



# Results from a GPS Timing Criticality Assessment

European Navigation Conference, GNSS 2008  
Session 2b - Timing

James Carroll, DOT/RITA Volpe Center

April 2008

# Introduction

## Timing Criticality Assessment Goals:

- Analyze the consequences of GPS timing services outages or disruptions
- Update the Department of Homeland Security/ Homeland Security Institute timing criticality study
- 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
- Get information from T/F Subject Matter Experts
- **Focus of this briefing: civilian T/F applications**

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

# Major Conclusions

- The T/F application sectors are **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
- 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

# 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
- Electric Power has a wide variety of production and distribution facilities; most of the revenue is in **Power Generation**
- **Distribution** of electric power is critically tied to reliable telecommunications, which in turn needs adequate time synchronization

# Timing/Frequency Overview



**NIST**

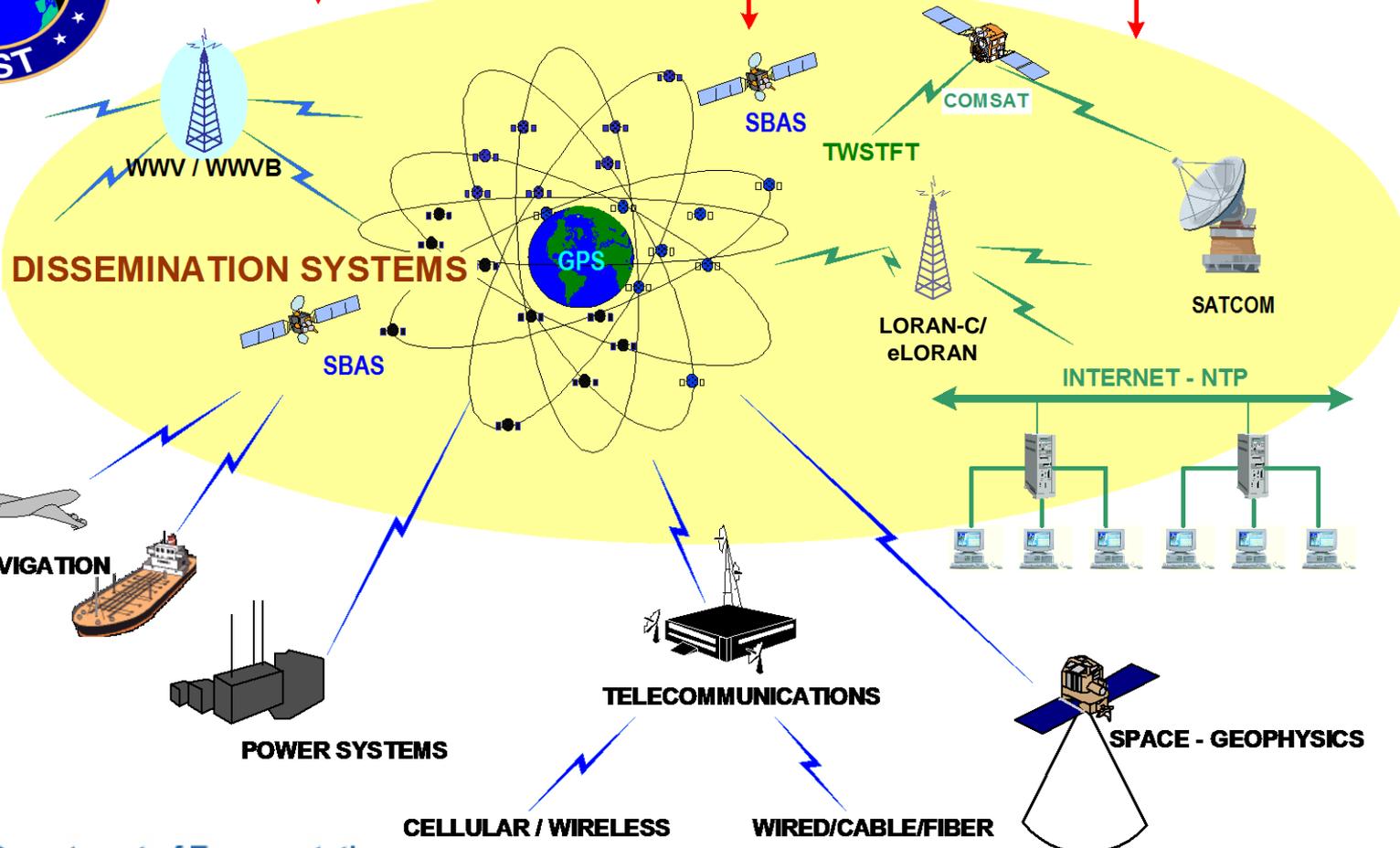
UTC (NIST)



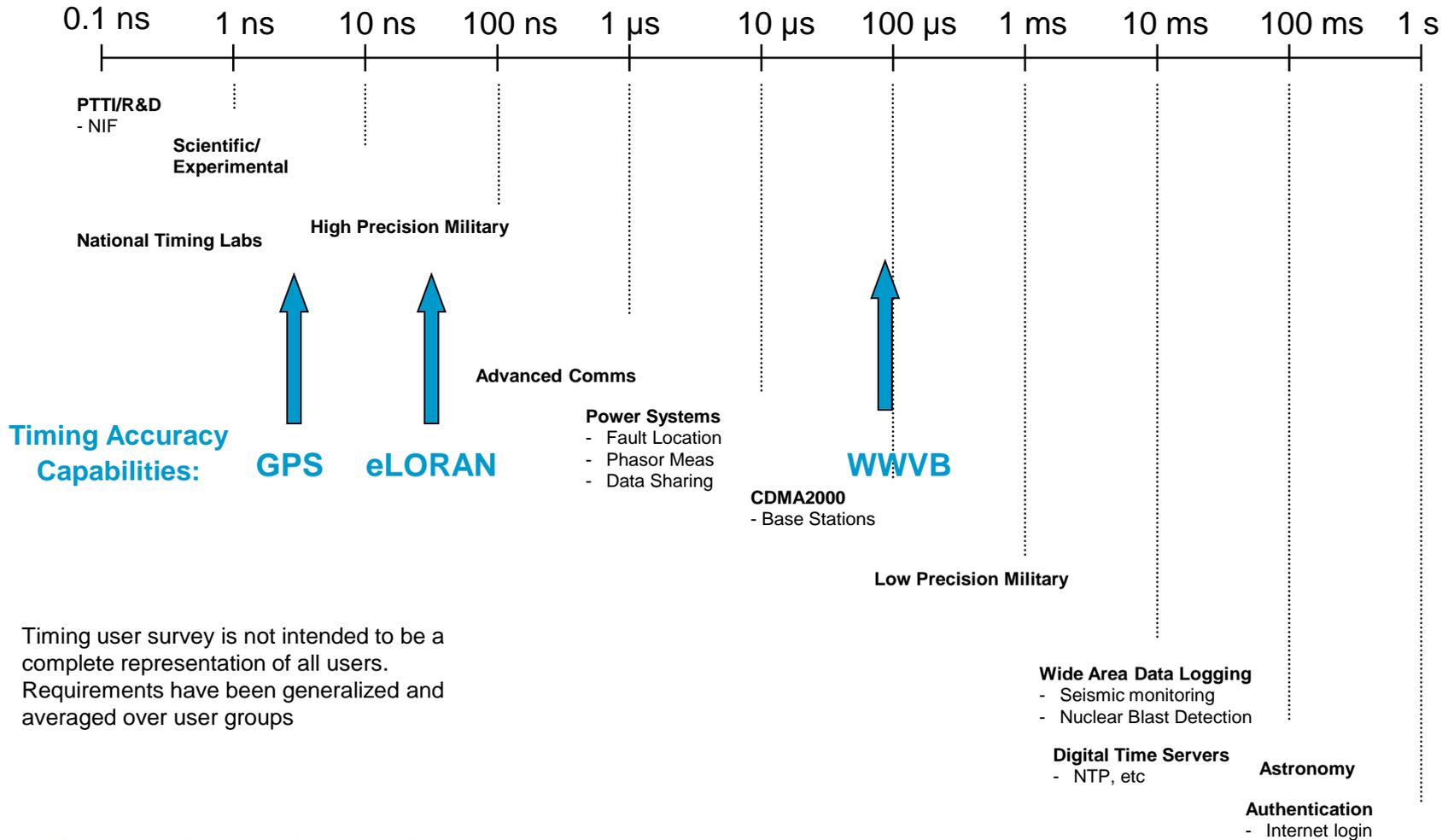
UTC (USNO)

INTERNATIONAL  
TIMING  
CENTERS

UTC (XYZ)<sub>N</sub>



# Timing User Range



Timing user survey is not intended to be a complete representation of all users. Requirements have been generalized and averaged over user groups

# UTC Time Synchronization

- Systems that meet Stratum 1 Primary Reference Source (“clock”) requirements:
  - GPS
  - Other GNSS (Galileo, GLONASS, Compass, etc.)
  - WAAS
  - Networks/Atomic Clocks (e.g., CDMA, GSM)
  - Loran-C (legacy) and Enhanced Loran (*eLoran*)
  - NIST Broadcast Radio (WWVB)
- The emphasis in this briefing is on civilian applications

# GPS: Enabling Technology

- Provides Stratum 1 capability globally
  - Backup clocks will mitigate loss of the GPS signal
- Supports Critical T/F Application Areas, e.g.,
  - o Electric Power
  - o Telecommunications/  
Communications/Radio  
Broadcast
  - o Transportation/maritime/a  
viation/land
  - o Emergency Response
  - o Internet/Cyber
  - o Defense
  - o Banking
  - o Water Supply
  - o Agriculture
  - o Chemical  
Industry/Hazmat
  - o Postal/shipping
  - o Weather

 = Focus Area

# 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
- Those responsible for grid architecture and operation should assess risks to reliable power distribution

# GPS Role in Electric Power

- Present GPS T/F uses include asset management & performance analysis; the grid does not at this time depend on GPS to function – could change in future
  - Electric power timing requirements are at, or are approaching, 1  $\mu$ sec absolute accuracy
- Energy management systems monitor consumption generation and the electric power paths. The newer systems use GPS for time stamps
- In the event of loss of a usable GPS signal, the quality of data on system operation deteriorates; the system does not fail, but very often revenue is needlessly lost
  - Actual diagnosis of the August 2003 blackout took a year to complete – and still had information gaps
  - A more effective T/F system could have taken about two weeks or less

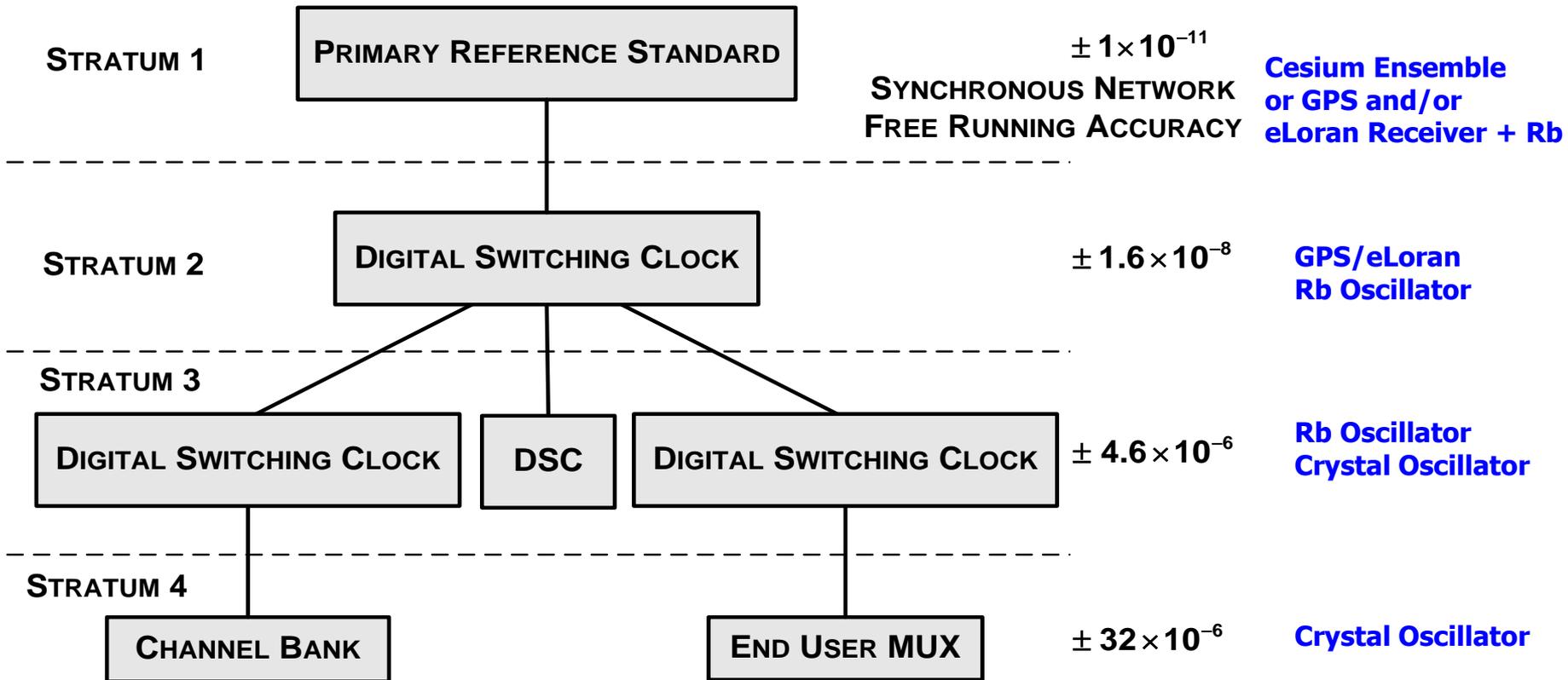
# Short Term Prognosis for Power

- U.S. & similar grids are increasingly burdened by growing demand; serious power failures occur almost annually; the next major failure is a matter of “when,” not “if”
  - U.S. grid monitoring equipment is decades old
  - There are concerns about grid robustness in near term future
- Deregulation has not worked as well as planned
  - Restructuring has obscured responsibility for a given region
  - Power plants have more revenue focus 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 “the network” 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)

# TELECOM STRATUM HIERARCHY



# 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 (San Diego RFI incident, January 2007)

# Summary of Activities

- Several Subject Matter Experts (SMEs) throughout the T/F area have contributed
- Analyzed the electric power distribution, wireless telecom, and some transportation application areas
  - Not all areas require precision T/F (e.g., banking/finance requires msec accuracy)
- DHS and DoT are supporting the study
- Project report is under review
- Volpe has a prototype eLoran Research Receiver and is testing its performance

# Background Material

[carrollj@volpe.dot.gov](mailto:carrollj@volpe.dot.gov)

# Project Background

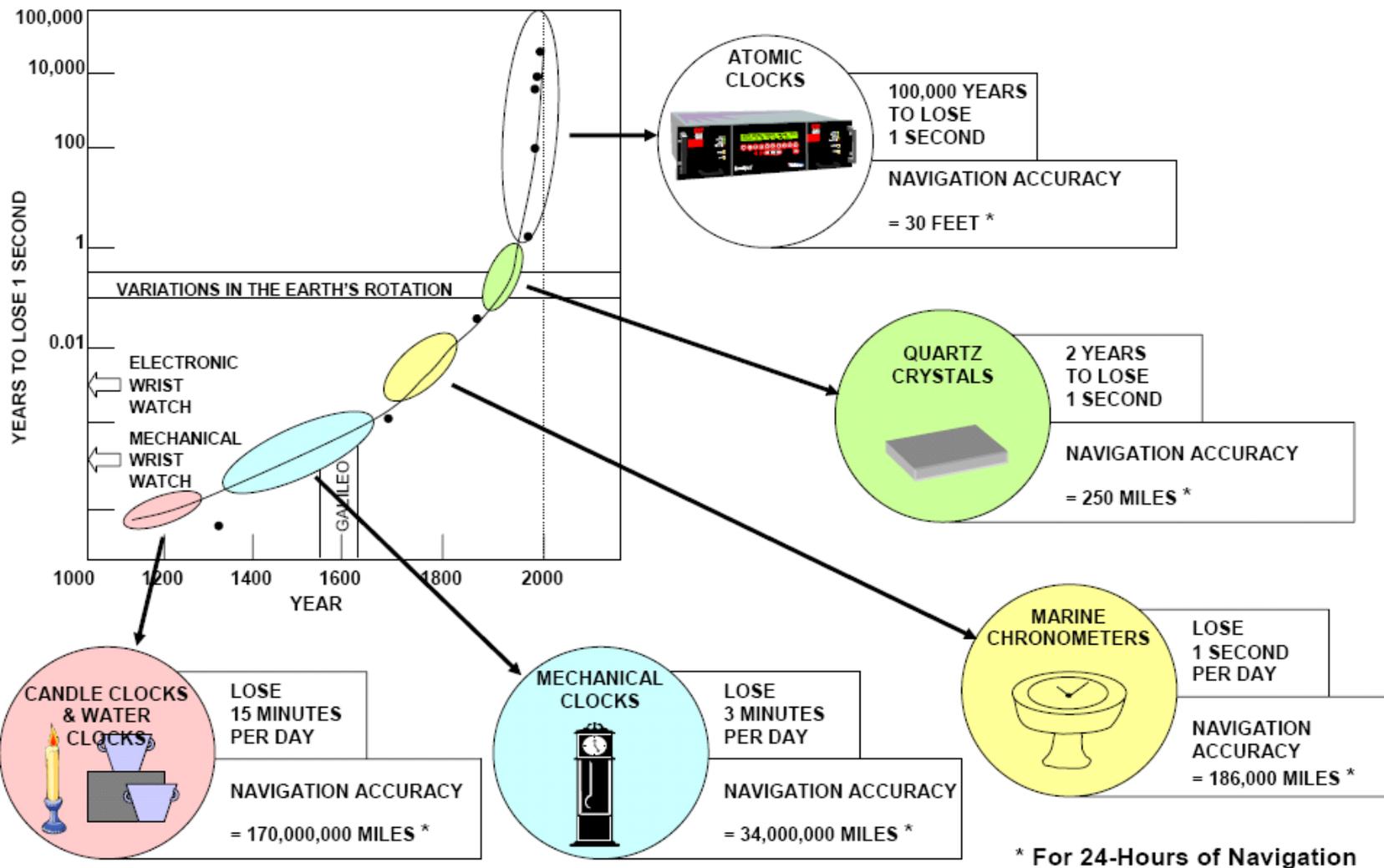
- An updated U.S. Space-Based PNT Policy was signed by the President in December 2004
- The 2004 Policy tasked DHS to develop an Interference Detection and Mitigation (IDM) plan
- A PNT Working Group, tasked by the IDM plan, was set up by DHS to implement the plan
  - Elements for plan implementation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

# Summary of Legal and Technical T/F Requirements

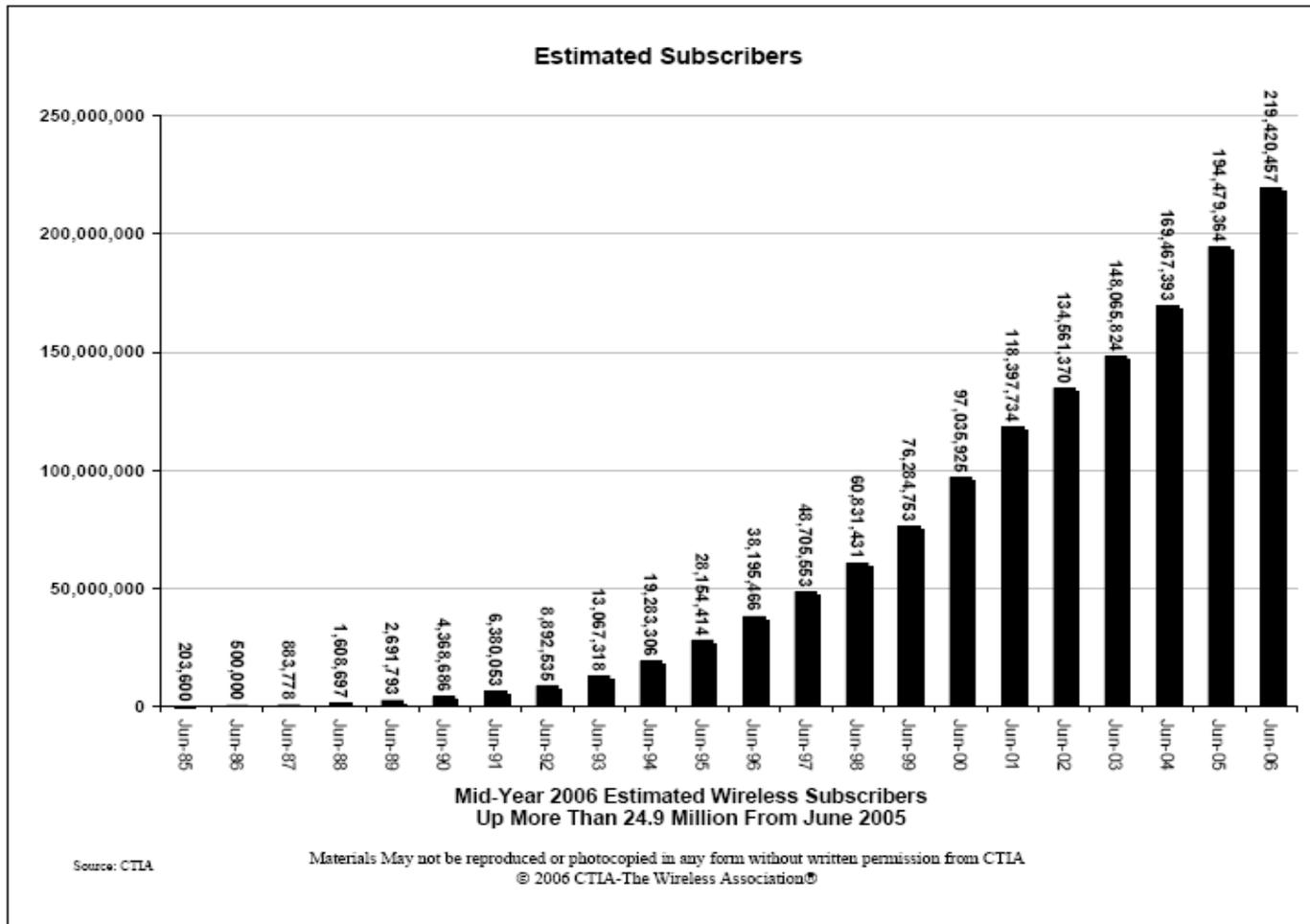
Application or Device	Required Uncertainty	
	Time	Frequency
Stock Market time stamp	3 s absolute accuracy	NA
AM Radio Carrier frequency	NA	$1.2 \times 10^{-5}$
FM Radio Carrier frequency	NA	$1.9 \times 10^{-5}$
TV Carrier Frequency	NA	$1.2 \times 10^{-6}$
Shortwave Carrier Frequency	NA	$1.5 \times 10^{-5}$
Color TV subcarrier	NA	$3 \times 10^{-6}$
Electric Power Generation	10 ms	NA
Electric Power Event Recorders	1 ms	NA
Electric Power Stability Controls	46 $\mu$ s	NA
Electric Power Network Controls	4.6 $\mu$ s	NA
Electric Power Fault Locators	1 $\mu$ s	NA
Electric Power Synchrophasors	1 $\mu$ s	NA
Telecommunications, Stratum-1 clock	NA	$1 \times 10^{-11}$
Telecommunications, Stratum-2 clock	NA	$1.6 \times 10^{-8}$
Telecommunications, Stratum-3E clock	NA	$1 \times 10^{-6}$
Telecommunications, Stratum-3 clock	NA	$4.6 \times 10^{-6}$
Mobile Telephones, CDMA	10 $\mu$ s	$5 \times 10^{-8}$
Mobile Telephones, GSM	NA	$5 \times 10^{-8}$
Wireless Networks, 802.11g	NA	$2.5 \times 10^{-5}$
Frequency Calibration Laboratories	NA	$1 \times 10^{-12}$
Josephson Array Voltage Standard	NA	$1 \times 10^{-11}$
GPS Space Clocks	NA	$6 \times 10^{-14}$
State-of-the-art time transfer	< 1 ns	parts in $10^{15}$

(M. Lombardi, NIST, 2006)

# Historical Development Of Accurate Clocks



# CTIA: 2006 Industry Survey, U.S.



## 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-millisecond 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  $\mu$ sec and frequency accurate to  $1 \times 10^{-13}$  (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  $\mu$ sec)
  - 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