On the Uses of High Accuracy eLoran Time, Frequency, and Phase

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Charles Schue
President & CEO
UrsaNav, Inc.

Overview

- The Problem:
  - We need time all the time!
  - Focused Example: Telecommunications Industry
- The Alternatives
- The Solution:
  - Co-Primary / Complementary GPS and eLoran
- Solution Basics
- Wide Area and Local Area Technology
- Early Trials
- Conclusions and Future Work
- Questions, and possibly answers.

The Problem: Addiction

"All in all, what is fascinating about the telecommunications ecosystem of 2014 is that mobile is on the leading edge of innovation that crosses virtually every industry and sector, and is a key engine of economic growth for the [U.S.]"

We are Addicted to Speed and Connectivity!

Source: Craig Wigginton, *vice chairman and U.S. Telecommunications leader, Deloitte & Touche*

The Problem: Pressures

- Ever expanding networks – more nodes ("hops")
  - Macro, micro, pico, femto
- More complex networks
  - GM, Edge GM, Boundary Clock, Transparent Router, Ordinary Slave Clock, Primary Reference Time Clock
  - Evolving protocols
  - Mix of delivery mediums: copper, optical, wireless
- Increasing demand on networks
  - Voice
  - (Big) data
  - (Streaming) video
  - Cloud
  - Security
  - Spectrum availability and optimization

The Problem: Disrupters

- Mobile payment systems
  - Near-Field Communications
  - Apple Pay
  - CurrentC
- Personal & Professional Vertical Market Growth
  - Health care
  - Education
  - Automobile
  - Home
  - Tourism
- Connected World. Connected Things.
  - Machine-2-Machine (M2M)

Source: Craig Wigginton, *vice chairman and U.S. Telecommunications leader, Deloitte & Touche*

The Problem: Shrinking Time

Application	Frequency Network /Air	Phase	Note
GSM, UMTS, WCDMA, LTE – FDD	16 ppb / 50 ppb	--	--
CDMA2000	16 ppb / 50 ppb	± 3 µs to ± 10 µs	--
LTE – TDD	16 ppb / 50 ppb	± 1.5 µs	≤ 3 km cell radius
		± 5 µs	> 3 km cell radius
LTE MBMS (LTE-FDD & LTE-TDD)	16 ppb / 50 ppb	± 10 µs	inter-cell time difference
LTE- Advanced	16 ppb / 50 ppb	± 1.5 µs to ± 5 µs	In discussion by members of the 3GPP

Figure 3: Frequency and Phase Synchronization Requirements

Source: Microsemi

The Problem: Shrinking Time

TABLE 1: LTE AND LTE-A REQUIREMENTS				
Application	Frequency/ air interface	Time/ phase	Why you need to comply	Impact of non-compliance
LTE (FDD)	16 ppb/50 ppb	N/A	Call initiation	Call interference Dropped calls
LTE (TDD)	16 ppb/50 ppb	±1.5 µs	Time slot alignment	Packet loss/collisions Spectral efficiency
LTE MBSFN (TDD or FDD)	16 ppb/50 ppb	±500 ns	Proper time alignment of video signal decoding from multiple base transceiver stations	Video broadcast interruption
LTE-A (TDD or FDD) CoMP/MIMO	16 ppb/50 ppb	±500 ns	Coordination of signals to/from multiple basestations	Poor signal quality at edge of cells Location-based services accuracy Lower data speeds

Source: electronic design magazine

Reviewing the Alternatives for Time

GPS.
GPS is the global, gold standard for PNT.
When it is available and trustworthy, you should always use it first.
GPS is cheap. Making it reliable and resilient is expensive.
Multi-frequency (L1, L1M, L2, L2C, L2M, L5) does not make GPS "sole means".
SAASM and M-Code do not help civilian users.
No built-in integrity.

Microsemi 5071A

Oscillators.
Holdover only. Not a co-primary source.
Require external reference input (usually GPS).
Many OCXO's are temperature sensitive.
Rb is more expensive than OCXO, but less expensive than Cs.
Cs is superb, but is expensive, big, and heavy.
CSAC?

Microsemi TimeProvider 2700
Edge Grandmaster Clock

IEEE 1588 (PTPv2)
Grandmaster sources time from GPS or Cs.

GNSS (GLONASS, CNSS, Galileo).
Even GNSS experience failures.
More satellites result in increased noise floor.
Same vulnerabilities as GPS.

HOLDOVER PERFORMANCE

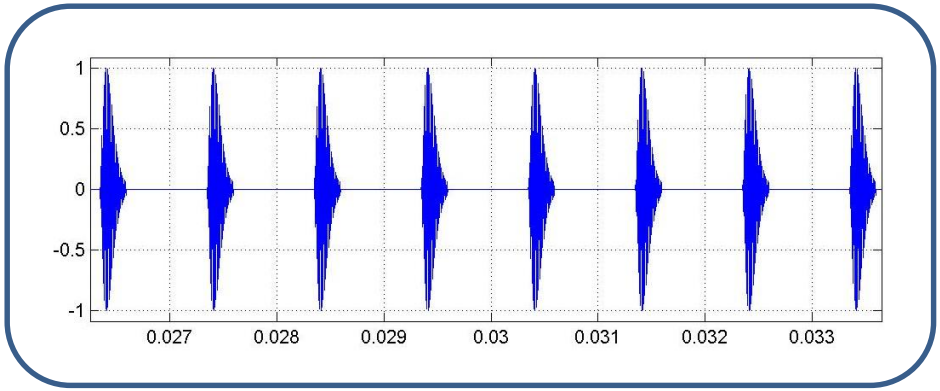
Oscillator	Phase ±1.5 µsec	Phase 5 µsec	Phase 10 µsec	Freq 16ppb
OCXO	1 hour	4 hours	12 hours	1 month
Rubidium	24 hours	3 days	5 days	5 years

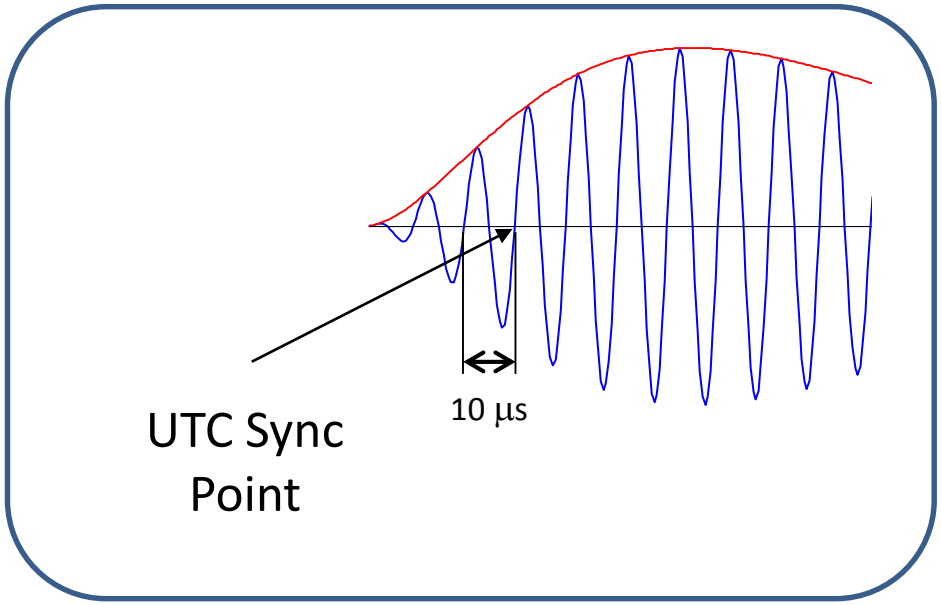
Holdover values are approximate and assume operation at constant temperature, no initial frequency or phase offset, and that the units has been powered on for 2 weeks and locked to GNSS for three consecutive days.

What about eLoran? The basics.

Key characteristics

- High power (~ 150 kW to >1 MW)
- Low frequency (100 kHz)
- Pulse shaped signals allow groundwave - skywave separation
- Data channel to provide UTC information, differential corrections, and integrity information
- Long range (>1,000 miles) coverage
- No common failure modes with GNSS
- Provides the same information as GNSS (time/phase, frequency, position, heading)





Legacy Loran and eLoran: Salient Differences

- Each transmitting site synchronized to UTC using "ensembling" of technologies and methods
  - Three Primary Reference Standards
  - "Sky-Aided"
    - GNSS input(s), when available; not directly coupled
    - TWSTT input from UTC source; not directly coupled
  - "Sky-Free"
    - Two-Way Low-Frequency Time Transfer (TWLFT)
- Differential corrections for improved accuracy
  - Differential Loran (dLoran)
- All-in-View signals
- No "chains" or "grid warping".
- Data Messaging Service (relatively low rate – one way)
  - Additional integrity
  - Other differential corrections (e.g., dGPS)
  - Other secure communications

The definition of complementary: GPS & eLoran

Parameter	eLoran	GPS
Frequency	100 kHz	1.2-1.5 GHz
Propagation	Groundwave	Line of Sight
Propagation Error	Conductivity, tropo variations	Iono delay variations*
Penetration	Walls, ground, 6' seawater	Very little penetration
Modulation	TD + CD	Spread spectrum CD
Rx Signal Strength	Relatively high	Very low
Timing Basis	Three Cs	Up to four Cs or Rb
Tx Location	Ground - stationary	Space - moving
Data Channel	Yes	No

* Propagation errors are affected at different times and places by components of solar storms.
* GPS propagation variations are not correlated with Loran-C or eLoran propagation errors.

eLoran: Interoperable, "integratable" with GNSS / INS / SAG / Augmentations / etc.

Seamless PNT for users.

Provides much, much better than 250 ns timing accuracy over long distances, without the use of differential corrections.

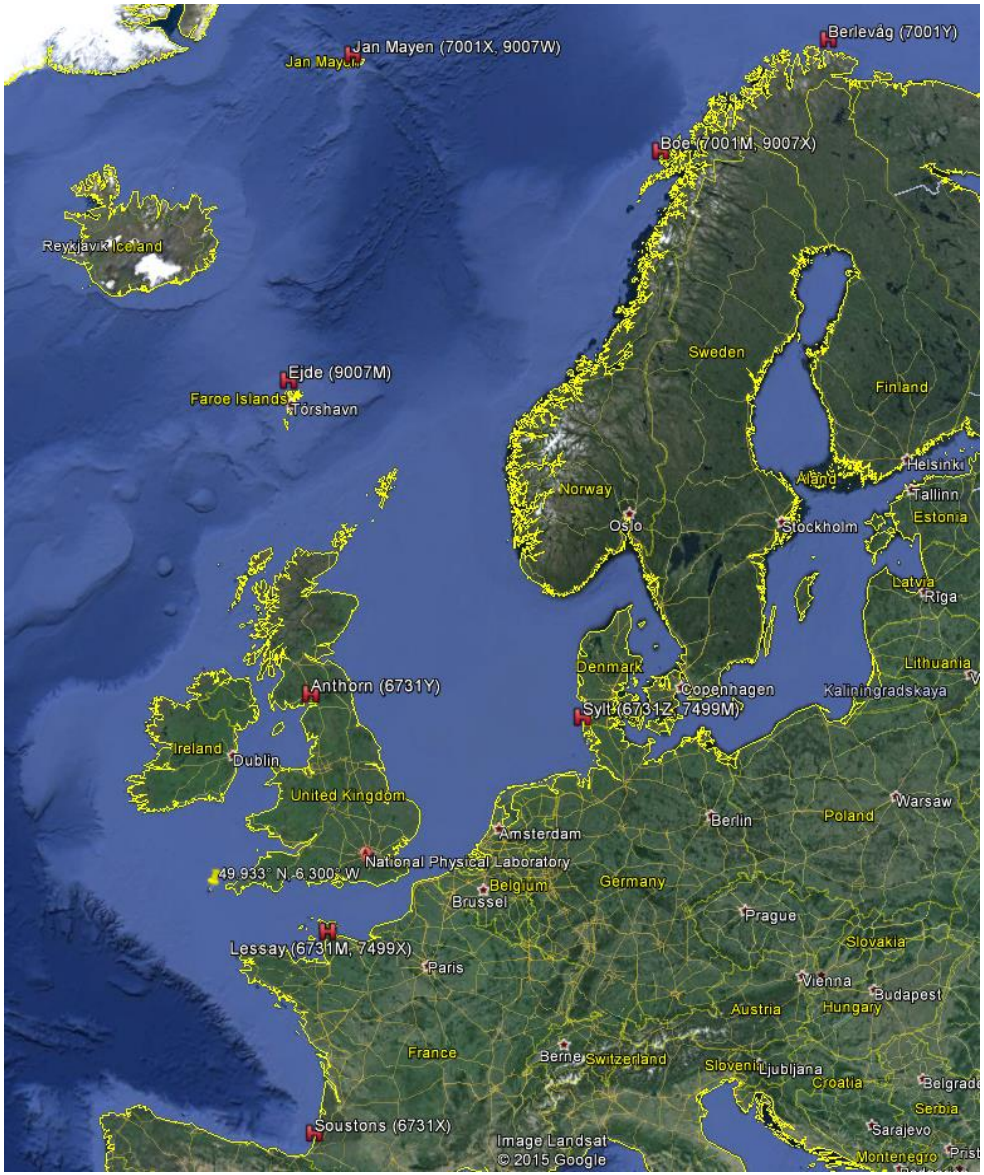
With differential corrections, provides better than 50 ns timing accuracy.

eLoran and GPS: Stratum-1 frequency sources.

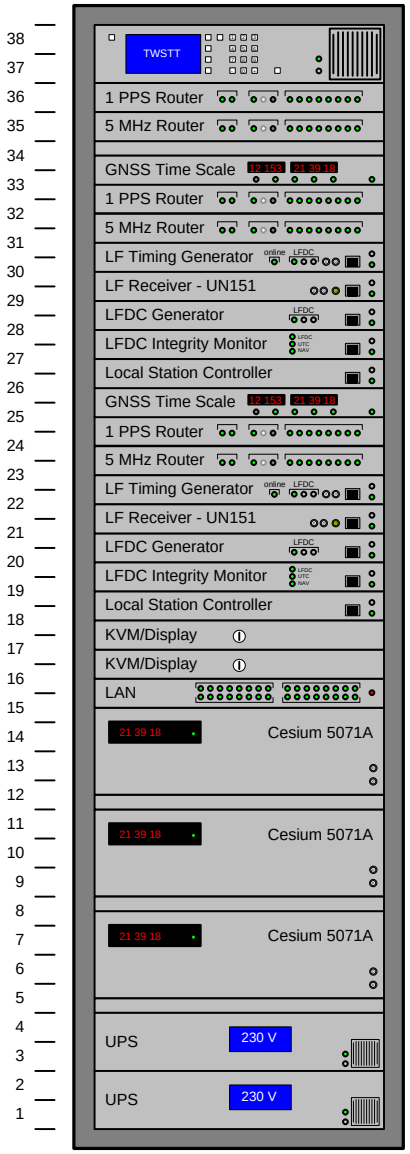
Provide UTC aligned 1 PPS, Time of Day, 10 MHz receiver output.

The Foundation for eLoran Already Exists

Norway
Denmark
UK
Germany
France



Wide Area Timing from the Transmitting Site



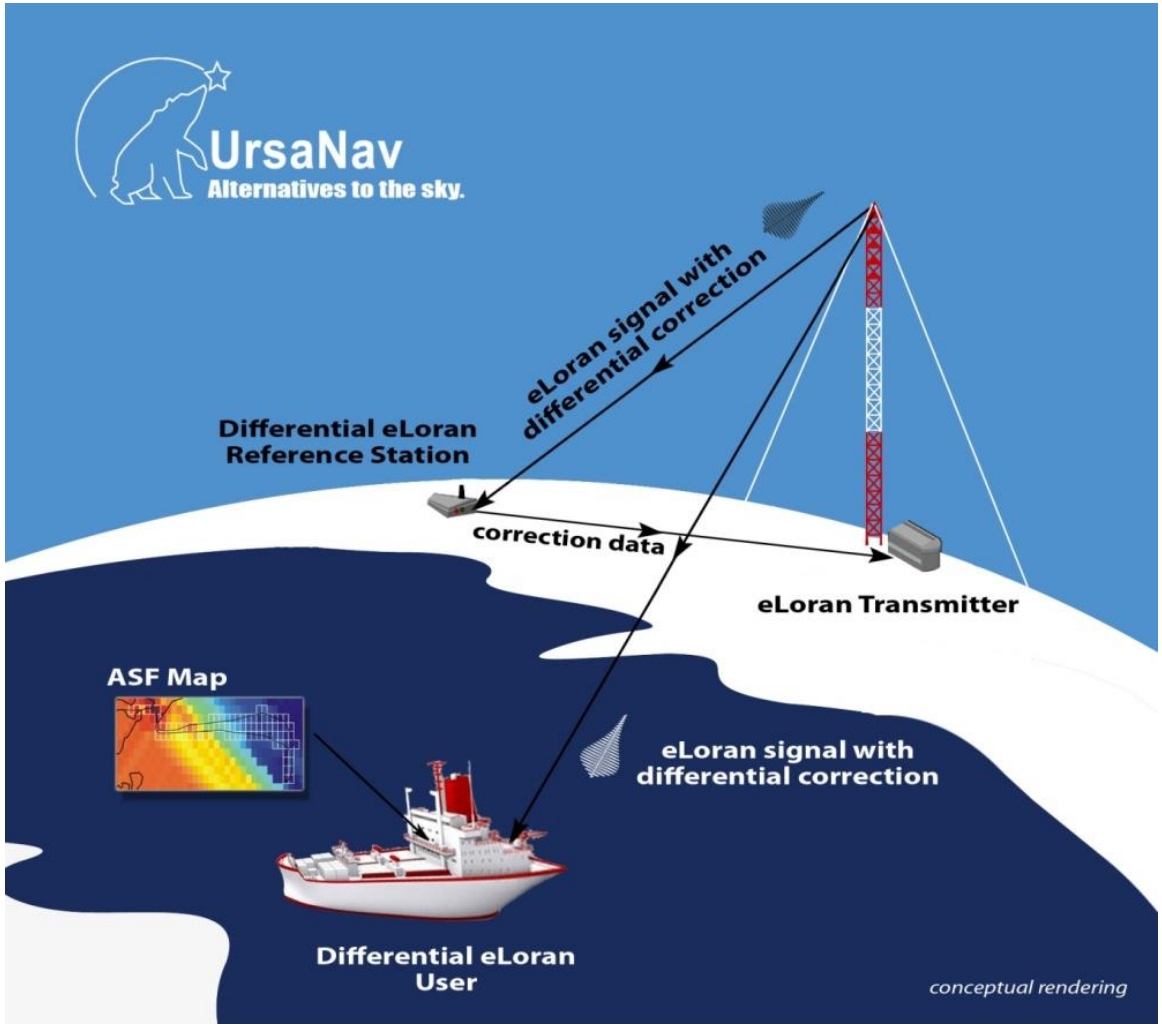
"Sky-Aided"
Remote Time Scale:
TWSTT
GNSS

"Sky-Free"
Remote Time
Scale:
TWLFTT

Local Time Scale:
Triple (disciplined) 5071A Primary Reference Standards

Locally Improved Timing via dLoran: Concept

- User is equipped with a receiver that has a stored Additional Secondary Factor (ASF) chart / map
- Corrections for the area of operation calculated at a fixed site
- Correction info sent to transmitter for broadcast via data channel
- Corrections can be applied by receiver and are monitored for integrity



Locally Improved Timing via dLoran: Technology

- Display

- Triple Rack-Mount 1u UN-154 differential eLoran RSIMs
  - Configurable as Reference Station (RS) or Integrity Monitor (IM) or Hot Standby (RS or IM)
  - Contains eLoran Receiver, Kontron CPU, and SSD
  - E-field antennas for each of the three UN-154s
- Server with three years of storage capability
- KVM
- UPS

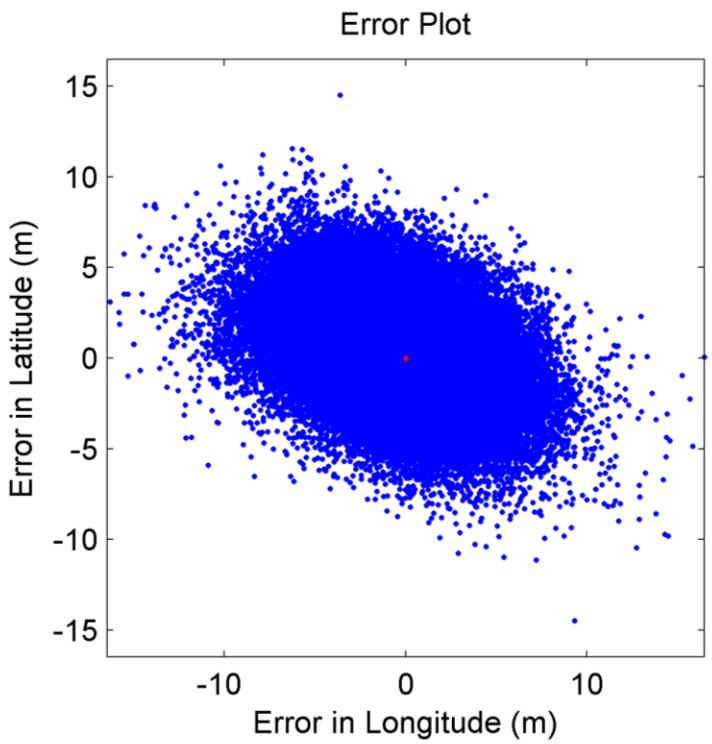
dLoran Reference Station System

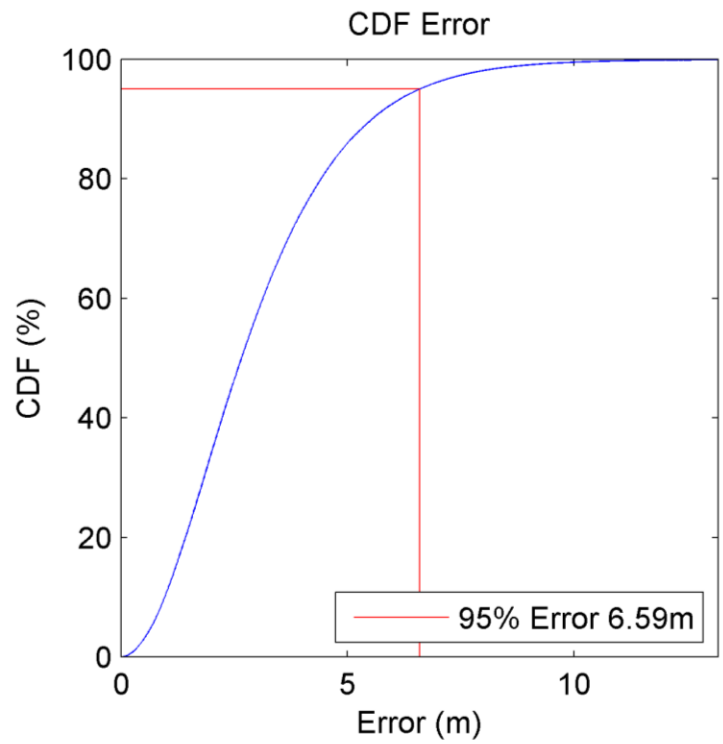
General Lighthouse Authorities' eLoran IOC

- GLAs have installed Differential eLoran Reference Stations at seven harbors along the UK East Coast
- RSIMs generate corrections for eLoran maritime **navigation** to enable 10-meter positioning accuracy to mariners
- Initial Operating Capability announced in 2014

Harwich dLoran Reference Station

GLAs system performance model of predicted versus actual accuracy.

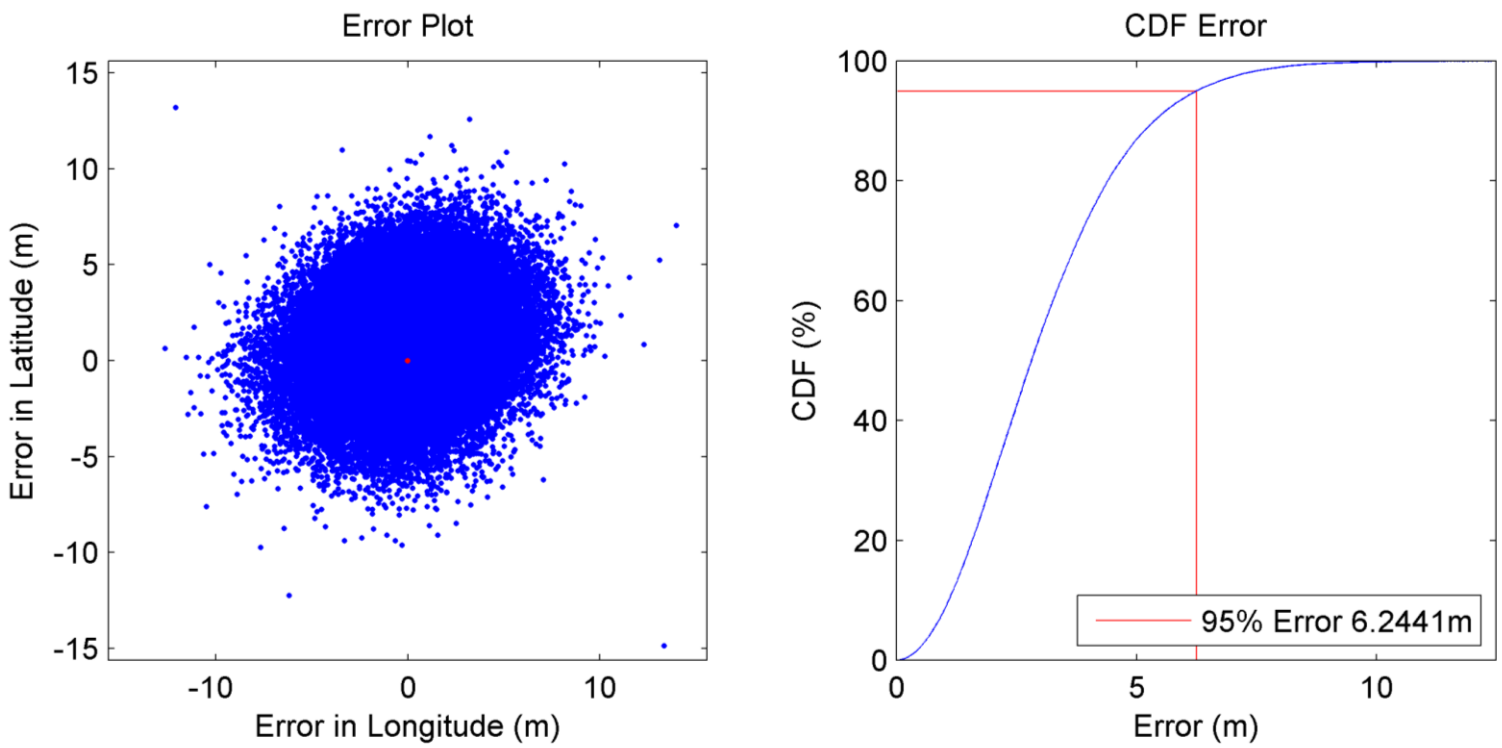




Measured data can be compared to predicted. Data shown analyzed for a one week period (5 sec TOA integration, 600 sec dLoran correction integration, dLoran update rate of 120 sec).

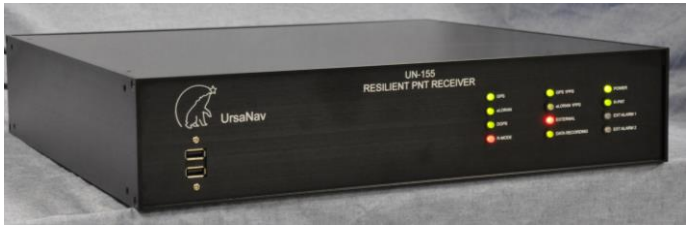
Humber dLoran Reference Station

GLAs system performance model of predicted versus actual accuracy.



Measured data can be compared to predicted. Data shown analyzed for a one week period (5 sec TOA integration, 600 sec dLoran correction integration, dLoran update rate of 120 sec).

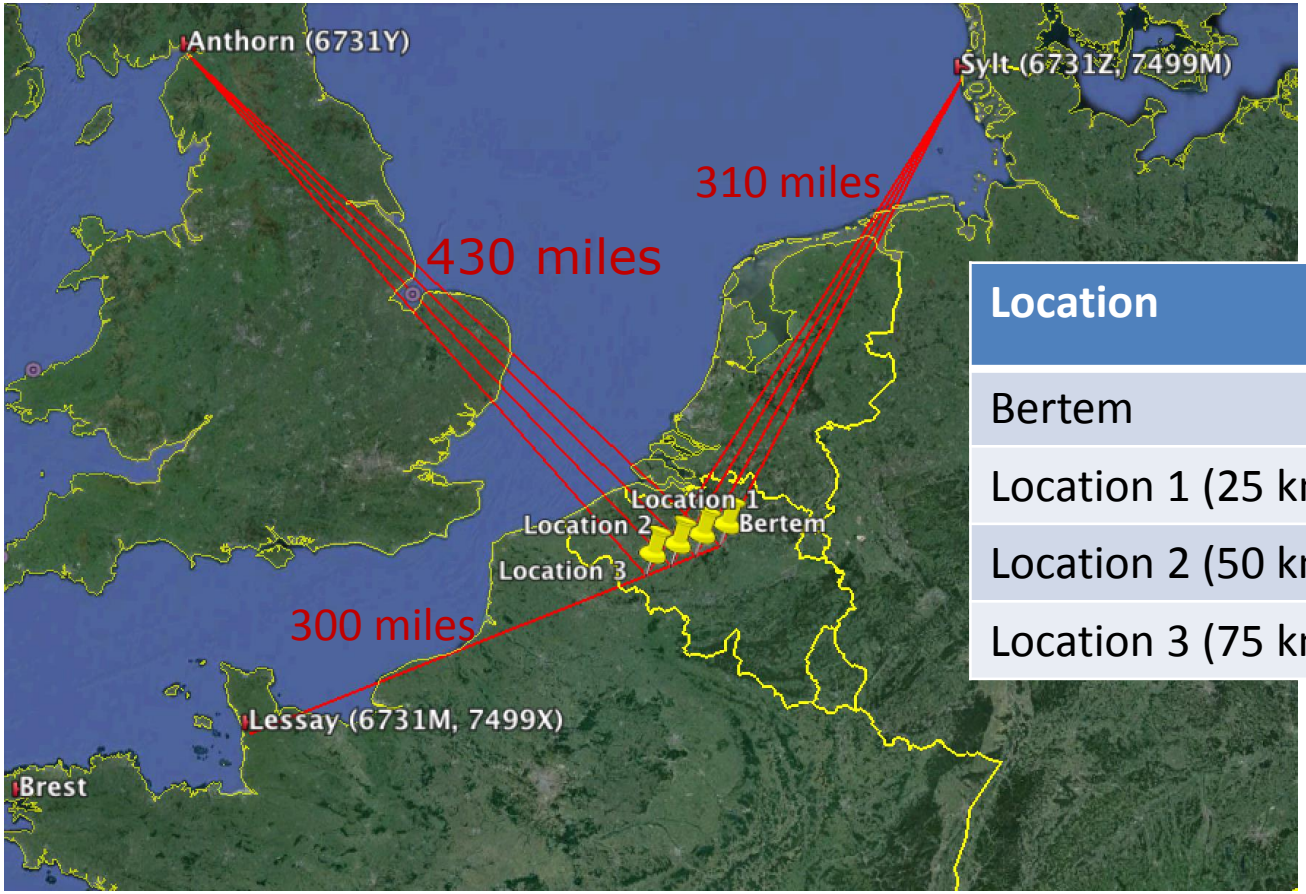
dLoran "Reference Station" for Time



- UN-155 Resilient PNT Receiver
  - GPS/DGPS/eLoran
  - Dual band (100/300 kHz) E-Field antenna
  - Custom user interface
- USB ports to access stored data
- Includes a UN-152 eLoran Timing receiver
  - Receiver oscillator disciplined by signals from Lessay Loran transmitter

- Reference Station eLoran antenna
- Zero-baseline Monitor eLoran antenna
- GPS antenna to provide independent source of UTC (Both Reference Station and Zero-baseline Monitor use the same GPS as a UTC reference)

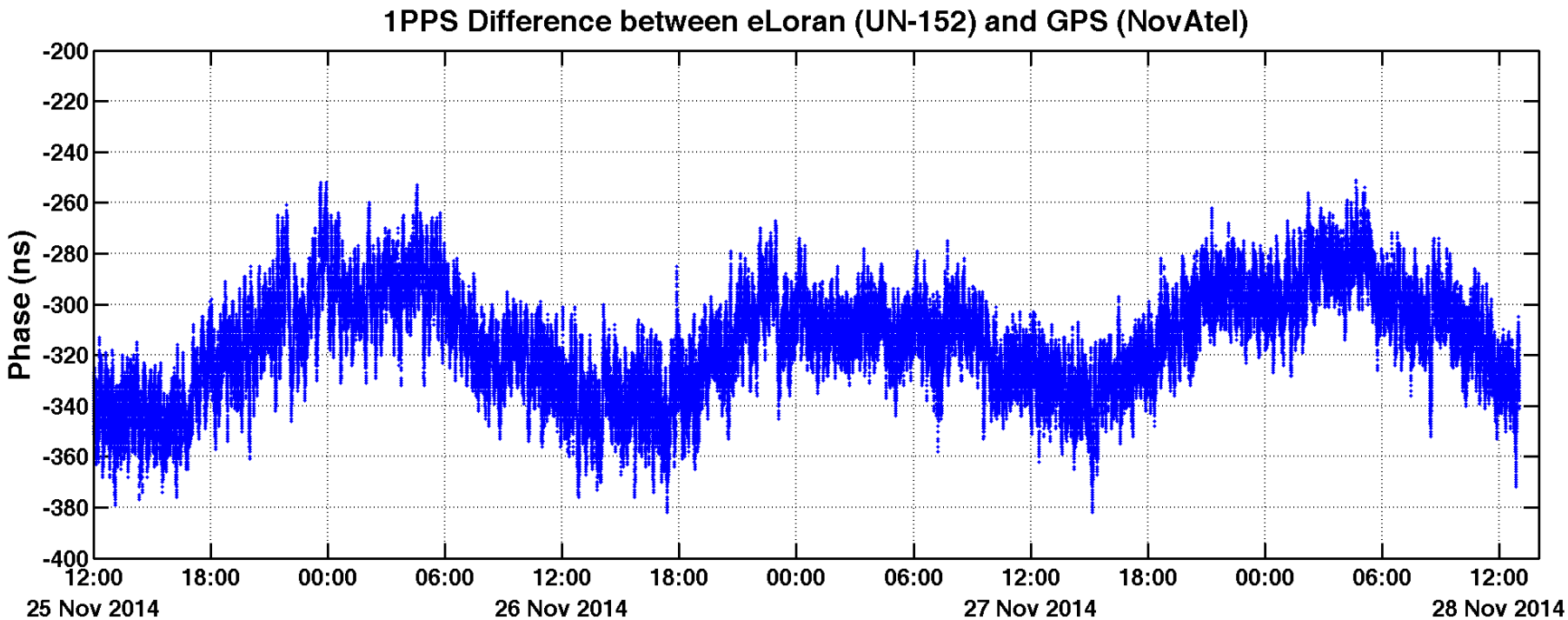
Initial Rover Receiver Results



Location	Measured Offset (Std)
Bertem	-7 ns (14.4 ns)
Location 1 (25 km)	118 ns (8.5 ns)
Location 2 (50 km)	-57 ns (8.5 ns)
Location 3 (75 km)	270 ns (6.7 ns)

- No ASF map used; only corrections from Reference Station applied
- Short duration (20 minutes) measurements
- Measured offsets within expected range of ASF change
- Receiver oscillator disciplined by signals from Lessay Loran transmitter

Zero Baseline Data

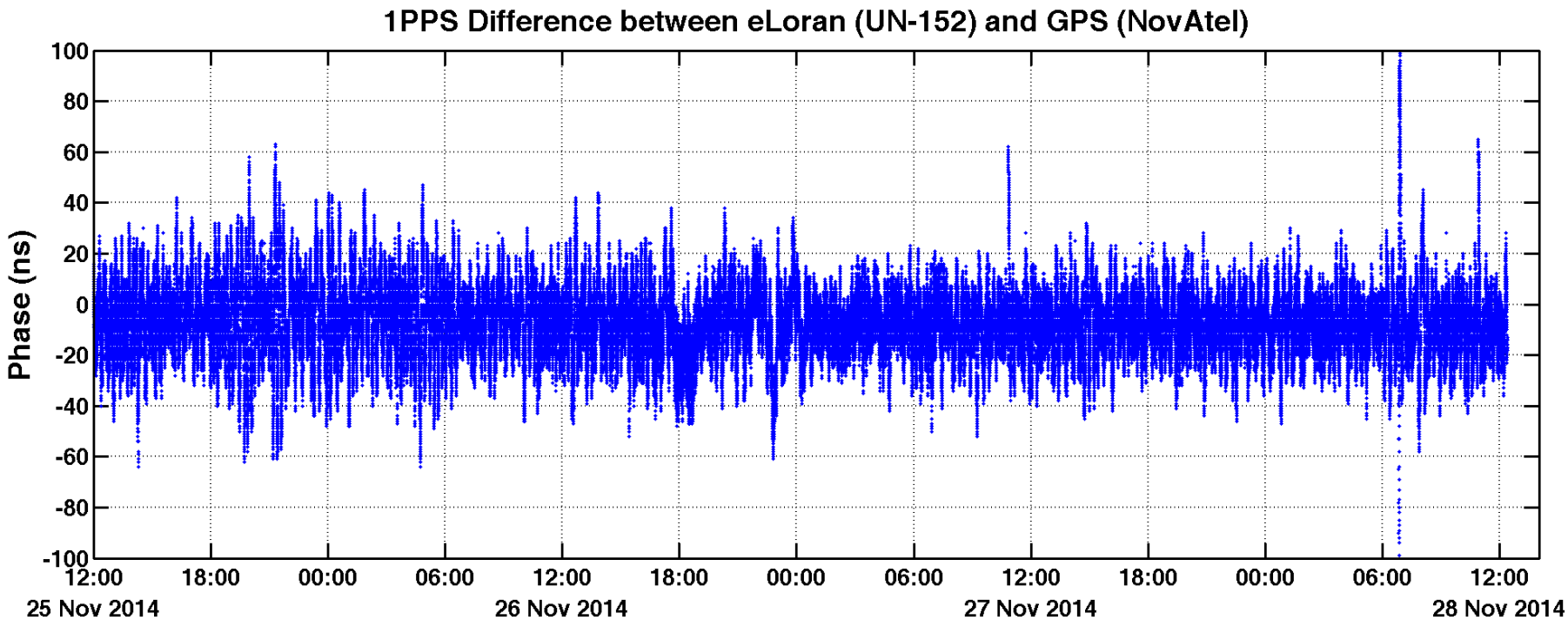


Zero-baseline ***before*** application of differential corrections

- Raw Data as measured by reference station

- Mean value of the data set is: -314.7 ns
- Standard deviation is: 20.2 ns

Zero Baseline Data

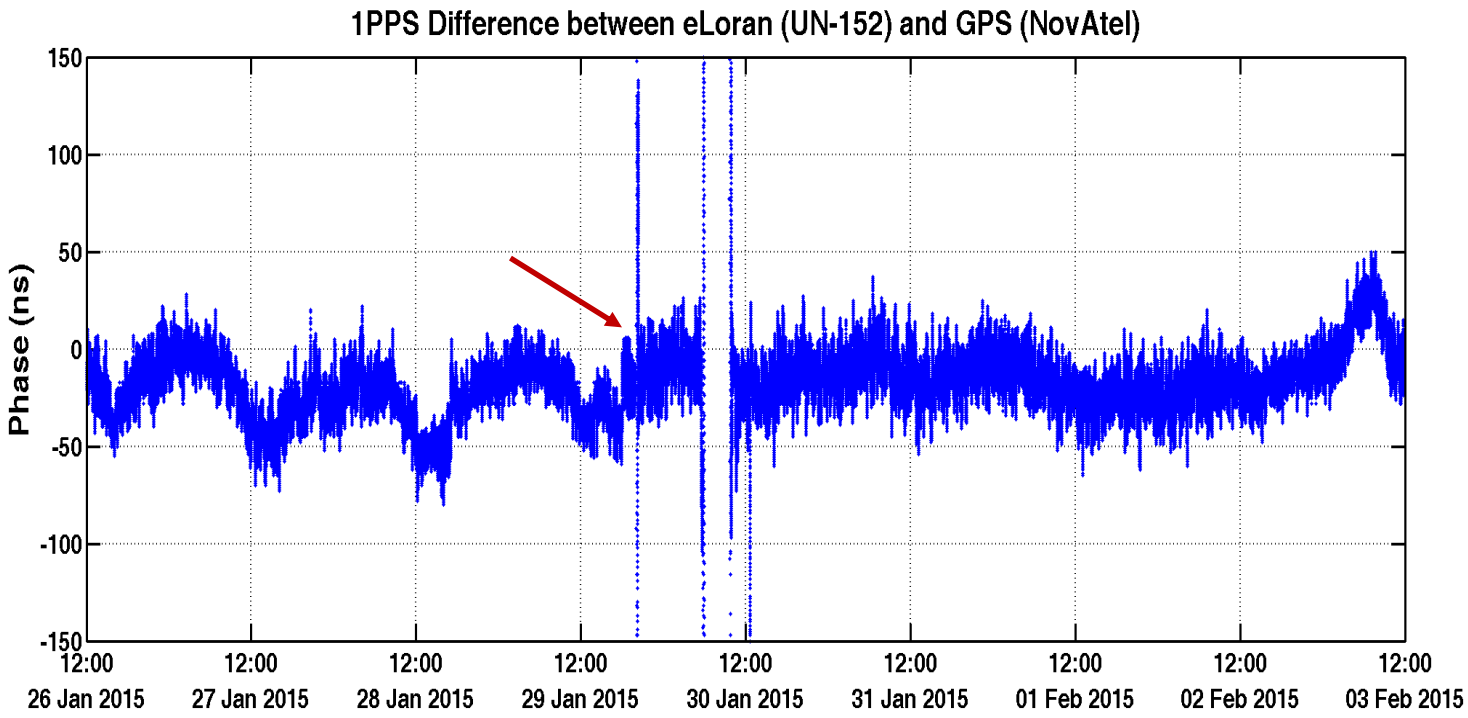


Zero-baseline ***after*** application of differential corrections

- Corrections based on 10-minute observation intervals, sent over the LDC every two (2) minutes

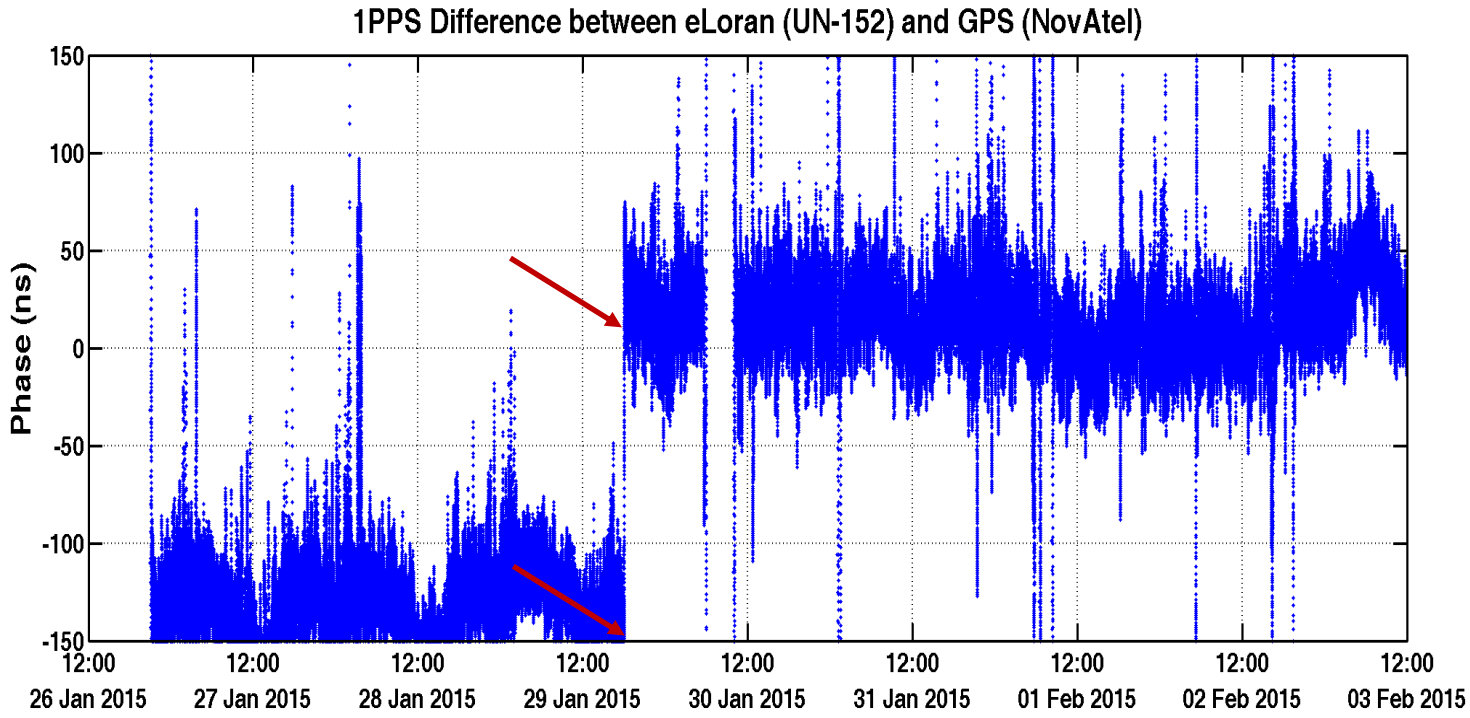
- Mean value of the data set is: -7.3 ns
- Standard deviation is: 14.4 ns

Recent Activity and Results



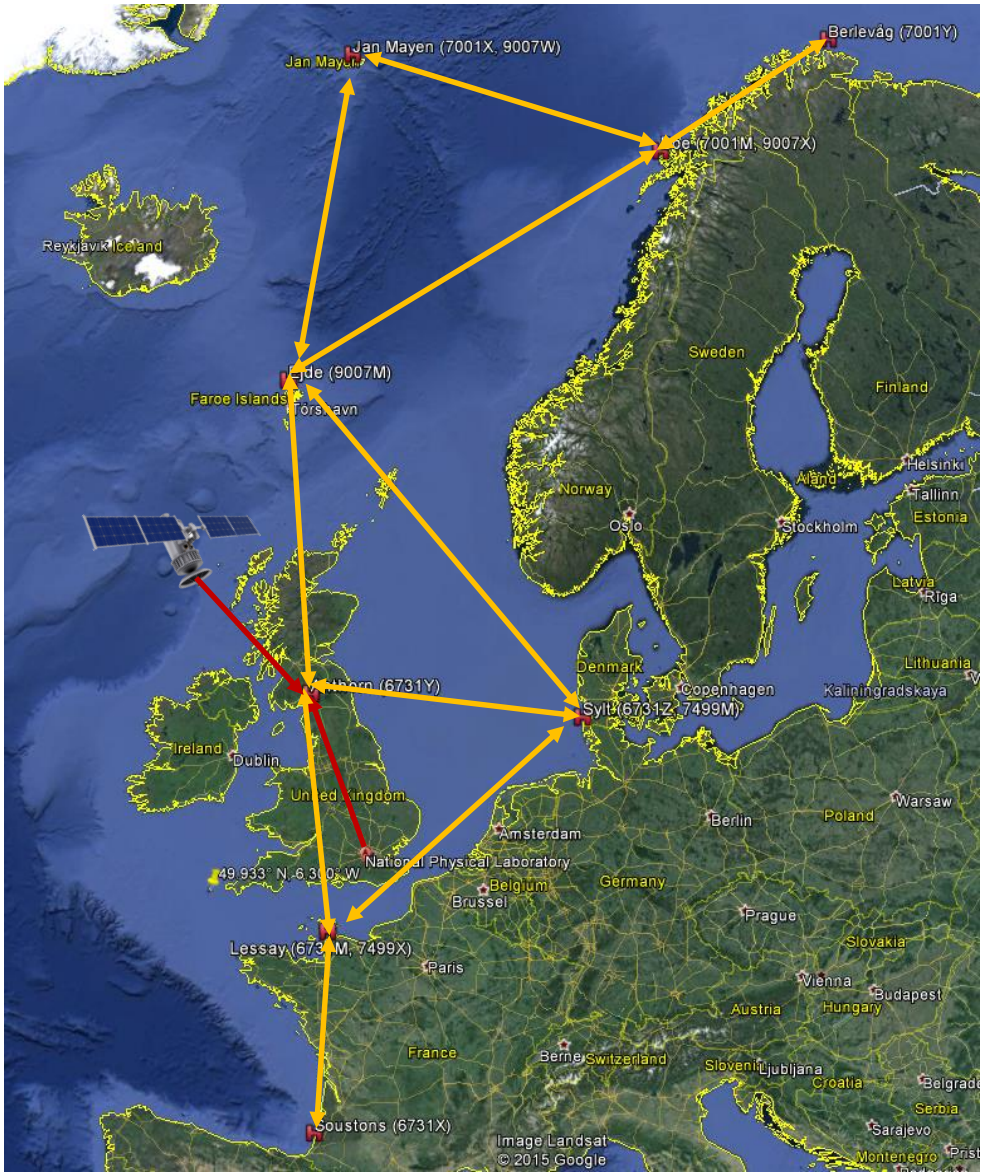
Zero-baseline performance with differential corrections applied from 29 Jan 17:00

Recent Activity and Results



Performance of Rover in Linden (10 km from Reference) before and after differential corrections applied, from 29 Jan 17 PM

Resilient Co-Primary Timing



Resilient Co-Primary Timing

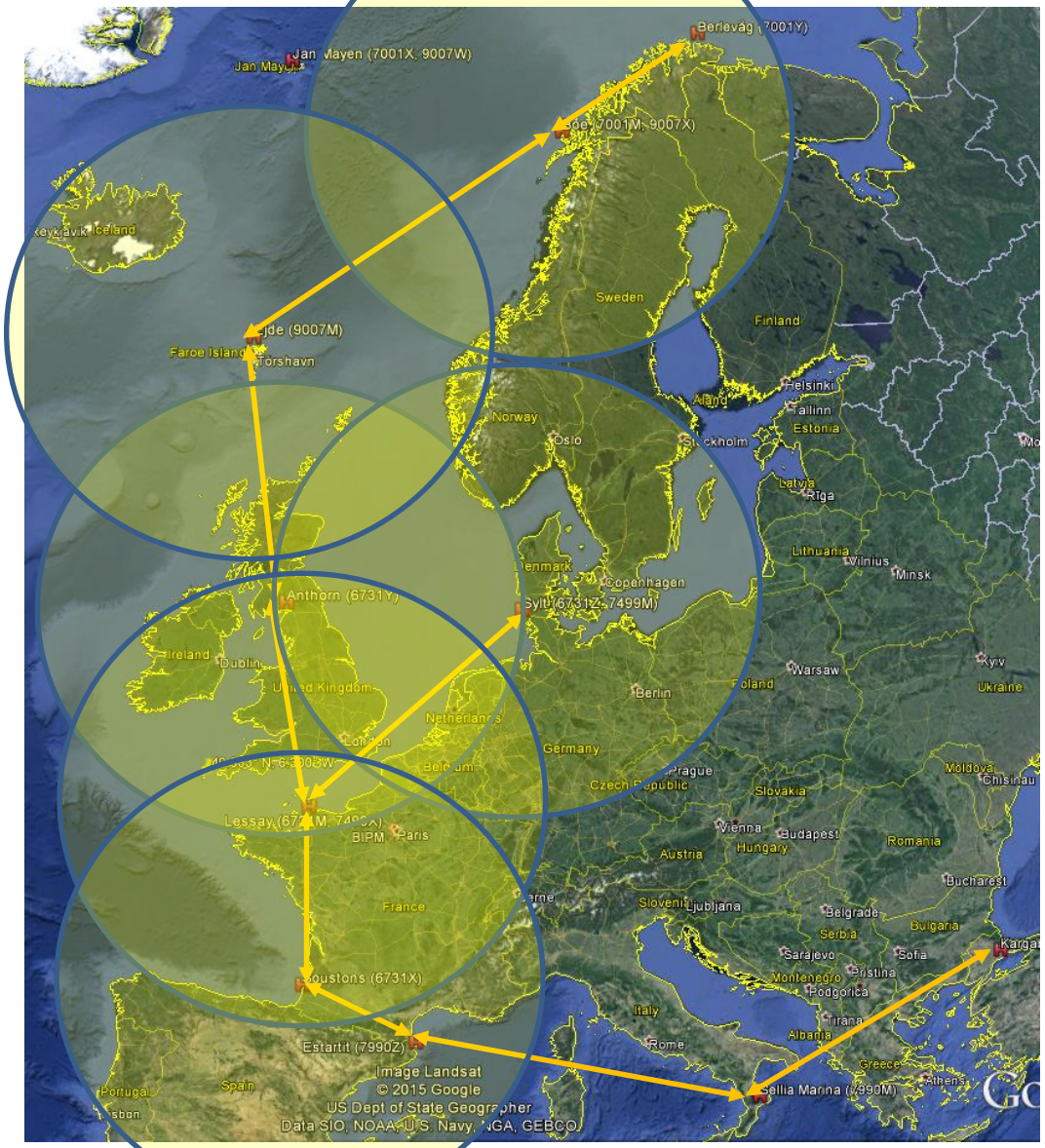
Former, still operating, Northern European Loran System (NELS) stations shown.

New eLoran station at Anthorn, UK shown.

Former, dismantled, Southern European Loran System (SELS) transmitting sites in Spain, Italy, and Turkey shown only for illustrative purposes.

Very conservative 500 mile radius circles.

Each overlap adds redundancy and resiliency.



Findings

- We implemented a very basic Differential eLoran service for Timing, Frequency, or Phase applications.
- We applied rudimentary Differential Corrections that removed diurnal variation.
- Because ASF maps are not available in Belgium yet, we used a one-time calibration to approximate ASF data at our Reference Station Site.
  - Differential Corrections are applicable over larger distances, but application of an ASF map (or one-time calibration) is needed to eliminate the offsets caused by different nominal ASFs at different locations (i.e., Reference and Rover sites).
- Even with an experimental version dLoran trial, we were able to show the considerable timing accuracy available to Critical Infrastructure / Key Resource sectors, such as the telecommunications ecosystem.

Future Work

- Develop an ASF survey at selected trial locations within a 100 mile radius of our Reference Station (i.e., 10, 25, 50, 75, and 100 miles).
- Find the midpoint ASFs for these selected trial locations.
- Perform more comparisons between E-Field and H-field antennas to determine which is best for timing, phase, and frequency.
- Incorporate additional terms into our model, such as dew point, to improve the ability to manage weather effects.
- Perform measurements around dLoran Reference Station Sites in the UK.
- Once we have been granted another Cooperative Research and Development Agreement (CRADA) with the U.S. Government, Department of Homeland Security, restart trials in the CONUS.

Acknowledgements

- Thanx and acknowledgement to Martin Bransby, Dr. Paul Williams, and Chris Hargreaves of the General Lighthouse Authorities of the United Kingdom and Ireland (GLA) for their inputs to this presentation.

- Thanx to the GLAs for allowing UrsaNav to trial differential UTC corrections from the transmitter at Anthorn, Cumbria, UK.

- Thanx also to the UrsaNav team of Dr. Gerard Offermans (Belgium); and Steve Bartlett, Andrei Grebnev, and Erik Johannessen (USA).

Thank-you for your attention.

Questions, and possibly answers?