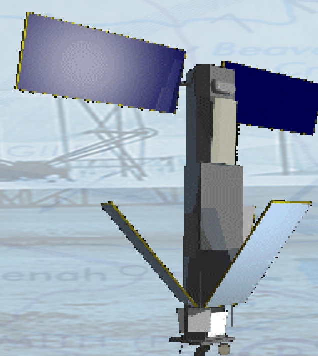


Alternative 1

Robust Satellite-Based Sources: GEOs, MEOs, and LEOs







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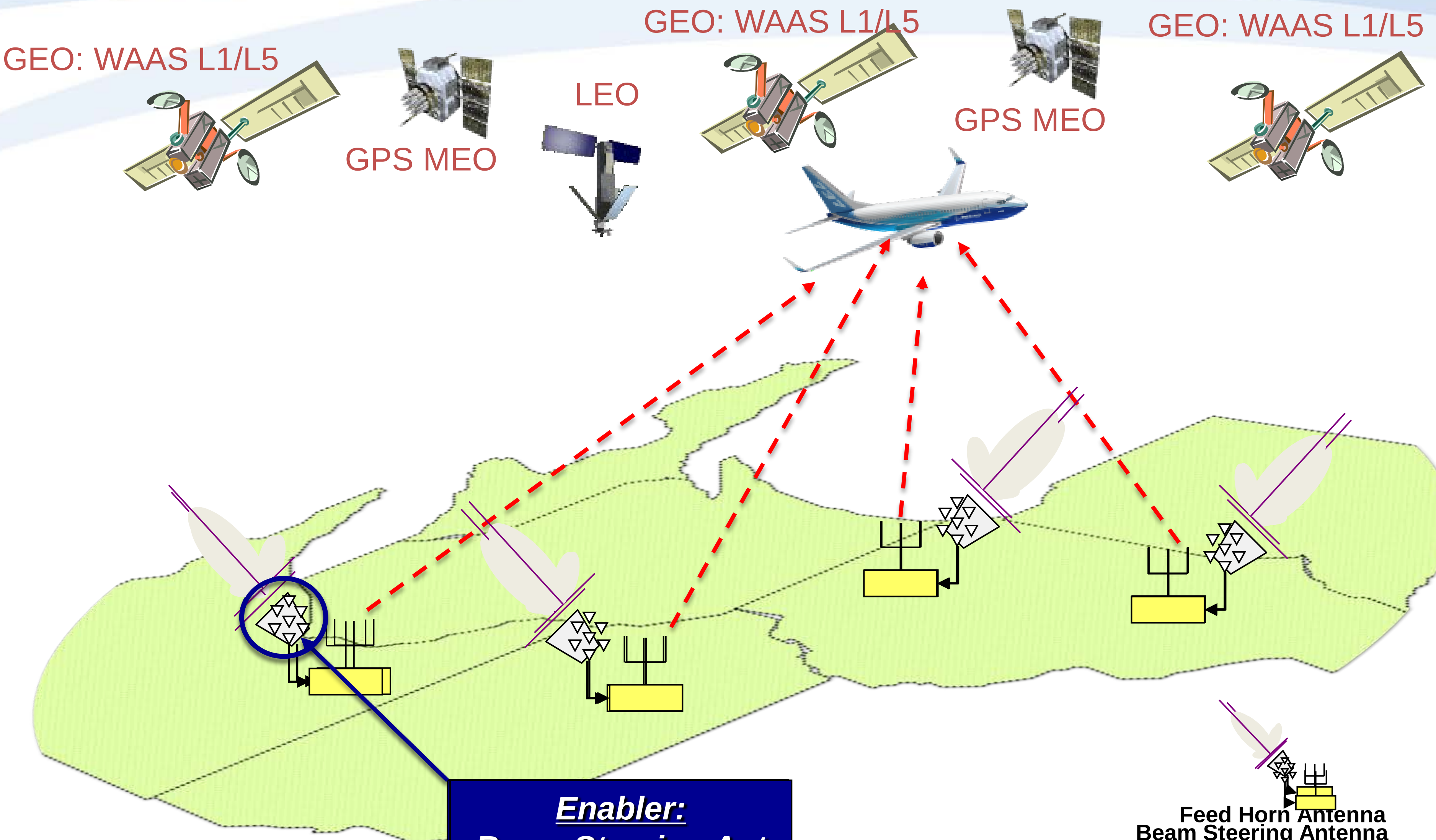
Robust Space-Based Time Transfer



Enabler:
Beam Steering Ant
Time Transfer RX

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Commercially Available
Controlled Reception Pattern Antennas (CRPA)




- Mitigate Radio Frequency Interference
- Provides Anti-Jam Performance

Alternative 2

Robust Wireless Ground-Based Sources

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Ground Based Wireless Time Networks

WWVB

0.2-15 milliseconds

?? Alternate PNT ??

~~Loran,~~ ~~eLoran~~, Future HP/LF GW

???-100 nanoseconds

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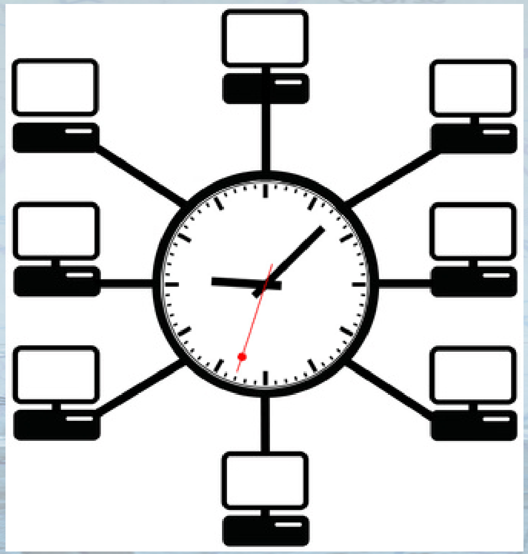
Alternative 3

Robust Wire-Based Sources



Internet Time Services

- **ITS* (NTP)**
  - 10 ms Time Accuracy
  - 1 x 10^{-7} Frequency Stability

*Internet Time Service

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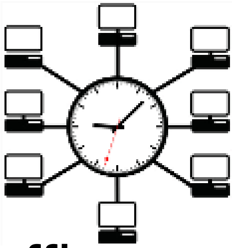

- ITS Timing Performance Limitations
  - Use of Ethernet connections
  - Use of different lines for incoming and outgoing traffic
    - Line length differences result in timing errors
    - Errors that increase over distance cannot be corrected
  - When implemented on a wide area network (WAN) such as the Internet, where the path delays are highly variable and uncontrolled, PTP accuracy becomes similar to NTP (i.e., milliseconds)

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Summary

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Questions