

# *A Robust PNT Architecture is Essential to Our Critical Infrastructure*

*PNT was once a nicety ...  
... now it has become a necessity!*



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**Federal Aviation  
Administration**



# Hypothesis:

## “A Robust PNT Architecture is Essential to Our Critical Infrastructure.”

- **Proposed Investigative Steps:**
  - Describe the significance of PNT;
  - Establish the metrics by which we will arrive at our conclusion;
  - Determine and describe the required enabling technology; and
  - Define the critical elements and architecture necessary for maintenance and operational advancements (e.g., in safety, surveillance, and security).
- **Help every one of you to become an advocate!**
- **In the process describe the work that has and is being done to enhance the Loran radionavigation/PNT system**

# The Significance of PNT as an Enabling Technology

- PNT is the technology that has permeated all aspects of our lives in the 21<sup>st</sup> century – in many cases we don't even realize it is being used
- **Government/Corporate/Professional/All users are extremely dependent on PNT and reap considerable benefits from it thanks to:**
  - The availability of low cost receivers and low cost, if not free service;
  - The availability of highly integrated PNT modules enabling high volume manufacturing supported by large and growing marketplaces;
  - The continued integration of PNT into consumer products; and
  - The increasingly innovative, sophisticated, yet affordable s/w applications that fuel growth and expansion into new marketplaces.

# Position, Navigation, and Time Today – *An all encompassing “addictive” need*

- **Transportation** – All modes of transportation (air, sea, & land) rely on accurate position, navigation, and timing for safety, security, economic efficiency, and other customer services.
- **Communications** – Public and private communications systems rely on timing and time synchronization to maximize circuit bandwidth and secure their communication channels – for both hardwired and mobile cellular services
- **Power Utilities** – Power companies rely on exact frequency and time synchronization to maximize power transmission through national electrical grids
- **Recreational/Other** – Personal use of positioning, navigation, and timing services continues to grow – unabated

# The Significance of PNT

- **Benefits are good, but “blind” dependence on a less than fully robust systems is not**
  - 10 September 2001: Volpe Transportation System Center study “Vulnerability Assessment of the Transportation Infrastructure Relying on the Global Positioning System” released
    - *“There is **a growing awareness** within the transportation community that the safety and economic risks associated with loss or degradation of the GPS signal have been underestimated ... Public policy must ensure that safety [and economic viability] are maintained in the event of loss of GPS.”*
  - “Unintentional Outages” have occurred (days/weeks, miles/hundreds of miles)
- **Business cases/risk assessments should address the continuity of operations aspects related to the provision and use of PNT services**

# Position, Navigation, and Time – *The Good News ... and the Bad News*

- **The Good News**





- Excellent positioning, navigation, and timing has become available to all levels of users with the advent of global navigation satellite systems (GNSS) such as the US Global Positioning (and Time) System (GPtS)
- Other GNSS services and capabilities are planned and are being developed.
- GNSS technology is improving, costs are going down, and users are increasing

- **The Bad News**

- Dependence on GNSS as a single source of position, navigation, and timing services (i.e., sole means) is also increasing in many sectors.
- There is a simple, but surprisingly ignored (inconvenient?) truth:
  - ***Whatever benefits one receives from PNT-enabled solutions are lost when the PNT service is lost!***

**That is both *The Challenge* and *The Opportunity!***

# Elements Critical to Many Applications Involving Safety, Surveillance, and Security

-  **Knowing (*reliably*) where you are and where everyone/ everything else is – when, and at all times;**
-  **Being able to provide, process, manage, and properly use the information in a timely manner;**
-  **Being able to *reliably* communicate data/information to those that need it when they need it; and**
-  **Gaining the acceptance and trust of the system by the targeted user community.**

# Reliance on PNT Systems May Dictate Adjustments in Concepts of Operations

- **Performance metrics are essential to defining PNT-enabled services**
  - Accuracy, Availability, Integrity, and Continuity
- **Choosing to use or not use a specific PNT service should depend on its performance as defined by these metrics**
- **Lack of adequate reliability/robustness is problematic**
  - In some cases merely an inconvenience (depending on the importance you place on customer satisfaction)
  - In other cases, it has the potential for contributing to loss of life and/or property
- **The robustness of PNT services is now a critical part of many applications and one that may still be overlooked**



# PNT Must Fail Soft, Fail Safe

– assume the worst, plan for the best

- **Redundant Capability**

- A failure of the GNSS system has *no effect on operations*
- “Other” Systems Capabilities are similar to those of GNSS

- **Backup Capability**

- A failure of the GNSS system *will affect operations*
- Must ensure safety and security location

- **Operational Contingency**

- Ensures safety at the onset of and during GNSS failure
- Precludes or limits operations

# PNT Alternatives

**Q1. What alternative PNT system(s) are available to meet the needs of GNSS PNT service users in the event of an “outage?”**

**A1. It depends.....**

**Q2. ...on what?**

**A2. Your requirements:**

- accuracy, availability, integrity, and continuity**
- your risk quotient/how lucky do you feel today?**
- regulatory/legal responsibilities**

# PNT Alternatives – an “Independent” View

PNT users need dissimilar, complementary, multi-modal, and independent sources of GPtS & PNT

Service	PNT	Multi-Modal	Independent of GNSS		
			System	Signal	User
Galileo	✓	✓	✓	✗	✗
eLoran	✓ (no 3D)	✓	✓	✓	✓
DGPS	✗	✓	✗	✓	✗
SBAS	✗ ✓	✓	✗ ✓	✗	✗
Radar	✗	✗	✓	✓	✓

**eLoran** is frequency and signal diverse as well as much more powerful (virtually unjammable)

# Some other “Time” stuff

- ***“GPS serves as a precision timing source for 100,000,000 cell phone customers in North America and 250,000,000 worldwide.”***

B. Greene, VP, Lucent, brief to DOC GPS Forum, Jan. 2006

- ***“Under no circumstances should the Government place total reliance on GPS and completely abandon its plans to continue to deploy eLoran.”***
  - Sprint Nextel Corp., comments in Federal Register, Feb. 2007
- ***“The proposal to develop an eLoran system would effectively address the need for a nationwide, distributed backup system. It is not clear that any widely reliable backup system exists now.”***

M. Lombardi, NIST, DHS briefing, July 27, 2006

# NIST Report on Time Backups for GPS

- **“We have reviewed all of the available broadcast signals that anchor the time and frequency infrastructure in the United States.”**
- **“We conclude that *eLoran* is the best available backup provider to GPS as a reference source for precise time synchronization and frequency control.”**

## ...so what is eLoran

- **The Enhanced Loran (eLoran) Definition Document, published by the International Loran Association and developed at the United States Coast Guard Navigation Center by an international team of authors states that eLoran:**
  - Is an internationally-standardized positioning, navigation, and timing (PNT) service for use by many modes of transport and in other applications that takes full advantage of 21<sup>st</sup> century technology.
  - Meets the accuracy, availability, integrity, and continuity performance requirements for aviation non-precision instrument approaches, maritime harbor entrance and approach maneuvers, land-mobile vehicle navigation, and location-based services, and
  - Is a precise source of time and frequency for applications such as telecommunications.
  - Allows GNSS users to retain the safety, security, and economic benefits of GNSS, even when their satellite services are disrupted.
- **But let's go back a bit – a bit of history – back to Loran-C**

*It's a big world and ...*

*... Loran still serves half of it!*



# Loran-C (according to the FRP)

- **A hyperbolic radionavigation system...**
  - ...operating between 90 kHz and 110 kHz...
  - ...that uses a very tall antenna...
  - ...that broadcasts primarily a groundwave
  - ...at high power...
  - ...that provides both lateral position...
  - ...and a robust time and frequency standard
- **A supplemental system for enroute navigation in the US National Airspace System (NAS)**
- **A system for maritime navigation in the coastal confluence zone (CCZ)**
- **A Stratum 1 frequency standard (i.e.,  $1 \times 10^{-11}$ ) that also provides time within 100 ns of UTC (USNO)**





# Loran-C (according to the FRP)

- **Provides:**
  - A predicted 2drms accuracy of 0.25 nm (460 m) and a repeatable accuracy of 60-300 ft (18-90 m)\*
  - An availability of 99.7% (based on triad operation)\*
  - A level of Integrity based on exceeding certain operational parameters measured at the transmitters and at system area monitor sites.
  - Continuity no greater than 99.7% (its availability), but potentially worse depending on receiver characteristics and geometry of the triad being used, and.....

***If this was all that Loran could do, the US would have turned it off!***



# US Loran-C Policy – 2001

*“While the Administration continues to evaluate the long-term need for continuation of the Loran-C radionavigation system, the Government will operate the Loran-C system in the short term. The U.S. Government will give users reasonable notice if it concludes that Loran-C is not needed or is not cost effective, so that users will have the opportunity to transition to alternative navigation aids. With this continued sustainment of the Loran-C service, users will be able to realize additional benefits. Improvement of GPS time synchronization of the Loran-C chains and the use of digital receivers may support improved accuracy and coverage of the service. Loran-C will continue to provide a supplemental means of navigation. Current Loran-C receivers do not support non precision instrument approach operations.”*

– *Para 3.2.5 B 1999 US Federal Radionavigation Plan*

# GPS Vulnerability – An Accepted Fact

- **GPS is vulnerable to unintentional and intentional disruptions covering small to extensive areas, for durations from minutes to days**
- **Illustrations:**
  - 1-5 watt intermittent jammers (confound detection) capable of disrupting the GPS signal are available today to place in harbor and shore areas
  - “Jamfest” testing in White Sands, NM (2005) recorded cell phone disruption within 20-25 min of jamming onset
  - San Diego disruption (Jan 07)
- **US public policy already requires that backup systems or procedures be available to mitigate GPS disruptions in critical applications (National Security Presidential Directive 39 Fact Sheet, December 15, 2004)**

# eLoran Program - Logo Collection – Fall 2007



International  
**Loran**  
Association

Megapulse

RTCM



**Rockwell  
Collins**

Booz | Allen | Hamilton

Symmetricon  
**TIMING SOLUTIONS**



LOCUS



reelektronika



**Raytheon**



OHIO  
UNIVERSITY



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HELIOS

# Loran- C vs. *eLoran* Metrics

## FAA 2002 “Murder Board” Requirements

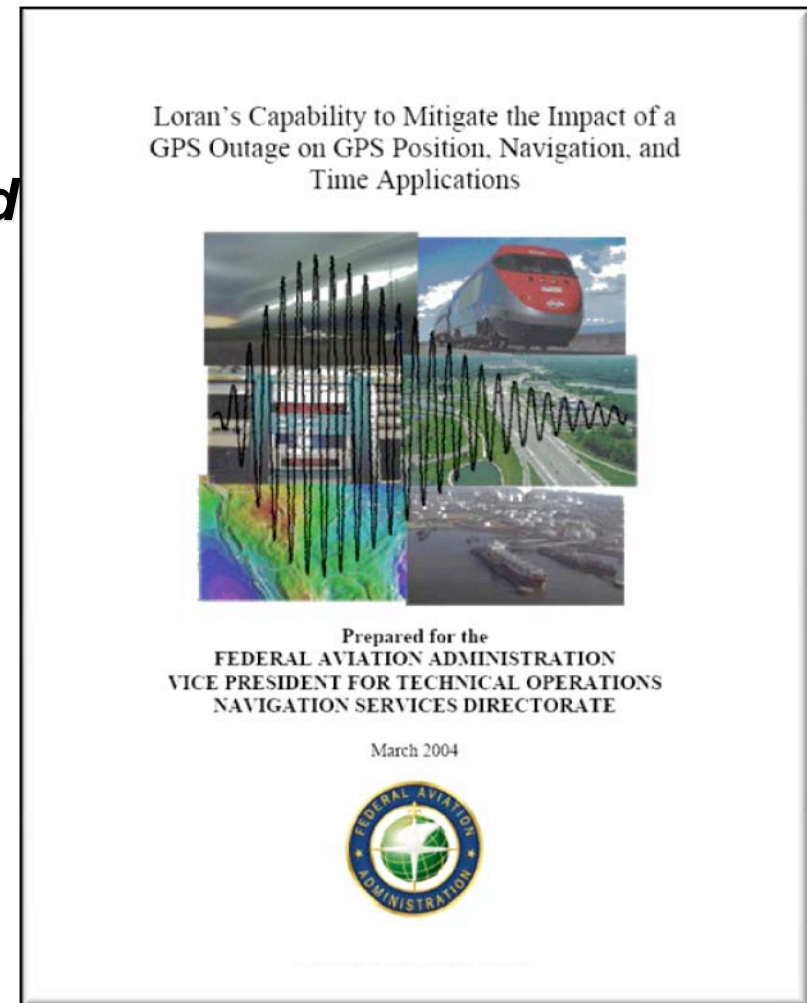
	Accuracy	Availability	Integrity	Continuity
Loran-C Definition of Capability* (US FRP)	0.25 nm (463 m)	0.997	10 second alarm/ 25 m error	0.997
FAA NPA (RNP 0.3)** Requirements	0.16 nm (307 m)	0.999 – 0.9999	0.99999999 (1 x 10 <sup>-7</sup> )	0.999 - 0.9999 over 150 sec
US Coast Guard HEA Requirements	0.004 - 0.01 nm (8 – 20 m)	0.997 - 0.999	10 second alarm/ 25 m error (3 x 10 <sup>-5</sup> )	0.9985 – 0.9997 over 3 hours

\* Includes Stratum 1 timing and frequency capability

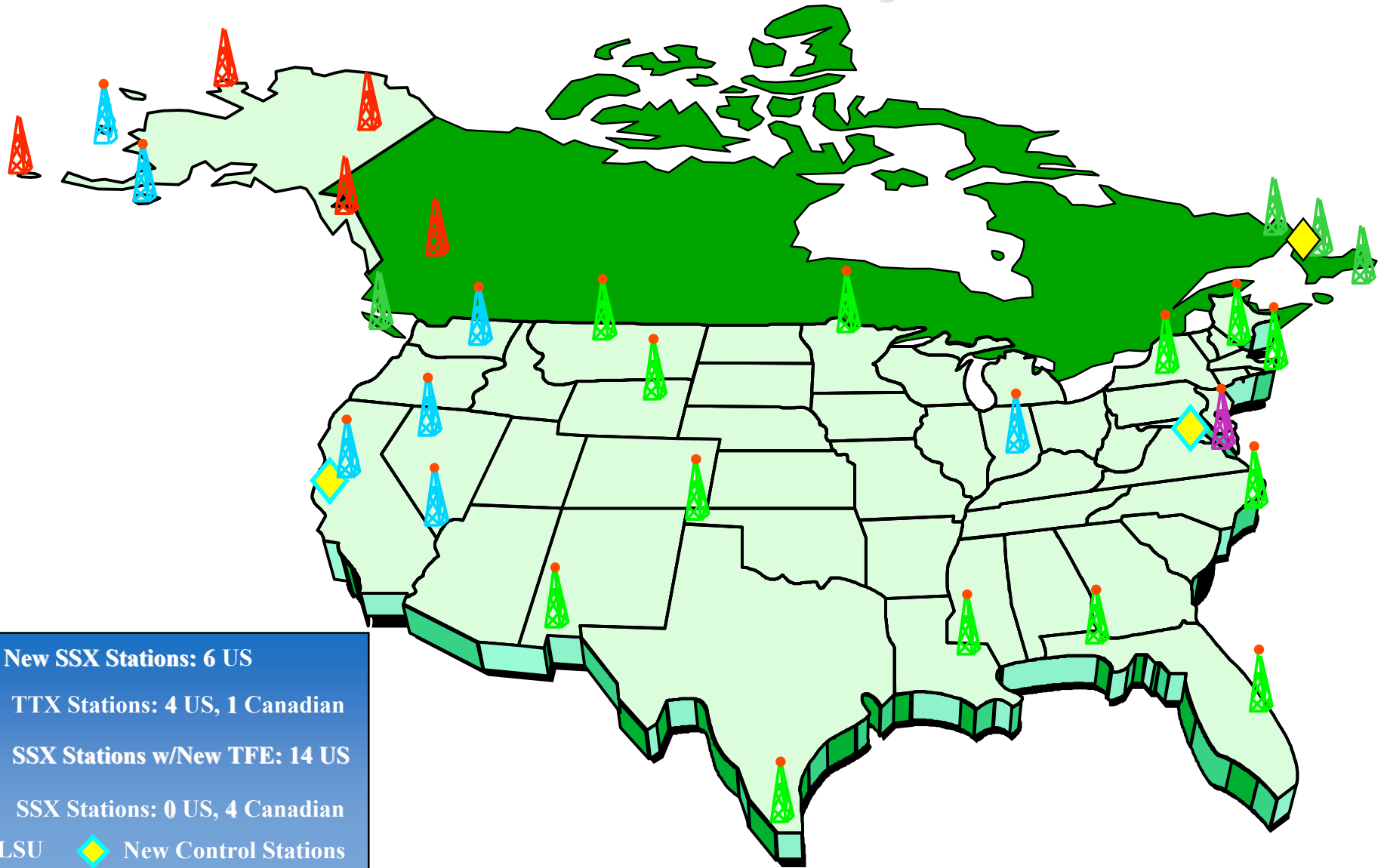
\*\* Non-Precision Approach Required Navigation Performance

# 2004: Loran Evaluation Team's Conclusion

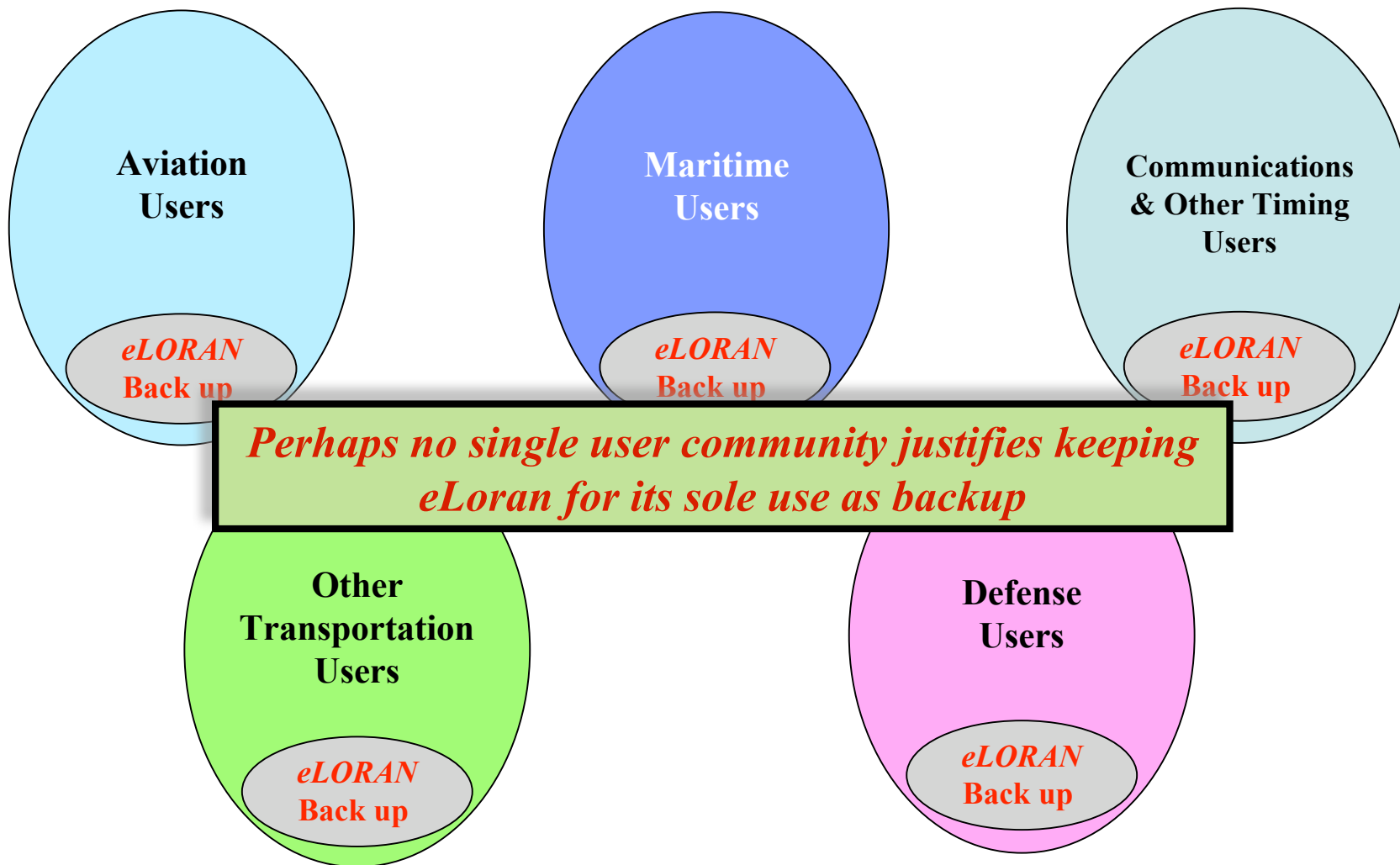
***“The evaluation shows that the modernized Loran system could satisfy the current **NPA, HEA,** and timing/frequency requirements in the United States and could be used to mitigate the operational effects of a disruption in GPS services, thereby allowing the users to retain the benefits they derive from their use of GPS.”***



# North American Loran System - 2007

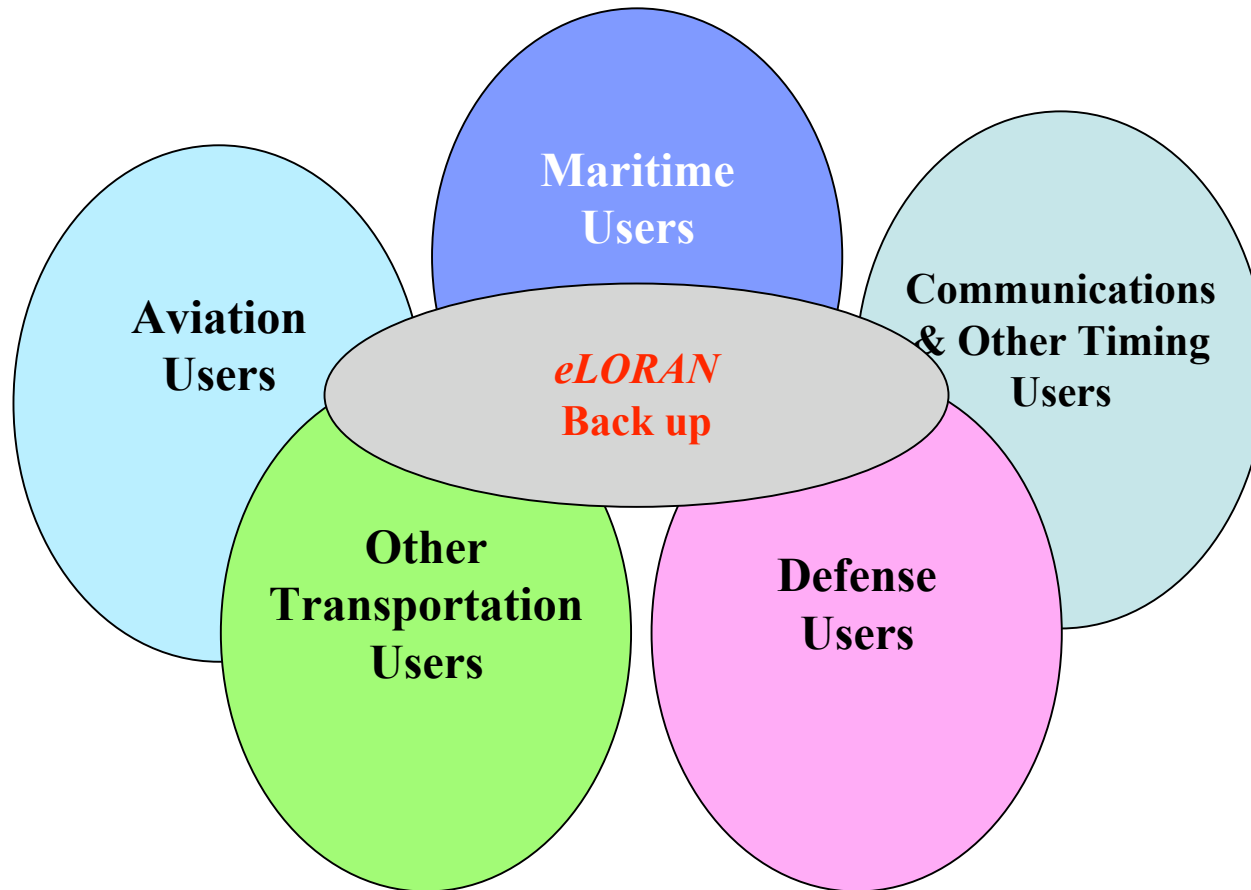


# Current Situation – GPS is Primary





# Combined Community Need



*But an ensemble of users needing backup could support continuing eLoran*

# Loran System Evolution Continues



\*TBD as part of Transition Plan



<b>Status Today</b>	<b>Loran-C</b>	<b>Modernized Loran</b>	<b>eLoran</b>
<b>Aviation</b>			
EnRoute (RNP 2.0 ->1.0)	Yes	Yes	Yes
Terminal (RNP 0.3)	No	No	Yes
NPA (RNP 0.3)	No	No	Yes
<b>Maritime</b>			
Ocean	Yes	Yes	Yes
Coastal Confluence Zone	Yes	Yes	Yes
HEA	No	No	Yes
<b>Time/Freq</b>			
Stratum 1 Frequency ( $1 \times 10^{-11}$ )	Yes	Yes	Yes
Time of Day/Leap Second/ UTC Reference	No	Yes	Yes
Precise Time [<50 ns UTC(USNO)]	No	No	Yes



*It's about time -- really!*

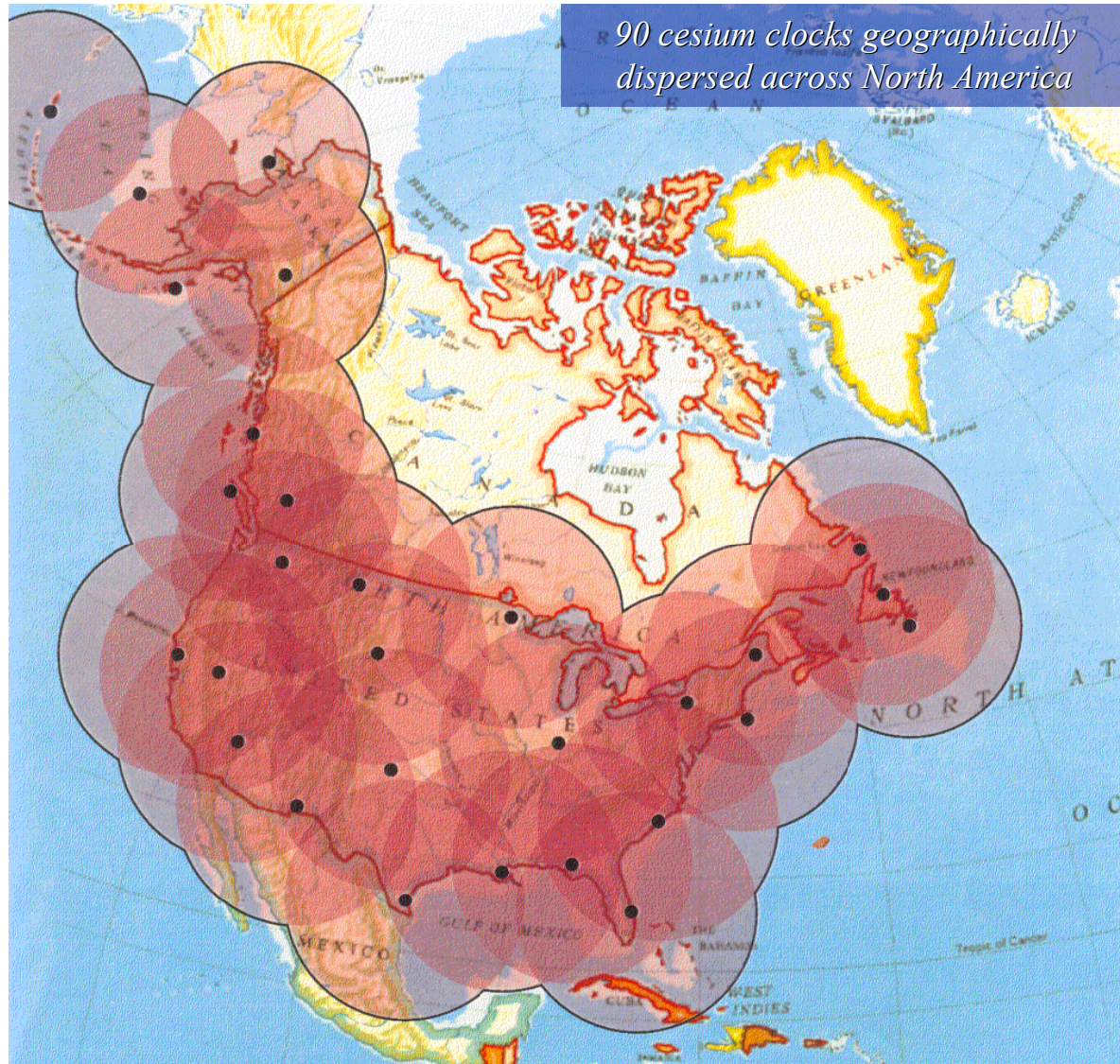
## The eLoran Clock



- **Loran Stations (US and Canadian) and the Loran Support Unit each have 3 new cesium clocks**
  - **90\*** very high stability clocks geographically dispersed across North America
- **All 90 clocks can be steered to UTC (USNO) (independently from GPS) with great accuracy**
- **Establishing a robust Loran clock akin to, but totally independent from the GPS clock, is a valuable national asset**

**\*(29 Loran Stations + LSU) x 3**

# North American Loran Time Coverage



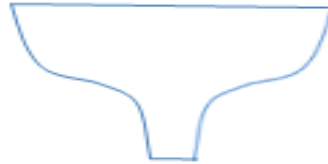


# It's also about “*place*”

## Geo-encryption – Something New

Who can receive the encrypted file?

**Conventional Cryptographic Algorithms**



Who has the random key?

**Geo-encryption and Signal Authentication**



Who has the navigational receiver  
& can locate at the *right* location

$$\underline{3400 \text{ m}^2 / 153,295,000 \text{ km}^2 = 2.2 \times 10^{-11}}$$

# Why Geocryption?

- **Unsecure world**
  - Data/Information security
  - Piracy concern
- **Traditional cryptosystems have inconveniences or weaknesses**
  - Something you know: PIN, passwords
  - Something you have: key, smart card
  - Something you are: biometrics

# Use of Location for Security

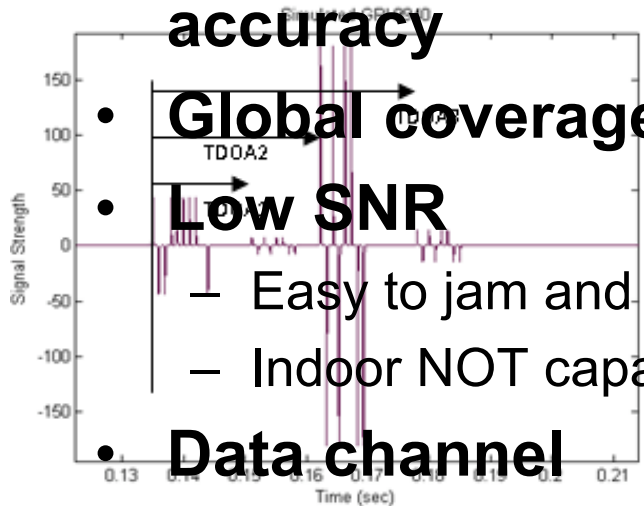
- **Universality**
  - Do all people have it?
- **Collectability**
  - How well can an identifier be captured or quantified?
- **Circumvention**
  - foolproof
- **Uniqueness**
  - Can people be distinguished based on an identifier?
- **Factors/Threats of Concern**
  - Spoofing, Replay, Parking Lot, Spatial Decorrelation



# Why eLoran?

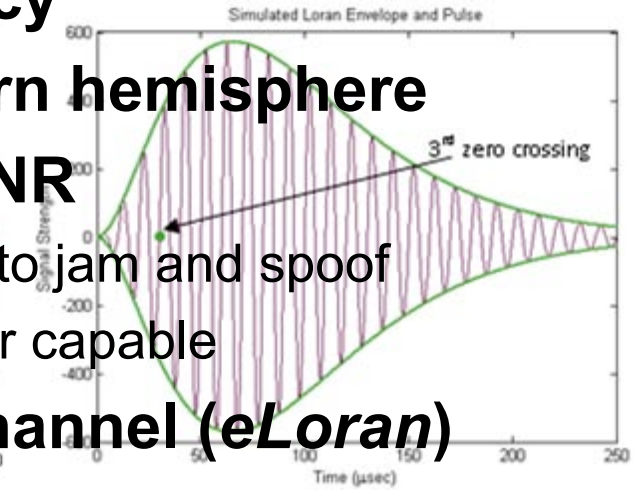
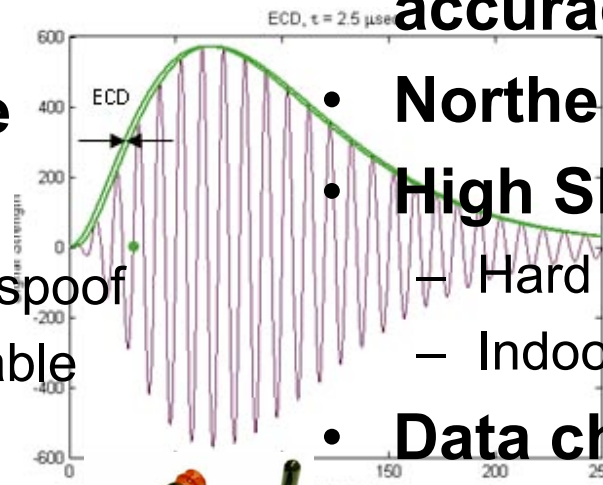
## GPS

- Non-stationary satellites
- High absolute accuracy, high repeatable accuracy



## Loran

- Stationary transmitters
- Low absolute accuracy, high repeatable accuracy



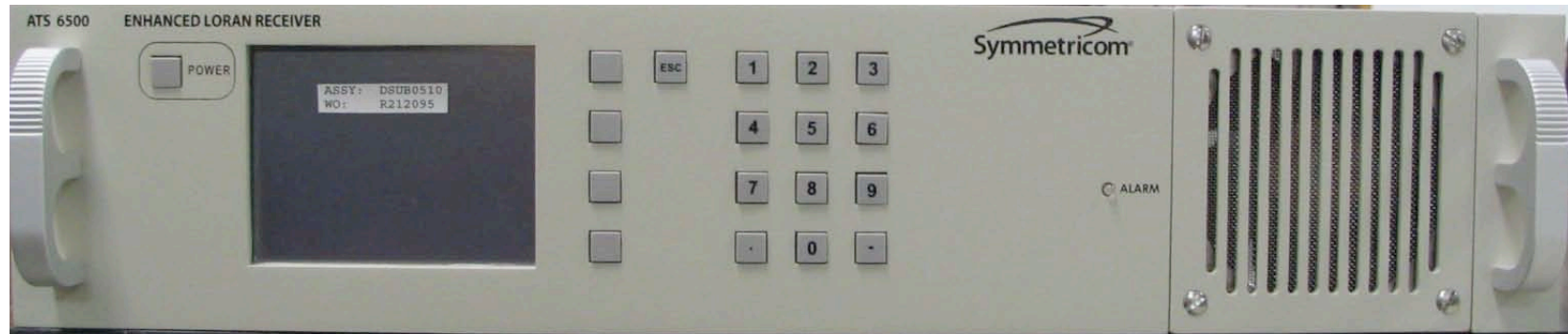
- Northern hemisphere
- High SNR
  - Hard to jam and spoof
  - Indoor capable
- Data channel (eLoran)



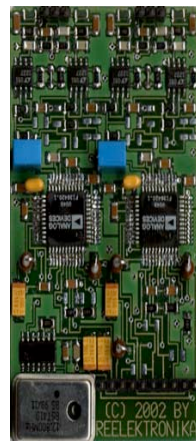
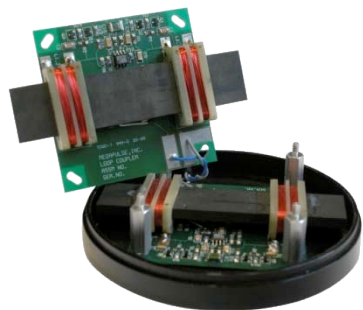
# Data Collection is Underway



# New eLoran Timing/Research/Monitor Receiver



# GPS/WAAS/eLoran Receivers for Maritime



# Applications Enabled by Robust PNT

- **Tracking vehicles to derive information regarding**
  - Traffic patterns and congestion
  - Best real-time routing for emergency vehicles
  - Tracking of hazardous cargo and overweight vehicles
  - School Bus and sensitive cargo vehicle tracking
  - Toll collection
  - Accident investigation
  - Mobile sensors to accumulate data on
    - Temperature
    - Air pollution
    - Pollen
    - Chemical/biological agents

# Applications Enabled by Robust PNT

- **Tracking of maritime vessels in and around harbors, inland waterways, and sensitive locations**
  - Sensitive and hazardous cargo
  - Entry into and out of Security zones
  - Container movement identification and tracking between transport modes
  - Identification, location, and speed of all vessels in the shipping channel
  - Mobile sensors to accumulate data on
    - Temperature
    - Currents
    - Pollution
    - Chemical/biological agents
- **Maritime domain awareness**

# It's *Open Season* for New PNT Ideas

- **21<sup>st</sup> Century PNT services offer potential benefits never before available; however,**
  - Reliance on the technology demands respect for its capabilities as well as its limitations;
    - Users/user groups accept capabilities without “doing the math” so service providers/enablers should.
  - Building and maintaining a robust infrastructure is not only prudent, but essential to ensure the continuation of safety, security and economic support services.
    - Alternatives exist and should be supported and secured.
    - Sole means is by no means a prudent strategy.



# *Questions*

