Update on eLoran

Introduction

1. This paper is based on a presentation given to the IALA 2010 Conference in Cape Town by the General Lighthouse Authorities of the UK & Ireland (GLA) and also formed the basis of an input to IMO NAV 56 .

2. GPS now underpins much of our critical infrastructure including telecommunications, power distribution, finance, and transport. However, the low-power, high-frequency GPS signals are fragile and vulnerable to all sorts of intentional and unintentional interference. More satellite systems are not the answer: existing low-cost jammers are designed to deny the civil and military signals of all Global Navigation Satellite Systems (GNSS - i.e. GPS, GLONASS, Galileo).

3. The requirement is for resilient positioning, navigation and timing: it needs to be inherently reliable, secured against obvious external threats and capable of withstanding some degree of damage.

4. A single, cross-sector solution that augments GNSS with an independent, dissimilar and complementary system is best for users: they will benefit from economies of scale to keep equipment costs low; existing networks - user, technology, business and regulatory - can be exploited; and this will all lead to lower long-term average costs than any other approach.

5. eLoran is the only candidate that can be deployed in a timely fashion.

Overview

6. The International Loran Association provides the following description of Enhanced Loran (eLoran):

“Enhanced Loran is an internationally-standardized positioning, navigation, and timing (PNT) service for use by many modes of transport and in other applications. It is the latest in the longstanding and proven series of low-frequency, LOng-RAnge Navigation (LORAN) systems, one that takes full advantage of 21st century technology.

eLoran meets the accuracy, availability, integrity, and continuity performance requirements for aviation non-precision instrument approaches, maritime harbour entrance and approach manoeuvres, land-mobile vehicle navigation, and location-based services, and is a precise source of time and frequency for applications such as telecommunications. eLoran is an independent, dissimilar, complement to Global Navigation Satellite Systems (GNSS). It allows GNSS users to retain the safety, security, and economic benefits of GNSS, even when their satellite services are disrupted.”

7. Any discussion of the difference between Loran-C and eLoran is complicated because Loran-C has been modernised at different times and to different extents in different parts of the World. The following descriptions are provided for clarification.

USCG Loran-C	The original version of Loran-C (c. 1960s) based on tube transmitters, SAM control, ASF look-up tables and hyperbolic navigation, requiring large numbers of people on site. Typical accuracy: 460m (95%).
Modernised	The original version of NELS (c. 1990s) based on solid-state transmitters,

Loran-C	time-of-emission timing, ASF model, hyperbolic or rho-rho navigation, and requiring very few people on site. Typical accuracy: 100m (95%).
Prototype eLoran	The GLAs' system (c. 2008) based on modernised Loran-C together with (i) Eurofix to carry UTC and differential-Loran, (ii) all-in-view navigation, (iii) precise ASF surveys, and (iii) differential-Loran reference stations for maritime use. Typical accuracy: 10-20m (95%). Real-time prototype eLoran has been in operation for two years and is now running continuously.
eLoran	This is the future (c. 2013?) based on prototype eLoran together with (i) updated station equipment to improve timing stability, (ii) mitigation of vulnerabilities to ensure high availability, (iii) Eurofix at all stations, and (iv) modernised control at Brest. Typical accuracy: 10-20m (95%).

8. Each of these generations delivers different levels of performance and so provides different capabilities in terms of the applications that it supports. eLoran is most applicable for 21st century applications.

9. It is important to note that all generations of Loran support Stratum 1 frequency for telecommunications. Prototype eLoran and eLoran support UTC time-of-day. eLoran will support sub-50ns precise timing.

GNSS Vulnerability

10. There is now broad agreement that Global Navigation Satellite Systems (GNSS – e.g. GPS, Galileo, Glonass, Compass) are vulnerable to unintentional and intentional interference. This includes natural phenomena, e.g. due to the ionosphere.

11. The use of GPS jammers, long foreseen in navigation circles, has become a reality as criminals employ them to overcome tracking systems and steal vehicles. Low-powered jammers are readily available over the Internet for as little as $150 and can block GPS reception in a vehicle's vicinity. They can also block all mobile phone bands used in the area.

12. Today's jammers are already configured to jam GPS, Galileo and Glonass civil and military signals simultaneously on both the L1 and L2 frequencies. It would be trivial to add L5. Some of these jammers are powerful, radiating 2W on each frequency.

13. GNSS performance can also suffer from system errors whether from satellite repositioning, software uploads, or system upgrades.

Extending GNSS Performance

14. Extending GNSS performance is also a driver for some eLoran developments. Specifically, integrated eLoran and GPS at the chip scale is being explored to give consumer GNSS receivers the extreme sensitivity needed to start up deep inside buildings, including concrete underground carparks. This translates into a requirement for tight integration at the chip level.

GLA Jamming Trials

15. The General Lighthouse Authorities have held two sets of GPS jamming trials in 2008 and 2009 to understand the impact of a loss of GPS on the safety of navigation. The following conclusions have been drawn.

- A 1.5W GPS jammer denies GPS for about 16 nautical miles.
- The precise impact of GPS jamming on a vessel depends on the bridge fit, configuration and level of system integration.
- Hazardously Misleading Information - GPS jamming can produce hazardously misleading information with positioning errors from a few nautical miles to several hundred and velocities of 10 knots to 20,000 knots.
- DSC / GMDSS – these alarmed when the GPS positioning input was lost. In the worst case, there is potential for search and rescue agencies to be directed to an incorrect location with obvious safety consequences.
- DGPS – this alarmed when the GPS positioning input was lost and had a knock-on effect on the position reporting on the ECDIS and the AIS.
- AIS – this alarmed when the GPS positioning input was lost. AIS lost its ability to identify the bearing and distance of other ships and AIS AtoNs. Other ships and vessel traffic services perceive the jammed ship to be in the wrong place.
- Gyros – these alarmed. The precise impact depends on the GPS / gyro integration.
- GPS receivers – one was affected to such an extent that it would not track GPS satellites automatically. The solution was to turn off the receiver for about an hour to force a cold start.

In addition, and although not specifically tested during the GLA trials, marine satellite broadband antennas include a GPS receiver for automatic pointing of the antenna towards the geostationary telecommunications satellite. Therefore, potentially, a satellite Internet based application could be disrupted by GPS denial.

Requirement for Resilient PNT

16. Resilient PNT (positioning, navigation and timing) is a requirement not just for the maritime sector but for critical infrastructure (e.g. transport, telecommunications, power distribution, finance, emergency services etc.) in general.

17. The UK Centre for the Protection of National Infrastructure uses the following definition for resilience: the equipment and architecture used are inherently reliable, secured against obvious external threats and capable of withstanding some degree of damage.

18. It has been stated that resilient physical and social systems must be 'robust, redundant, resourceful and capable of rapid response', where:

Robustness:	The inherent strength or resistance in a system to withstand external demands without degradation or loss of functionality
Redundancy:	System properties that allow for alternate options, choices, and substitutions under stress
Resourcefulness:	The capacity to mobilize needed resources and services in emergencies
Rapidity:	The speed with which disruption can be overcome and safety, services, and financial stability restored

GNSS Interference Detection and Mitigation

19. The need for GNSS interference detection and mitigation is being explored in the US and UK. In our safety-critical environment this needs to be available on board the ship. There are different ways of detecting interference. However, interference *mitigation* needs to ensure that a user's operation is not disrupted.

The requirement should be to maintain the user's concept of operations with a seamless transition from GNSS to a backup. This is what is really needed for e-Navigation. An inferior approach would provide a backup that does not maintain the user's concept of operations and requires manual intervention.

Systemic Backup

20. Users not only need resilient PNT, they also need it to be cost-effective and so a systemic backup is the best solution. In this case, *systemic* means that the backup can be used within many user sectors – air, maritime, land, telecommunications, critical infrastructure …

21. Key benefits of a systemic backup include:

- short-term economies of scale – broad, cross-sector demand will ensure that cost of the systemic backup is very low. In practice, this means that chip-level integration with GNSS can be achieved swiftly and the cost to the user is small.
- linking into existing GNSS networks – these include technology research, product development and manufacturing, sales and marketing, user networks for retrofitting and regulation.
- lower long-term average costs – the cost of a systemic backup should always be lower than sector-specific backups and should decrease over time. On this basis, systemic backups should decrease the long-term average costs for many stakeholders.

The Solution - eLoran

22. At the highest level, the requirement is for resilient PNT. GNSS will undoubtedly be one of the sources of PNT. The requirements for a GNSS complement are given below.

23. The GNSS complement should:
- enable resilient PNT for use by critical infrastructure applications including maritime transport.
- be readily integrated with GNSS at chip-level.
- support interference detection and mitigation.
- maintain the user's concept of operations with a seamless transition to a complement when GNSS is lost.
- have the potential to be deployed world-wide.
- support maritime general navigation applications.
- be independent of GNSS.
- be dissimilar in terms of failure modes.
- provide similar levels of performance as GNSS

24. eLoran is the only system that can meet all these requirements in a timely fashion and support the development and implementation of e-Navigation.

eLoran Standardisation

25. eLoran standardisation efforts began in October 2007 with the first meeting of the Radio Technical Commission for Maritime Services Special Committee-127 (RTCM-SC127). SC-127 was established to consider the need for the development of standards for eLoran position, navigation and timing (PNT) system components, including, but not limited to maritime eLoran receivers, and/or combined GNSS/eLoran receivers. Once such a need was identified the group would develop appropriate RTCM Standards or Reports addressing performance requirements, technical requirements, and/or test procedures, with a view to their use for the production of eLoran systems, and as the basis for eventual IMO, ITU and/or IEC

recommendations or standards, as appropriate. The release of a draft RTCM eLoran Receiver Minimum Performance Standard (MPS) is imminent at the time of writing.

Hardware

26. There are a number of receivers available:

- Maritime receivers are available. These generally use a crossed-loop H field Loran antenna so that the receiver also acts as an accurate True North compass and so is useful for driving heads-up displays.
- Timing receivers are also available.
- Electronics companies have been investigating chip-level integration.

27. Differential-Loran reference stations, ASF Measurement Equipment and an eLoran simulator are available.

28. In the UK, the GAARDIAN Project is developing a joint GPS / Loran interference detection and mitigation system to alert service providers and users when there is a potential problem. GAARDIAN is a UK initiative that is funded by the Technology Strategy Board, part of the Department for Business, Innovation and Skills.

Performance

29. Researchers worldwide have already shown that eLoran can meet the accuracy, availability, integrity, and continuity performance requirements for aviation non-precision instrument approaches and maritime harbour entrance and approach.

30. The GLAs have been developing initial proof of concept systems, and testing them in challenging environments. To demonstrate performance in an archipelago the GLAs performed eLoran trials in the Orkney Islands, off the northern coast of Scotland. This is an area of excellent Loran geometry and signal strength from the stations at Ejde, Vaerlandet and Anthorn.

31. Three routes were followed on three separate days. The total distance travelled was some 230Nm with a total steaming time of about 23 hours at 10kts, the biggest trial the GLAs have performed to date.

32. To establish an eLoran system in the area for the duration of the trials two things were required:

- A differential-Loran Reference Station
- A map of signal propagation corrections, (Loran ASFs) stored within the receiver.

33. A temporary differential-Loran Reference Station was installed at Kirkwall – the capital city of the Orkney Islands. ASFs were measured from the data collected during the performance of the routes.

34. The most technically difficult part of the voyage occurred in the Hoy Sound; a channel with complex land-sea signal paths. However, accuracies of 11m (95%) were achieved using eLoran. These accuracy levels are typical of those realised in widespread trials over the past four years.

35. The conclusion so far is that where there is good eLoran transmitter geometry and signal strength, and a maritime eLoran service has been established, complete with propagation correction maps (ASFs) and differential-Loran, there is no reason why eLoran should not provide close to (if not better than) 10m (95%) positioning accuracy. Other challenging areas

include mountainous terrain and fjords, and these will need to be investigated in the near future. The GLAs have developed the ability to quickly and accurately establish a temporary eLoran installation for trial purposes, and measure and analyse the system's performance.

Challenges

36. The main challenge is to ensure that resilient PNT based on GNSS, with a complementary system such as eLoran, is available to support the introduction of e-Navigation. This is recognised in IALA's World Wide Radio Navigation Plan (WWRNP):

37. GNSS (in particular GPS) has become the primary means of navigation in many maritime applications. However, the vulnerability of GNSS to accidental or deliberate interference is well known and the need for more than one position input to e-Navigation is recognised.

38. It is noted that Loran/Chayka is the only wide area terrestrial radio-navigation system currently available

39. Members of IALA with Loran/Chayka facilities within their jurisdiction are encouraged to retain them in operation and make plans to upgrade them to eLoran capability, so that they can form part of the WWRNP

40. A second challenge is to bring together interested parties from around the World to develop an implementation plan based on a common understanding of user and functional requirements.