# The Capability of e-Loran to Mitigate the Impact of GPS Outage

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## ABSTRACT

The Global Positioning System (GPS) is the primary source of Position, Navigation and Timing (PNT) information in maritime applications, whether stand-alone or augmented with additional systems. This situation will continue in the future with GPS, together with other GNSS, being the core PNT technology for e-Navigation. GPS is vulnerable. Its signals, measured at the surface of the earth, are very weak. As such, the system is susceptible to jamming and unintentional interference, resulting in the possible denial of the service in large geographical areas. The result of such interference could be the complete failure of the mariner's GPS receiver or, possibly worse, the presentation to the mariner of hazardously misleading information depending on how the GPS receiver reacts to the jamming incident.

This paper provides the knowledge, understanding of the difference between the hyperbolic Loran-C of old and enhanced Loran system (eLoran), and presents the eLoran's capability to mitigate the impact of a GPS outage on GPS position, navigation, and time applications.

Finally, the introduction of eLoran provides 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.

**مُستخلص**

نظام تحديد المواقع العالمي (GPS) هو المصدر الرئيسي لمعلومات الموقع والملاحة والتوقيت (PNT) في التطبيقات البحرية، سواء كانت قائمة بذاتها أو مع أنظمة إضافية. وسوف يستمر هذا الوضع في المستقبل مع نظام تحديد المواقع العالمي، جنبا إلى جنب مع الأنظمة الأخرى، لكونها الوسيلة الأساسية لمعلومات الموقع والملاحة والتوقيت لتكنولوجيا تعزيز الملاحة (e-Navigation). هو عرضة للخطر لضعف إشاراته، على سطح الأرض. على هذا النحو، فإن هذا النظام عرضة للتشويش والتداخل غير المقصود، مما يؤدى إلى فقدان الخدمة في مناطق جغرافية واسعة. نتيجة لمثل هذا التدخل يمكن أن يكون الفشل الكامل لأجهزة استقبال GPS، أو ربما أسوأ، إن يعرض معلومات مضللة بشكل خطر اعتمادا على كيفية رد فعل أجهزة استقبال GPS على التشويش.

وتقدم هذه الورقة البحثية دراسة وافية وفهما شاملا للفرق بين نظام لوران سي (Loran C) الذي يعتمد علي ملاحة القطع الذائد ونظام لوران المُعزز (eLoran)، وتعرض قدرة نظام eLoran الرامية إلى التخفيف من تأثير انقطاع إشارات نظام GPS علي تطبيقات تحديد الموقع والملاحة، والوقت.

وأخيرا، إدخال نظام eLoran يوفر خدمة مستقلة، متباينة، واستكمالا لأنظمة الملاحة بالأقمار الصناعية (GNSS). أنه يسمح لمستخدمي GNSS الإبقاء على سلامة الملاحة، والأمن، والفوائد الاقتصادية من تلك النظم، حتى عندما تتعطل خدمات الأقمار الصناعية الخاصة بهم.

**KEYWORDS:** GNSS – Vulnerability – Interference – e-Loran – Mitigation

# 1 BACKGROUND AND CURRENT USE OF GPS

The Global Navigation Satellite Systems (GNSS) has changed the way the world operates. This is especially true for marine operations, including search and rescue. GNSS provides the fastest and most accurate method for mariners to navigate, measure speed, and determine position. This enables increased levels of safety and efficiency for mariners worldwide.

It is important in marine navigation for the ship's officer to know the vessel's position while in open sea and also in congested harbors and waterways. Vessel traffic and other waterway hazards make maneuvering more difficult, and the risk of accidents becomes greater. While at sea, accurate position, speed, and heading are needed to ensure the vessel reaches its destination in the safest, most economical and timely fashion.

Mariners are increasingly using GPS data for navigation, distress, communications, collision avoidance, and ensure compliance with regulations. An enhancement to the basic GPS signal known as Differential GPS (DGPS) provides much higher precision and increased safety in its coverage areas for maritime operations. Many nations use DGPS for operations such as buoy positioning, sweeping, and dredging. This enhancement improves harbor navigation.

International Maritime Organization (IMO) approved Electronic Chart Display and Information System (ECDIS) as a primary means of navigation, which use GPS and/or DGPS for positioning information. These systems are modernizing marine navigation and are leading to the replacement of paper nautical charts. With DGPS, position and radar information can be integrated and displayed on an electronic chart, forming the basis of the Integrated Bridge System which is being installed on commercial vessels of all types.

GPS information is embedded within a system known as the Automatic Identification System (AIS) transmission. The AIS, which is endorsed by the International Maritime Organization, is used for vessel traffic control around busy seaways. This service is not only vital for navigation, but is increasingly used to support the security of ports and waterways by providing governments with greater situational awareness of commercial vessels and their cargo. The adoption of AIS depends on the continuous availability of an input of GPS.

AIS uses a transponder system that operates in the VHF maritime band and is capable of communicating ship to ship as well as ship to shore, transmitting information relating to ship identification, position, vessel type, and cargo information, all on a real-time, wholly automated basis. Because the ship's GPS position is embedded in these transmissions, all essential information about vessel movements and contents can be uploaded automatically to electronic charts. The safety and security of vessels using this system is significantly enhanced.

GPS is only effective aid to provide position information for Global Maritime Distress and Safety System (GMDSS), including radio beacon EPIRBs are now produced with an integral GPS receiver. This additional data transmitted to the COSPAS/SARAST organization and to the relevant rescue co-ordination center. The loss of GPS signal would therefore remove the extremely useful position data.

Major floating aids have station monitoring using GPS. This includes all light vessels, light floats, and critical buoys. The current system is fully automatic obtaining position information from a GPS receiver. Position data is transmitted to a central station via a two way data communication link.

GPS is playing an increasingly important role in the management of maritime port facilities. GPS technology, coupled with geographic information system (GIS) software, is the key to the efficient management and operation of automated container placement in the world's largest port facilities. GPS facilitates the automation of the pick-up, transfer, and placement process of containers by tracking them from port entry to exit. With millions of container shipments being placed in port terminals annually, GPS has greatly reduced the number of lost or misdirected containers and lowered associated operation costs.

Wireless telephone and data networks use GPS time to keep all of their base stations in perfect synchronization, Digital broadcast radio services use GPS time to ensure that the bits from all radio stations arrive at receivers in lockstep; Companies worldwide use GPS to time-stamp business transactions, providing a consistent and accurate way to maintain records and ensure their traceability, Major investment banks use GPS to synchronize their network computers located around the world, Large and small businesses use automated systems that can track, update, and manage multiple transactions made by a global network of customers.

The loss of GPS signal would have a significant impact on maritime operations that could affect both safety and environment.

## 2 GNSS/GPS VULNERABILITY

All of the GNSS systems in existence, USA (GPS), Russian Federation (GLONASS) or planned, European Union satellite navigation system (Galileo), and Chinese satellite navigation system (Beidu) have common attributes. The received signal powers available at user terminal are extremely small; they range from -160 dBW to – 155 dBW. The transmissions are usually of spread spectrum nature and their resistance to interference ranges from value of 20 to 30 dB; giving very low edge interference limits of -140 dBW – 125 dBW [4] . As a result, there is no guarantee of continuous GNSS services, due to the possible nature loss of the signal due to building shadowing, or tunnels or interference.

### 2.1 Unintentional GNSS/GPS signal loss

The timing and positioning information from GNSS/GPS signal can be lost if a vehicle enters urban area, where GPS satellites visibility, is very low, this can also occur in mountainous areas. This loss may not be of a continuous nature, but sufficient to affect certain applications.

Alternatively, the GPS signal can be lost through an external interference source that exceeds the GPS threshold limits. GNSS/GPS applications are very vulnerable to relative low-level radio frequency interference. Spurious and harmonic emissions from other radio frequency transmissions such as mobile satellite terminals could be one cause of interference; others sources could be broadcast transmissions [11].

Although, more GNSS satellites may be launched in future, this will only increase the number of satellites in view and help reception of signals in area blocked by buildings. It will not help against jamming or external interference, becaouse all these satellite systems must share a small number of radio frequency bands where they are being thereatened there by raising levels of radio interference. Each new satellite adds to that noise level, with more than 70 satellites, satellite noise exceeds the cosmic noise floor. Therefore, the more satellites, the worse the reception, until eventually the user can receive none at all, this threat is self-inflicted by the world GNSS community [10].

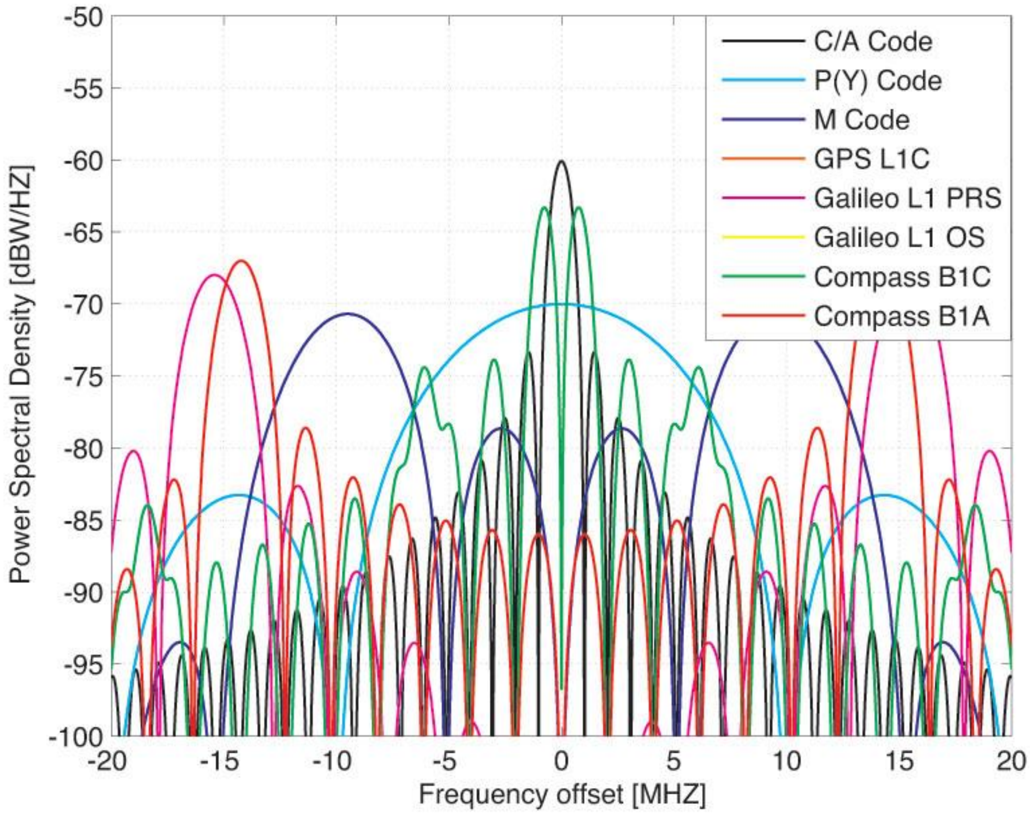


Fig. 1: Power spectral densities of GPS, Galileo, and Compass signals in the L1 band [13].

### 2.2 Intentional GNSS/GPS signal loss

Jamming, spoofing, and meaconing are three distinct forms of international interference. Jamming is raising the noise level and cause loss of lock, spoofing a more serious thereat has now appeared, transmitting fack GPS signal.

jamming comes from hackers; those seeking privacy in their vehicles from the boss or law enforcement, criminals defeating security systems, and governments. A jammer of less than one thousandth of the power of a mobile phones makes GPS receivers gave false positions and velocities, when the jammer power increased a little, all GPS receivers failed, and differential GPS went out, taking down multipile systems; the Electronic Chart Display and Information System (ECDIS) lied, the vessel AIS will report false positions to nearby ships. So a low-cost, low-powered jammer will make GPS die or lie over tens of meters, it will block mobile phones, and disable the security cameras as well. Jammers up to ten thousand times more powerful, they can take out GPS over much of a city, or a harbour. Jammers that operate in the L1, L2, and L5 frequency bands block GPS, GLONASS, Compass-Beidou, QZSS, WAAS, EGNOS, GAGAN, and will block future Galileo [10].

# 3 THE e-LORAN SYSTEM

eLoran is a low frequency terrestrial navigation system based on a number of transmission stations, which emit precisely timed and radio pulses centred at 100 kHz radio frequency. Each station emits a sequence of 8 pulses spaced 1000 microseconds apart. The stations are grouped into chains, which each consists of a single master station and two or more secondary stations. The master station transmits first, followed by successive transmissions from each of the secondary stations of the chain. The master/secondary transmission sequence is repeated periodically, with the period between repetitions called the Group Repetition Interval (GRI).

eLoran represents a move away from the hyperbolic Loran-C of old. Today, modern receivers can measure the time of arrival of signals from many stations (and from multiple chains) at once. eLoran is derived from the Loran-C system, but uses solid-state transmitters, precise timing using atomic clocks and a data channel to provide correction and integrity messages. The use of built-in microprocessors means that the receiver is also able to output latitude and longitude directly. Modern eLoran works in much the same way as GPS but it is an independent and complementary system, offering a navigation system with no failure modes in common with GPS or any other satellite based system.

eLoran, together with a future maritime service of differential-Loran, can offer the increased accuracy, integrity, and continuity of service modern navigators demand[14] .

The core eLoran system comprises modernized control centres, transmitting stations and monitoring sites. eLoran transmissions are synchronized to an identifiable, publicly-certified, source of Coordinated Universal Time (UTC) by a method wholly independent of GNSS. This allows the eLoran Service Provider to operate on a time scale that is synchronized with but operates independently of GNSS time scales. Synchronizing to a common time source will also allow receivers to employ a mixture of eLoran and satellite signals.

The principal difference between eLoran and traditional Loran-C is the addition of a data channel on the transmitted signal. This conveys application-specific corrections, warnings, and signal integrity information to the user's receiver. It is this data channel that allows eLoran to meet the very demanding requirements of landing aircraft using non-precision instrument approaches and bringing ships safely into harbour in low-visibility conditions. eLoran is also capable of providing the exceedingly precise time and frequency references needed by the telecommunications systems that carry voice and internet communications [7].

## 3.1 Positioning Using e-Loran

eLoran transmissions synchronised to UTC, the user receiver measures Time of Arrival to three (or more) transmitters, the difference between Time of Arrival and Time of Transmission is the Propagation Delay $T_{Prop}$

$T_{Prop}$ (in seconds) needs to be converted to a pseudo-range ρ (in meters) by multiplication with the speed of light (c) to calculate the user position:

$$\rho = R + PF + SF + ASF + \delta + \varepsilon + B$$

Where

R = true range (what we want to know)

PF = Primary Factor

SF = Secondary Factor

ASF = Additional Secondary Factor
δ = variation in PF, SF and ASF
ε = remaining measurement errors
B = the receiver clock bias

The Primary Factor delay is the difference between propagation of the signal in the earth's atmosphere as opposed to in free space

The Secondary Factor delay accounts for signal propagation over sea-water

PF and SF are known and considered constant; the receiver uses a model to calculate the delays

The Additional Secondary Factor is the delay caused by signal propagation over land and elevated terrain as opposed to over sea-water, The ASF delay build-up depends on the type of soil, The ASF delay is the total cumulative delay the signal experiences of sections with different ground conductivity, Not taking ASFs into account may result in positioning errors of several kilometers, ASFs are published as a map with an ASF grid for each transmitter. Any variation in PF, SF or ASF due to weather, water vapor, air pressure, seasonal influences is captured in δ.

δ also contains any misalignment of the transmitter timing with respect to UTC, δ is unknown, but can be measured by a reference station at a known and fixed location In differential eLoran, these corrections are broadcast to the users to improve their positioning and UTC time accuracy.

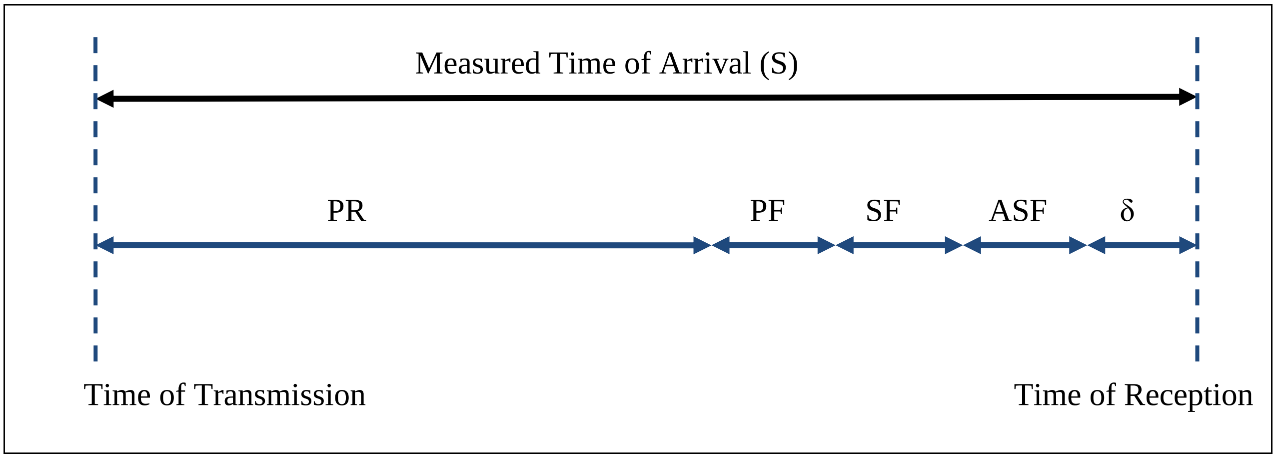


Fig. 2: Components and factors affecting measured time of arrival

Here, the pseudo-ranges (PR) are corrected for PF, SF and ASF. Three unknowns must be found latitude λ longitude φ clock bias B, three pseudo ranges may solve position and clock bias, and four or more pseudo ranges additionally offer integrity and/or improved reliability.

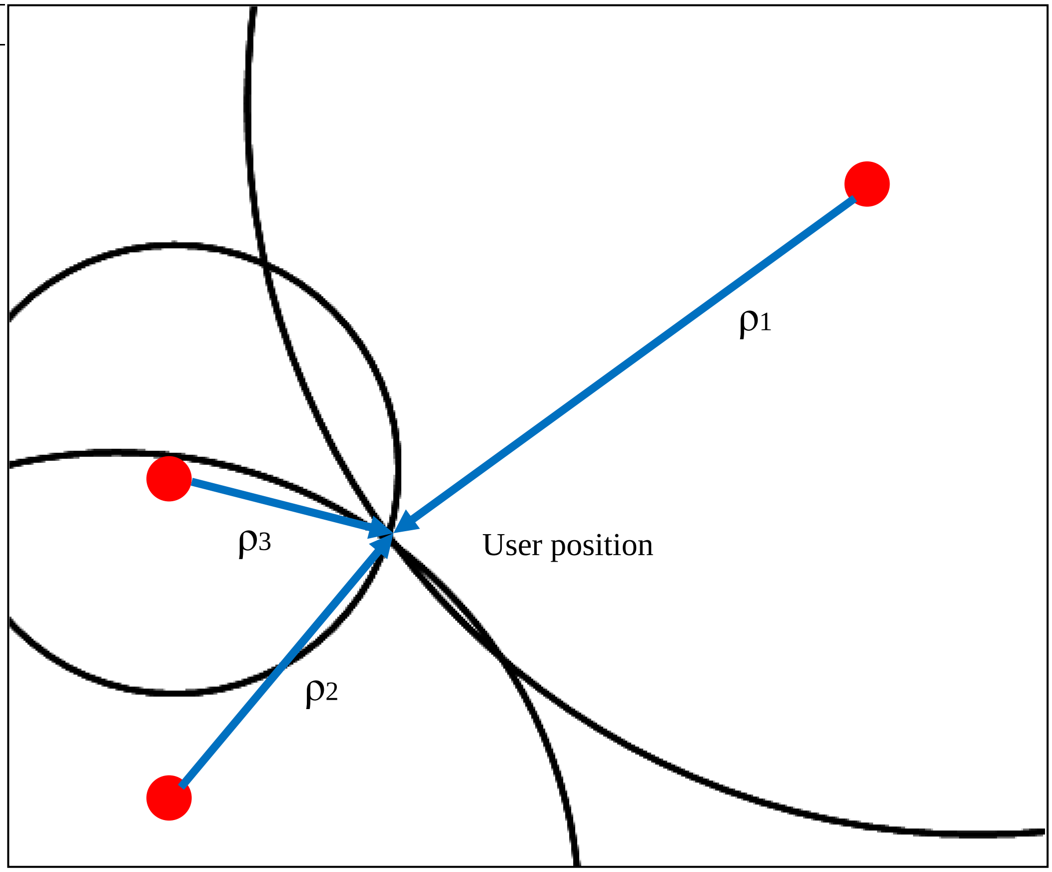


Fig. 3: Calculate user position and clock bias from three pseudo ranges

### 3.2 e-Loran Service Provision

eLoran services are provided by a Core eLoran Service Provider and various Application Service Providers:

- Core eLoran Service Provider

delivering a highly precise version of the core signal originally described in the US Coast Guard Specification of the Transmitted Loran-C Signal; and

- Application Service Providers – (e.g. aviation, maritime)

delivering application-specific data (e.g. differential Loran messages or early skywave warnings) application data is broadcast to the users over the Loran Data Channel (LDC), application data are treated as corrections or integrity warnings and will not influence the delivery of the core eLoran service.

The core eLoran service needs to provide signals with good geometry and signal strength in the maritime coverage area. Signals are synchronized to an identifiable source of UTC for all stations instead of Service Area Monitoring (SAM) timing control.

The Maritime Application service provider publishes an ASF map for the maritime coverage area, providing grid data with nominal propagation corrections per transmitter and the Differential eLoran Reference Station provides real-time corrections on the nominal published

ASFs for each transmitter through the LDC. The maritime user applies the ASFs from the map and differential corrections from the LDC to improve its positioning accuracy to better than 20 m (95%).

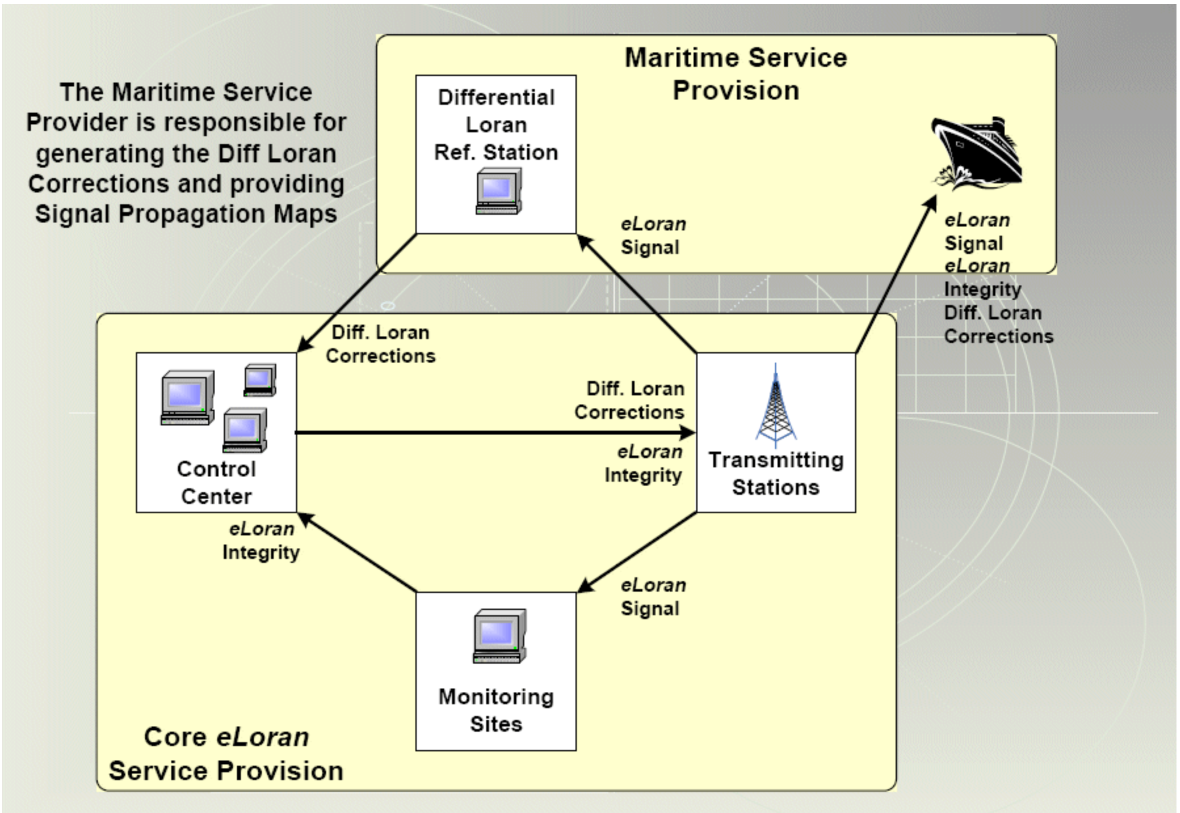


Fig. 4: eLoran maritime service provision [9].

eLoran's enhanced accuracy, availability, integrity and continuity meets the requirements for aviation non-precision instrument approaches, maritime harbour entrance and approach manoeuvres, land-mobile vehicle navigation, and location-based services. It also allows absolute UTC time to be recovered with an accuracy of 50 nanoseconds as well as meeting the standard needed by telecommunications users. The position accuracy as well as meeting maritime harbour entrance and approach, Availability, integrity and continuity to meet aviation non-precision approach.

Table 1: e-Loran Service Provision [9].

| Accuracy | Availability | Integrity | Continuity |
|---|---|---|---|
| 0.004 – 0.01 nautical mile (8 – 20 meters) | 0.999 – 0.9999 | 0.999999 (1 x 10-7) | 0.999 – 0.9999 over 150 seconds |

## 3.3 e-Loran System Performance Requirements

eLoran services will deliver safety, security and economic benefits to a wide range of stakeholders (e.g. governments, service providers) and users (e.g. aviation, maritime):

- allowing aviation communications, navigation and surveillance functions to migrate to digital communications;
- enabling maritime e-Navigation including permanent or temporary virtual AtoNs to be used to mark dangerous waters;
- supporting road user charging providing authentication; and
- maintaining synchronization of wired and wireless telecommunications without the need for expensive external oscillators.

eLoran is an independent, dissimilar complement to GNSS. As such, it will allow PNT users with demanding safety-critical or mission-critical applications to secure their safety, security and economic benefits even when their satellite services are disrupted.

eLoran is capable of meeting the accuracy, availability, integrity, and continuity performance requirements for:

- Aviation non-precision instrument approaches;
- Maritime harbour entrance and approach manoeuvres;
- Land-mobile vehicle navigation;
- Location-based services; and
- Precise time and frequency users.

# 4 CASE STUDIES

## I. GLA Jamming Trials

The General Lighthouse Authorities of the United Kingdam and Ierland (GLA) 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 [2]. The following conclusions have been drawn.

- A 1.5W GPS jammer denies GPS for about 30 Kilometres.
- The precise impact of GPS jamming on a vessel depends on the bridge fit, configuration and level of system integration.
- Hazardously Misleading Information (HMI) - GPS jamming can produce HMI with positioning errors from a few to hundreds of kilometres and velocities of 10kts to 20000kts.
- 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 the 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.

## II. GLA eLoran Trials

The GLAs have been developing initial proof of eLoran concept systems, and testing them in challenging environments. One such type of challenging environment is densely packed island regions.

In response to this challenge the GLAs performed eLoran trials in the Orkney Islands – an archipelago off the northern coast of Scotland. The Orkney Islands lie some 20 km from northeast Scotland in an area of excellent Loran geometry and signal strength from the stations at Ejde, Vaerlandet and Anthorn (Fig. 5).


Fig. 5: eLoran trials in the Orkney Islands and an archipelago off the northern coast of Scotland [2].

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

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, (or Loran ASFs) stored within our receiver.

A temporary differential-Loran Reference Station was installed at Kirkwall – the capital city of the Orkney Islands. Signal propagation maps were derived from the data collected during the performance of the routes. The most technically difficult part of the voyage occurred in the Hoy Sound (see Figure 5); a channel with complex land-sea signal paths. However, the trail still achieved accuracies of 11m (95%) using eLoran. These accuracy levels are typical of those realized in widespread trials over the past four years.

The conclusion so far is that where we have good eLoran transmitter geometry and signal strength, and we have established a maritime eLoran service, complete with propagation correction maps and differential-Loran, there is no reason why eLoran should not provide close to (if not better than) 10m (95%) positioning accuracy [14].

## III. eLoran for Backup in the English Channel

The General Lighthouse Authorities of the UK and Ireland (GLAs) have taken eLoran technology forward from a feasibility demonstration to a prototype system. It has been operating reliably, since May, 2010. It is now serving the East Coast of the United Kingdom, ships in the Port of Dover, its approaches and part of the Dover Strait can now use eLoran radio navigation technology as a backup to GNSS systems like GPS and Galileo. What is considered the world's busiest shipping route is the first to deploy eLoran to counter jammers and space weather, The Dover area, the world's busiest shipping lane, is the first in the world to achieve this initial operational capability (IOC). Although primarily intended as a maritime aid to navigation, eLoran could become a cost-effective backup for a wide range of applications that are becoming increasingly reliant on the position and timing information provided by satellite systems. signals from eLoran transmitters could also provide essential backup to telecommunications, smart grid and high frequency trading systems vulnerable to jamming by natural or deliberate means.

Table 1: Performance delivered by different generations of Loran System [2].

| | **Accuracy (m, 95%)** | **Integrity** | **Availability** |
|---|---|---|---|
| USCG Loran-C | 460 | Low | Low |
| Modernised Loran-C | 100 | Moderate | Moderate |
| Prototype eLoran | 10-20 | High | Moderate |
| eLoran | 10-20 | High | High |

Table 2: Applications supported by different generations of Loran System [2].

| **Supported Application** | **USCG Loran-C** | **Modernised Loran-C** | **Prototype eLoran** | **eLoran** |
|---|---|---|---|---|
| Resilient PNT | | | | √ |
| Maritime: Ocean | | √ | √ | √ |
| Maritime: Coastal & Harbour | | | √ | √ |
| Aviation: Non-Precision Approach | | | | √ |
| Stratum 1 Frequency | √ | √ | √ | √ |
| UTC | | | √ | √ |
| Precise Timing | | | | √ |
| Land Mobile | | | √ | √ |
| Interference Detection & Mitigation | | | √ | √ |

## 5 CONCLUSION

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.

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.

eLoran meets a set of worldwide standards and operates wholly independently of GPS, GLONASS, Galileo, or any future GNSS. Each user's eLoran receiver will be operable in all regions where an eLoran service is provided. eLoran receivers shall work automatically, with minimal user input.

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

At the local level, Egypt has 6 DGPS stations considered as infrastructure for the construction of eLoran system to secure the safety of navigation on the coast of the Mediterranean Sea, the Red Sea, and the Suez Canal to Mitigate the Impact of a GPS Outage on GPS Position, Navigation, and Time Applications.

At the regional level, the countries of the Mediterranean and the Red Sea region, should cooperate to establish eLoran system to ensure the safety of navigation from the Strait of Bab el Mandeb to the Strait of Tiran, and many other applications that require precise location and time in case of GPS outage.

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