Global Positioning System Timing Criticality Assessment Preliminary Performance Results

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U.S. Department of Transportation
Research and Innovative Technology Administration

Introduction

- There is increasing demand for precise time and time interval (PTTI) services
  - Especially in critical infrastructures worldwide
- The Global Positioning System (GPS) is the pre-eminent PTTI provider
  - Dependence on GPS is growing significantly
  - GPS still has vulnerabilities (weak signal, jamming)
- The Volpe Center's GPS timing criticality study reviewed mitigations that would make GPS more robust

NOTE: ***The material in this briefing reflects the opinion of the authors only, and does not necessarily reflect U.S. Government policy***

Major Goals of T-C Study

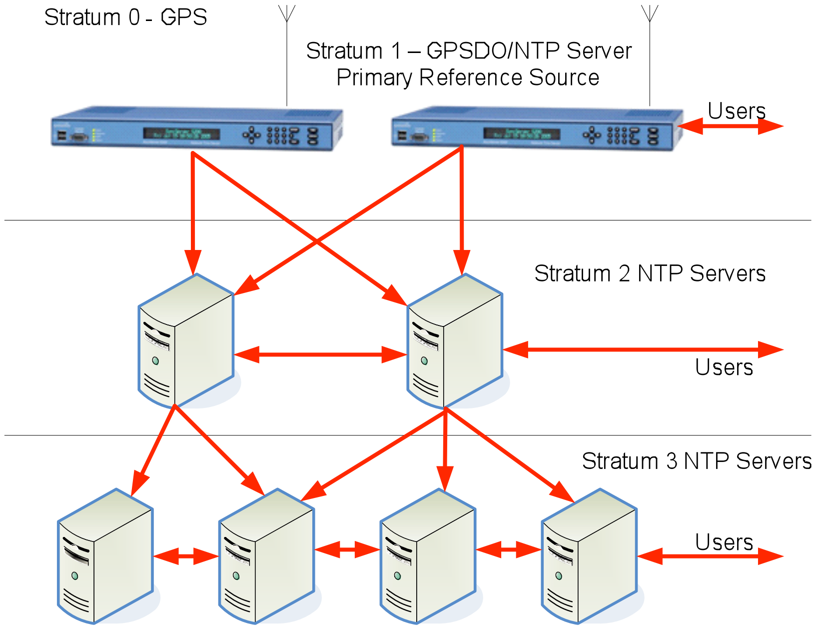
- Analyze the consequences of GPS timing services outages or disruptions
- Determine the benefits and relative costs of alternate systems that mitigate the impact of a GPS outage or disruption on the national Time and Frequency (T/F) infrastructure critical to the safety, security or economic well-being of the United States

Analysis

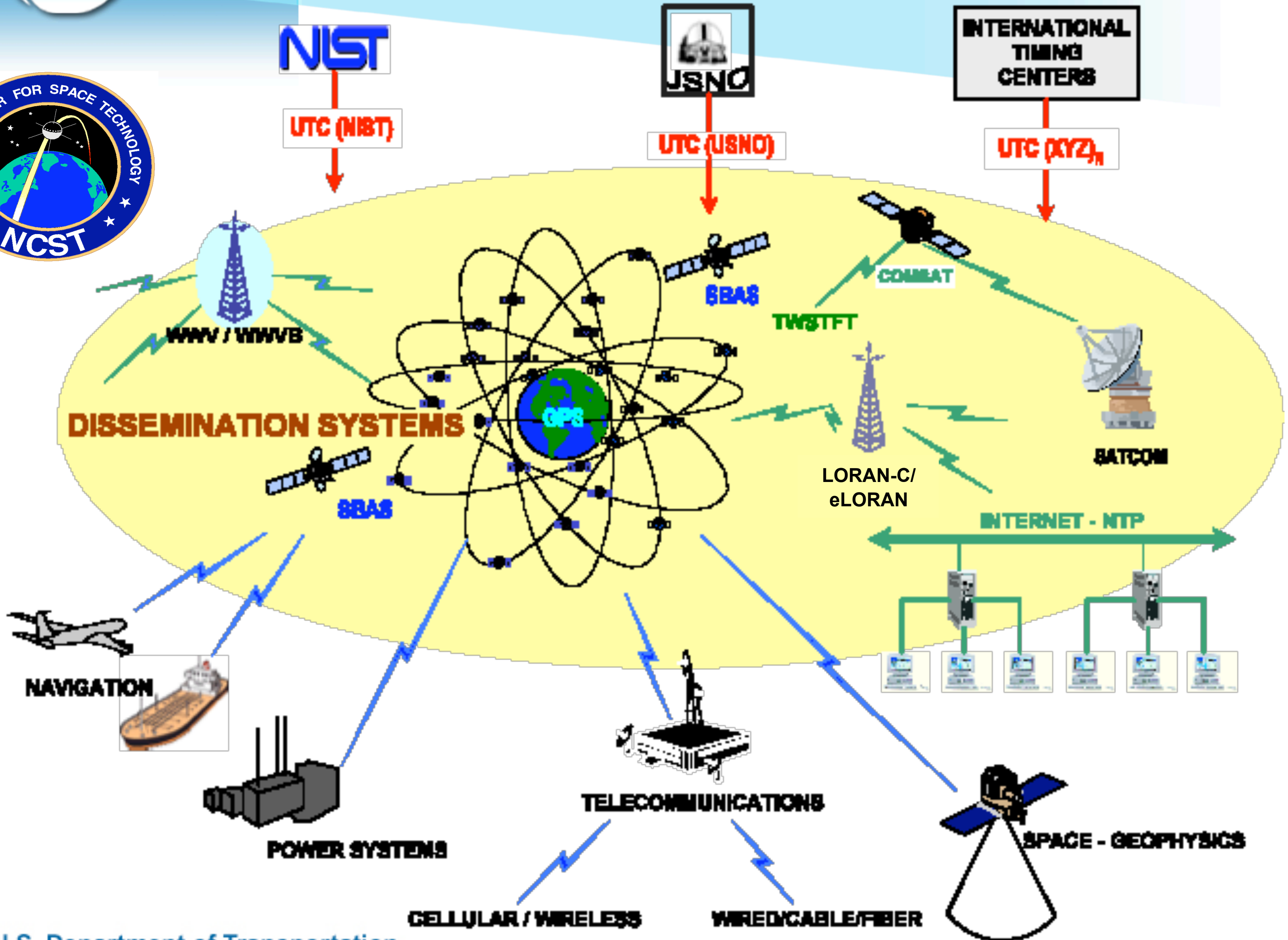
- Time and Frequency play an important role in just about every human activity worldwide
- Coordinated Universal Time (UTC) is the international standard for accurate time
  - U. S. sources:
    - U. S. Naval Observatory
    - National Institute of Standards and Technology

T/F Strata

- GPS Provides Stratum 1 capability globally. Backup clocks will mitigate loss of the GPS signal
- Systems that meet Stratum 1 Primary Reference Source ("clock") requirements:
  - GPS, other GNSS (Galileo, GLONASS, Compass)
  - Wide Area Augmentation System (aviation)
  - Networks/Atomic Clocks (e.g., CDMA, GSM)
  - Loran-C (legacy) and Enhanced Loran (*eLoran*)
  - NIST Broadcast Radio (WWV, WWVB)



T/F Interactions

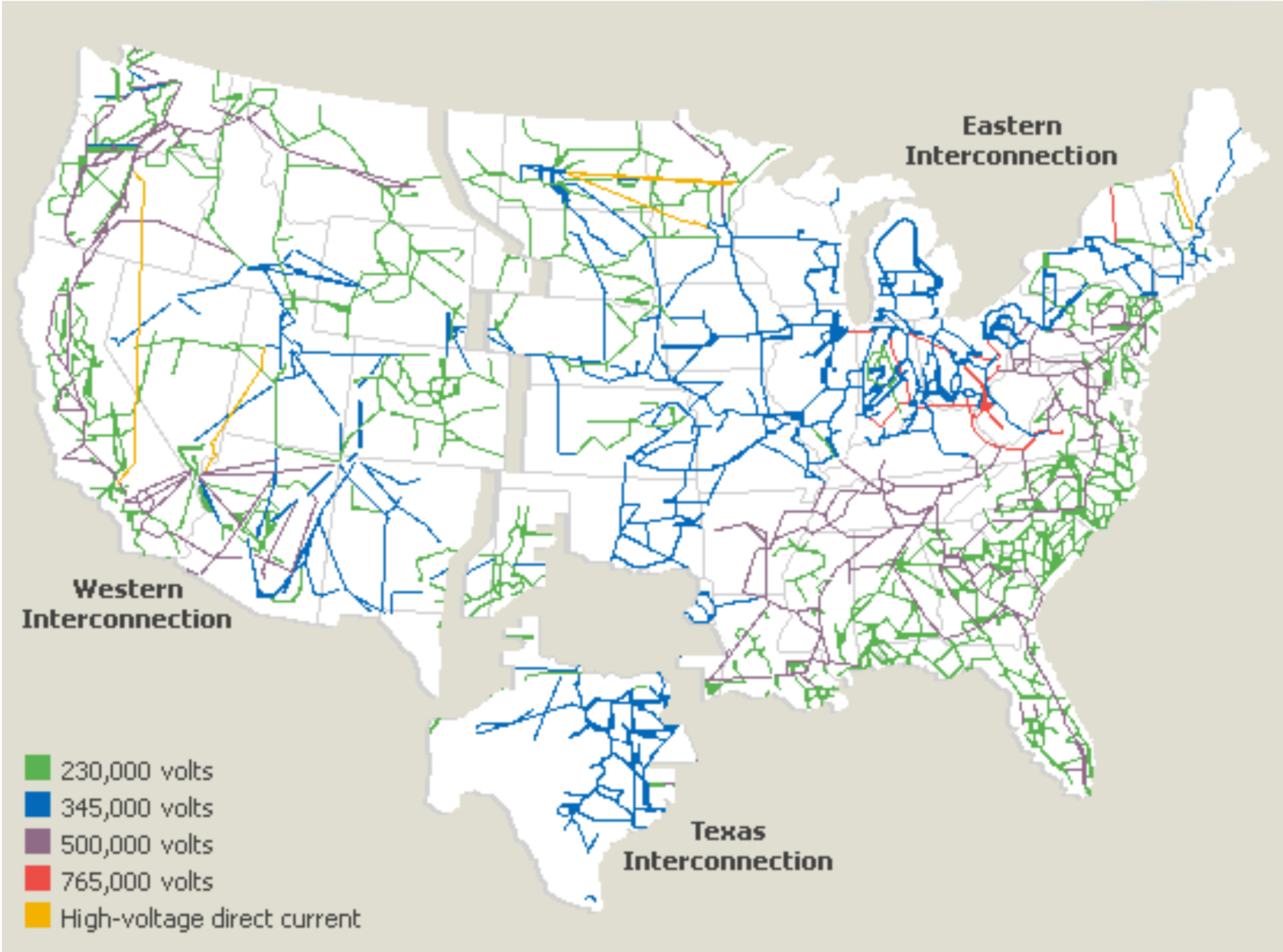


Ron Beard, NRL, 2003 CGSIC

Electric Power Distribution

- There are four major power grids ("Interconnections") in North America: Texas, Quebec, Western U.S., and Eastern U.S.
  - Also six Independent System Operators
- Operating revenues of the share-holder owned electric companies are $325.6B per year (2004 data)
- The total annual cost of "large" blackouts only is estimated at $100B per year
- The industry is reluctant to utilize new technology
- Distribution of electric power is critically tied to reliable telecommunications, which in turn needs adequate time synchronization
- Those responsible for grid architecture and operation should assess risks to reliable power distribution

Major Power Interconnections



Short Term Prognosis for Power

- U.S. & similar grids are increasingly burdened by growing demand; serious power failures occur almost annually; the next major failure: "when," not "if"
  - U.S. grid monitoring equipment is decades old
  - There are concerns about **grid robustness** in the near future
- Deregulation has not worked as well as planned
  - Restructuring has obscured responsibility for a given region
  - Power generating plants gain more revenue than the distribution grid
- A way out: "smart grids" – real time control, self-healing, and superconductivity
  - Superconductivity cables have 10% diameter, do not need bulky circuit breakers
  - Hydro Quebec is very active in using GPS for grid stability

Telecommunications

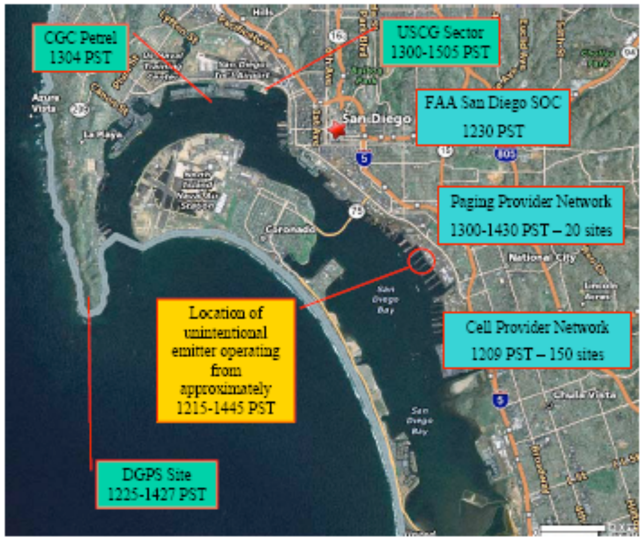
- The telecommunications industry considers GPS as the primary precise time reference source, and network timing as secondary
- GNSS and Loran are somewhere in between GPS and network timing, in terms of performance
- “Signals of Interest” (to selected commercial entities)
  - GPS, WAAS, EGNOS, Loran
- Mobile phones can operate globally
  - Protocols for this are Global System Mobile (GSM) or Code Division Multiple Access (CDMA)

Cell Phone Usage

- Cellular Telephone Industry Association (CTIA) Survey
  - Nearly 220 million U.S. Subscribers (2006)
  - Nearly $120B annual revenue (2006)
    - Average monthly bill: ~ $50.00
  - U.S. cell sites: 200,000
- C. Meyer, Lucent (2004)
  - About 100,000,000 CDMA users in U.S.
  - About 100,000 CDMA cell sites in U.S.

Short-Term Prognosis for Telecommunications

- GPS plays an increasing role, leading to dependence and subsequent need for backup capability to ensure continuity
- San Diego RFI incident (January 2007)
  - Disabled medical paging in downtown area for about 90 minutes
  - Shut down two cell towers in the area (of 150)
  - Some small aircraft were affected
  - No casualties



Selected Transportation

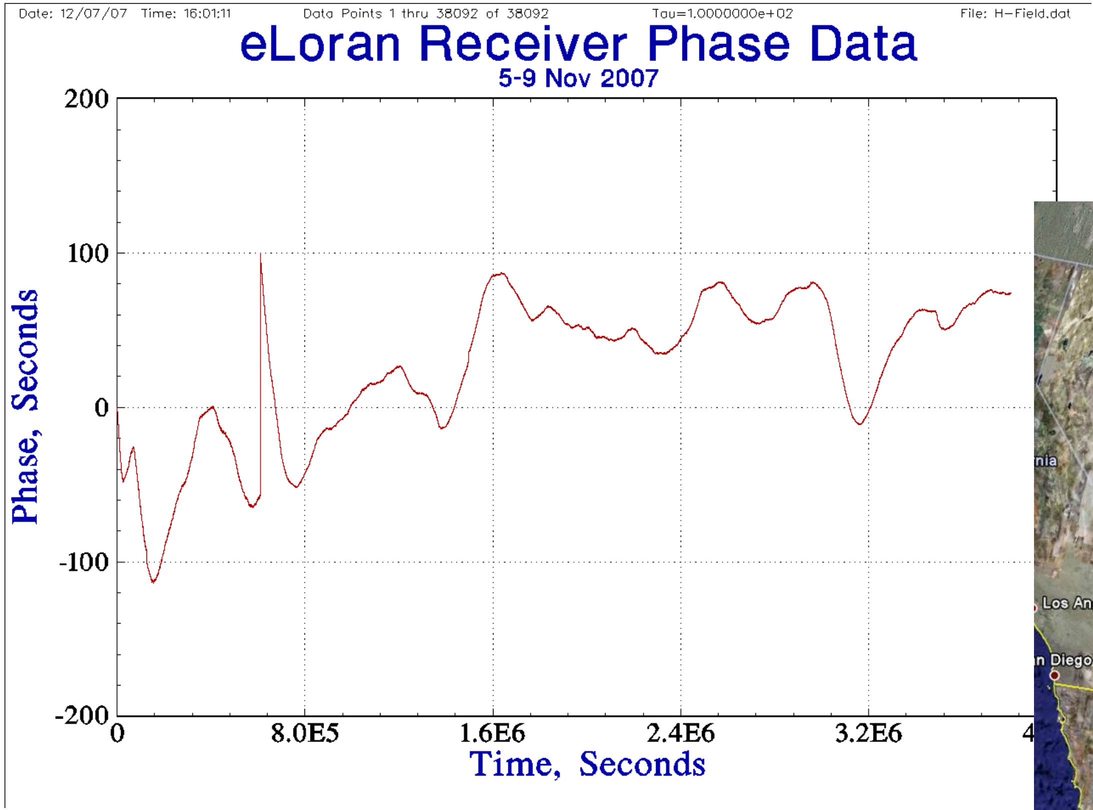
- **Civil Aviation** – WAAS Network
  - WAAS network, including GEOs, has clock system independent of GPS
    - Still have common L1 signal strength issue, but can use in some cases (e.g., directional antennas for GEOs)
  - Potential use: WAAS ground network could be used to generate comparable precision timing signals (XM radio, Iridium, eLoran, FM radio links, Internet)
- **Maritime** – Automatic Identification System
  - Collects and disseminates information on maritime vessel traffic in major U.S. ports and waterways
  - AIS relies on GPS
  - Over-reliance on GPS without backup can curtail critical missions if GPS is disrupted, as in San Diego

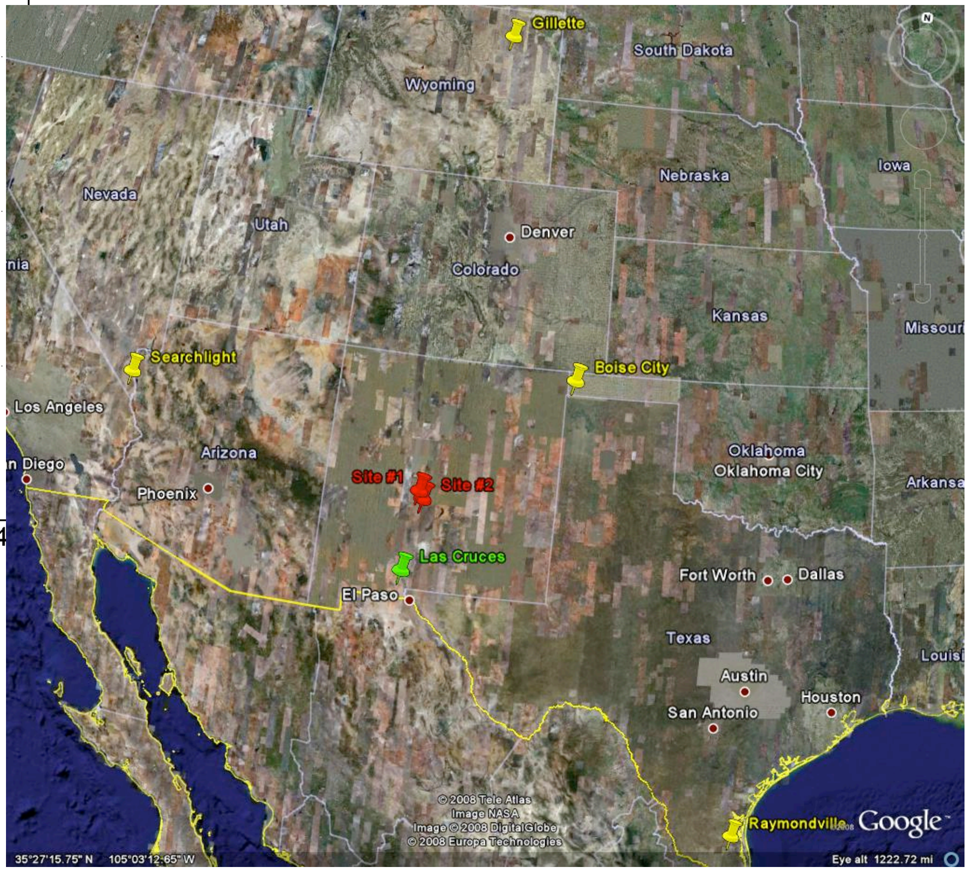
New Developments

http://dsc.discovery.com/news/2008/10/02/gps-spoofing.html

- Heightened interest in using – and in defeating – spoofing; new work at Cornell & Virginia Tech
  - A spoofer creates a false GPS signal that passes as a valid GPS signal
  - Spoofing could cause exploding power generators & plane crashes; also can avoid being tracked
  - Research spoofers now expensive. This may change
  - Next generation spoofers could be low-tech (J. David Last)

JAMFEST 2007





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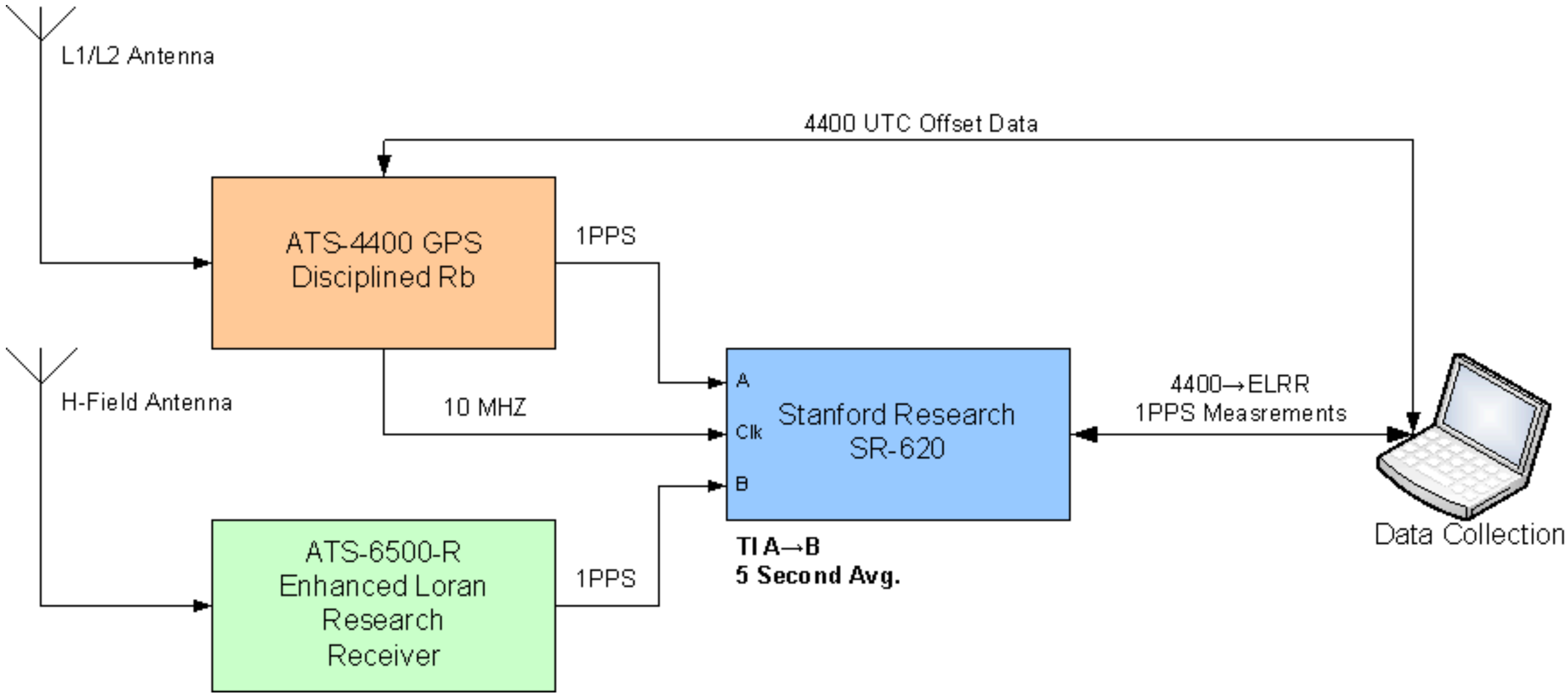
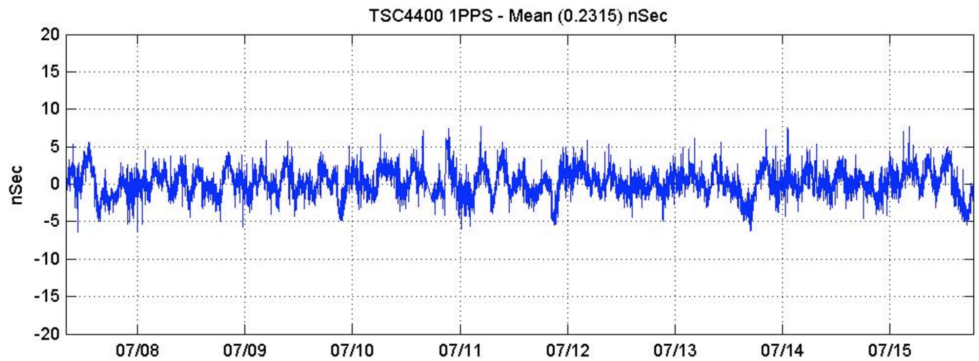
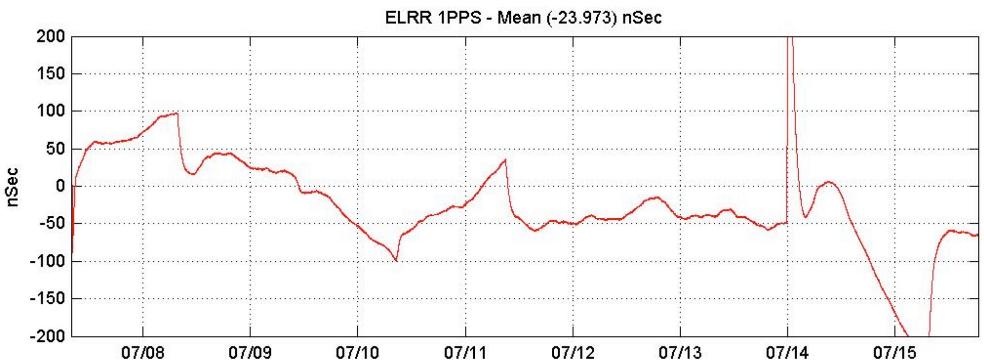
Recent Testing



Recent Test Results



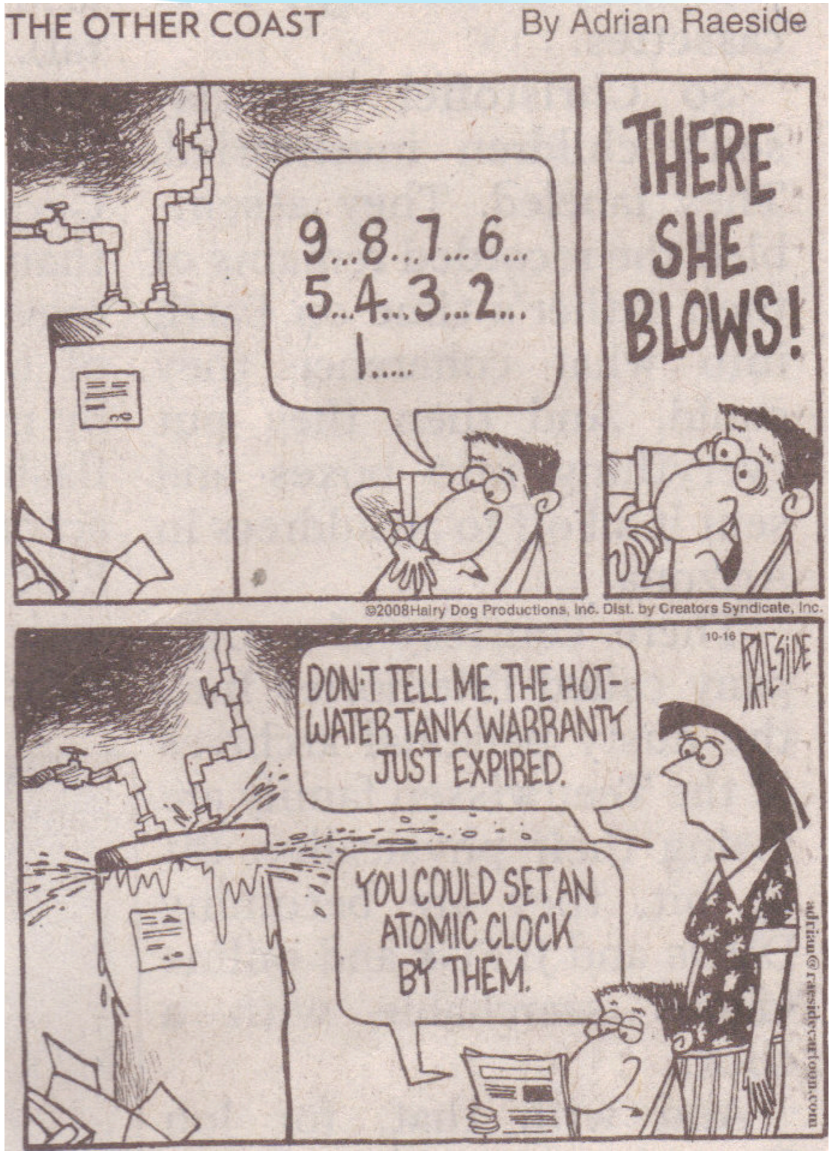


Major Conclusions

- The T/F application sectors **Electric Power** and **Telecommunications** play a vital role and are highly reliant on GPS
  - **Electric Power** and **Telecommunications** also have large influence on the performance of the rest of the national infrastructure
- Civilian GPS is increasingly used for highly accurate timing services
- Because GPS (& GNSS) are vulnerable to radiofrequency interference, using backup T/F sources is crucial in mitigating GPS disruptions during critical applications
- Many important applications (e.g., many financial transactions) may not require accurate timing now, but evolving trends support a growing need for more accurate time - for efficiency, safety, and security

QUESTIONS?

Another potential source?



Background Material

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Project Background

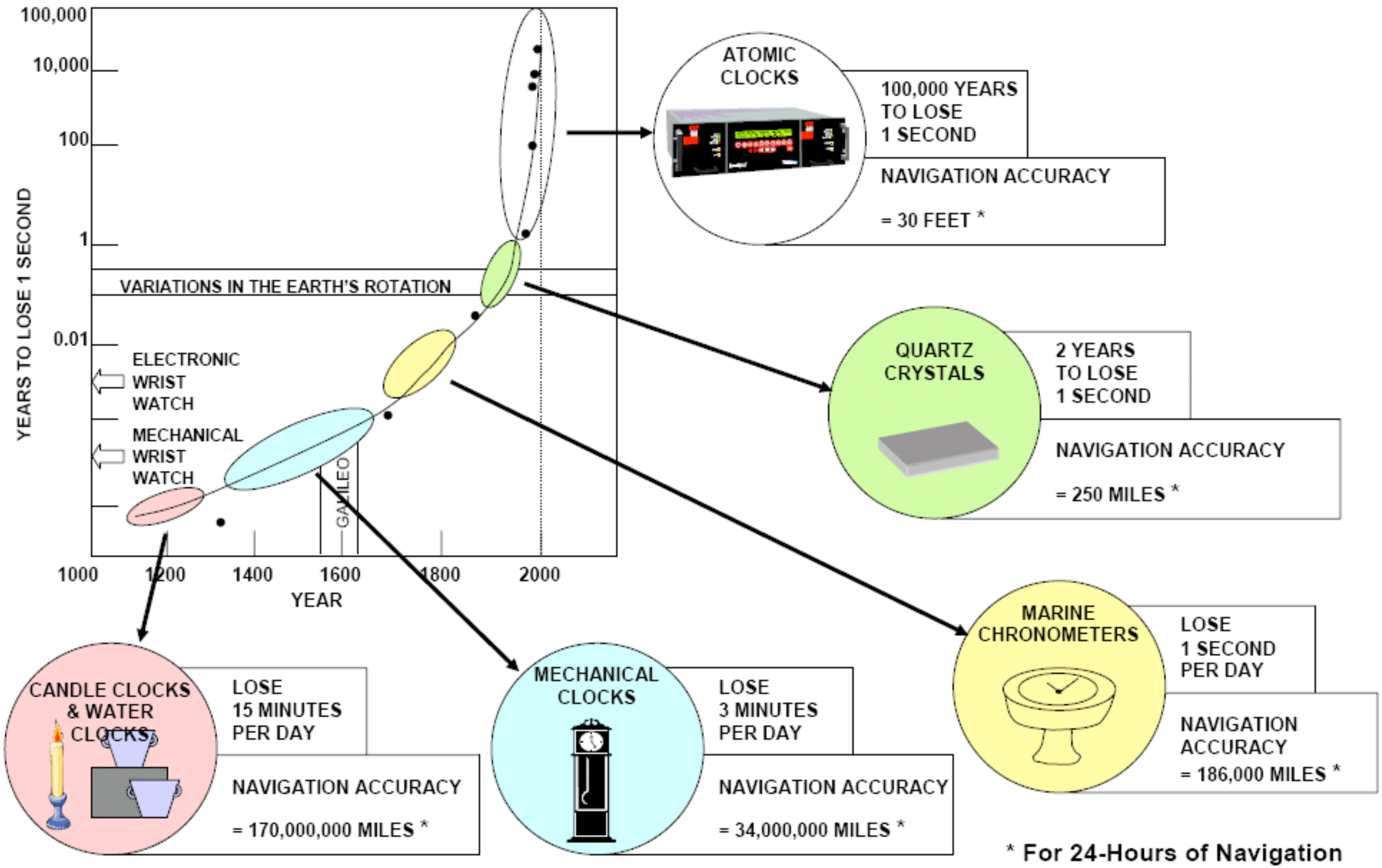
- An updated U.S. Space-Based PNT Policy was signed by the President in December 2004
- The 2004 Policy tasked DHS to develop an Interference Detection and Mitigation (IDM) plan
- A PNT Working Group, tasked by the IDM plan, was set up by DHS to implement the plan
  - Elements for plan implementation include
    - Timing Criticality update study (HSI, January 30, 2006)
    - Update of Volpe GPS Vulnerability study (2001)

Summary of Legal and Technical T/F Requirements

Application or Device	Required Uncertainty	
	Time	Frequency
Stock Market time stamp	3 s absolute accuracy	NA
AM Radio Carrier frequency	NA	1.2×10^{-5}
FM Radio Carrier frequency	NA	1.9×10^{-5}
TV Carrier Frequency	NA	1.2×10^{-6}
Shortwave Carrier Frequency	NA	1.5×10^{-5}
Color TV subcarrier	NA	3×10^{-6}
Electric Power Generation	10 ms	NA
Electric Power Event Recorders	1 ms	NA
Electric Power Stability Controls	46 µs	NA
Electric Power Network Controls	4.6 µs	NA
Electric Power Fault Locators	1 µs	NA
Electric Power Synchrophasors	1 µs	NA
Telecommunications, Stratum-1 clock	NA	1×10^{-11}
Telecommunications, Stratum-2 clock	NA	1.6×10^{-8}
Telecommunications, Stratum-3E clock	NA	1×10^{-6}
Telecommunications, Stratum-3 clock	NA	4.6×10^{-6}
Mobile Telephones, CDMA	10 µs	5×10^{-8}
Mobile Telephones, GSM	NA	5×10^{-8}
Wireless Networks, 802.11g	NA	2.5×10^{-5}
Frequency Calibration Laboratories	NA	1×10^{-12}
Josephson Array Voltage Standard	NA	1×10^{-11}
GPS Space Clocks	NA	6×10^{-14}
State-of-the-art time transfer	< 1 ns	parts in 10^{16}

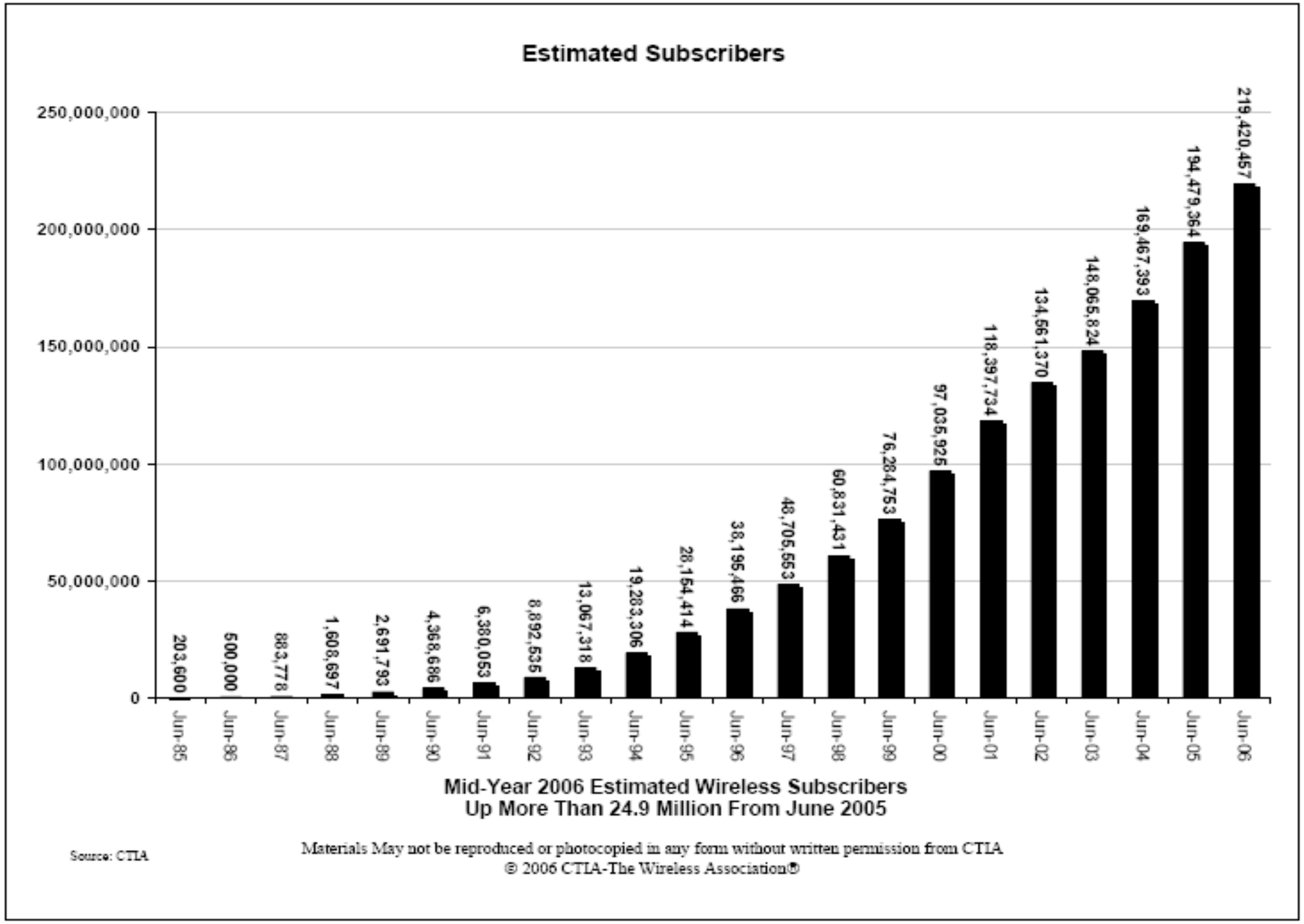
(M. Lombardi, NIST, 2006)

Historical Development Of Accurate Clocks



* For 24-Hours of Navigation

CTIA: 2006 Industry Survey, U.S.



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GPS Role in Electric Power (2)

- A GPS signal disruption in 2006 did not disable system operation in the affected area but did disrupt billing. It became very difficult to determine which grid sector was lending or borrowing power during this disruption
- Phasor synchronization devices are regularly being installed. Each device will be time-stamped using GPS. This evolving trend may leave system operators unsure of how to respond if GPS is disrupted
- Grid stability analysis researchers at Cornell, Carnegie-Mellon and VA Tech say GPS “could” be a real help
  - They recommend GPS-based real-time network monitoring and time-stamping of phasors; sub-millisec precision is needed
  - Industry approach is to “go slowly” with high tech; DOE & North Am. Elec. Reliability Corp. (NERC) want an automatic network for real-time monitor and control of grid (P. Overholt, DOE)

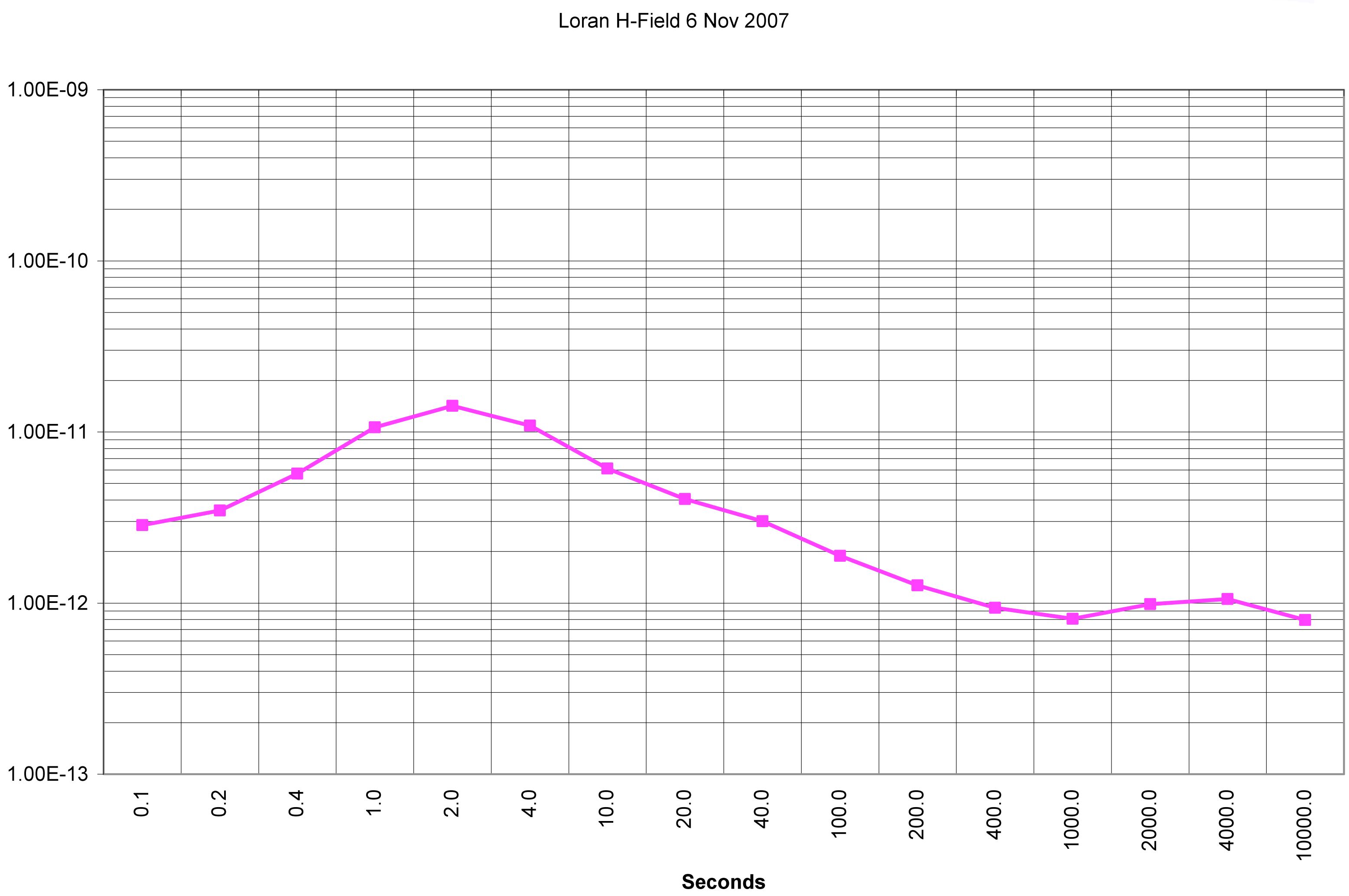
Wireless Communications

- GPS serves as a precision timing source for 100,000,000 CDMA cell phone customers in North America and 250,000,000 worldwide
  - A GPS-disciplined oscillator can provide time accurate to within 0.1 μsec and frequency accurate to 1×10^{-13} (1 day averaging)
- Wireless communications includes phones (including 911-equipped phones), pagers, and messaging devices
- CDMA networks have a GPS dependence
  - Require a precise time reference (errors within 3 to 10 μsec)
  - The industry already has lost money and inconvenienced customers during GPS signal loss incidents
- CDMA & GSM require a transmitter carrier frequency under 0.05 ppm ($\pm 5 \times 10^{-8}$), and TDMA requires 0.50 ppm

Transportation – Aviation (2)

- Automatic Dependent Surveillance – Broadcast: Multilateration
  - Two types of multilateration: Active and Passive
    - Active uses existing transponder equipment; can, but not required to, use ADS-B data links
    - Passive must equip with ADS-B data links
  - In either case, Loran is the recommended GPS data link backup T/F source for MLAT, because of cost, performance and availability in the U.S. National Airspace System
    - Note: multilateration is not under active consideration for the ADS-B backup system at this time

ELRR AllanDeviation



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