
# A Holistic Approach to Trusted, Resilient PNT: GNSS, STL and eLoran

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April 2018

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## INTRODUCTION

Positioning, navigation and timing (PNT) services are indispensable. Ensuring that users always have service when and where needed, and that they can trust that information, is essential to supporting current critical infrastructure and business applications. Without a trusted, reliable, resilient PNT foundation, additional economic growth in almost every sector is impeded.

Providing trusted, resilient PNT solutions requires us to look beyond individual systems and methodologies to focus upon the user. PNT is an invisible utility that users expect and demand to be correct and available without question. An architecture that can meet this demand must, by definition, include multiple systems with diverse technologies so that any single threat or source of disruption is unlikely to leave users without service, or worse, with hazardously misleading information.

Signaling technologies such as eLoran and STL are **complementary**, each with its strengths and weaknesses. Both allow GNSS users to retain the safety, security and economic benefits of GNSS, even when those services are disrupted. Systems that rely upon multiple, secure technologies for backup GPS/GNSS signals will, inevitably, be more robust than those that rely upon a single source.

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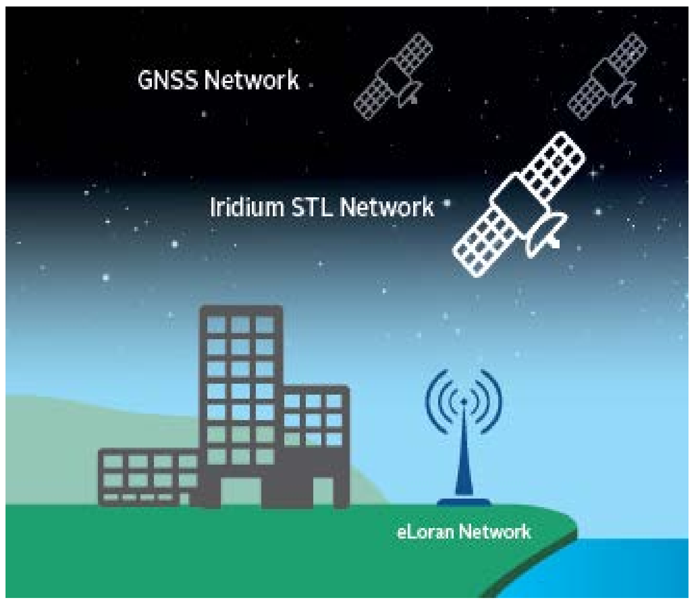
## WHY GO WIRELESS?

Although there is a place for fiber, clocks and inertial systems in a resilient PNT system, wireless provides the most scalable, flexible and economic method for providing PNT. Once in place, it can serve an infinite number of new users of existing applications and, if needed, can generally be modified inexpensively to accommodate new applications.

STL and eLoran are ideal complements for GNSS and for each other. Both STL and eLoran can be used for timing and positioning/navigation. Both are much more difficult to disrupt than GNSS (see table). Because the combination of eLoran and STL provides users signals at low frequency (100 kHz) and ultra-high frequency (1.620 GHz), from both space-based and terrestrial transmitters, and at higher power levels than GNSS, the combined signals are much more difficult to jam or otherwise disrupt. Integrating GNSS, STL, and eLoran into a single user solution provides the most robust and resilient combination of PNT services available.

The encrypted feature of STL and the optional encrypted features available with eLoran mean that users receive authenticated, trusted time and location. When combined with GNSS, users have information from three independent sources to cross compare, and the possibility of dual encrypted authentication, all traceable to UTC.




The addition of eLoran brings a secure, one-way "SMS-like" data capability to the mix, allowing one-way communication to its users. This adds numerous possibilities and benefits for an integrated time or navigation GNSS/STL/eLoran suite.

## WHAT IS STL?

STL is a unique signal transmitted from Iridium satellites using re-purposed high-power paging channels. Iridium's network of 66 cross-linked low-earth orbiting (LEO) satellites connect to the ground stations throughout the world. The signal is available worldwide today and has been demonstrated in hundreds of locations throughout North America and Europe, Japan, Australia, and Hawaii. However, the broadcasts are managed as to which geographical areas of the world will receive the signal. Eventually, the signal will be broadcast everywhere, all the time, but until there are enough baseline subscribers, only areas populated with STL subscribers are "lit up."

## STL Performance

Iridium LEO satellites are much closer to Earth than the GNSS constellation. As a result, STL signals at the Earth's surface are 30dB (or 1000x) stronger than GNSS. This dramatically enhances STL's ability to penetrate structures. For example, a concrete wall will typically "eat" 10dB of link-budget. STL clients will typically be able to receive a good signal in most above-surface structures (exact performance to be validated).

## Spoofing and Jamming

Compared to any other GNSS service, STL is much more resilient to spoofing and jamming. This anti-spoofing capability is derived from cryptography: The PNT data packet is encrypted and can only be decoded by a paying subscriber. In addition, the signal structure is proprietary. It is not an open specification available to all, though this could change over time. The higher level of jamming resistance comes from the higher signal power level, which requires a much more powerful jammer to interfere.

When compared to GNSS, there are negatives as well. The primary one is that location is less accurate (30-50m accuracy compared with ~3m for GNSS). In addition, time is less accurate (200-500 ns compared to 20 ns for GNSS) and the PNT performance degrades faster with moving objects. In addition, and perhaps most important, GNSS is a free service, provided worldwide. STL is a for-fee service, with a recurring annual charge per receiver.

## STL Traceability to UTC

The root time source for the STL network is provided by ground stations around the world (Iridium Teleports). Geographically, these are widely distributed. The system contains 25 redundant GNSS receivers that feed a mix of rubidium and Cesium atomic clocks, which serve as the time base for STL. The system is very resilient to GNSS glitches due to its cross-comparison and redundancy. Currently, atomic clocks will hold over the precise time, maintaining an UTC accuracy better than one microsecond for GNSS system disruptions of up to one day in duration. By the end of 2018, system upgrades are expected that would make the STL service resilient to a system-wide GNSS problem.

The Iridium constellation is undergoing a refresh with new Iridium Next satellites. Fifty (50) new Iridium Next have been launched in groups of 10 by SpaceX since 2016. The success of these SpaceX launches means that the Iridium constellation will likely be fully refreshed by 2019.

## STL Limitations

STL is only available commercially in a selective number of countries for strategic reasons, although technically it is global. In addition, as a relatively new signal, STL receivers are not as readily available as GNSS receivers. Today, they are only available in module level form factors. However, the signal processing requirements for STL are similar, if not simpler, than GNSS, so expectations are that STL reception will eventually become an integrated feature in many low-cost, low power, single chip GNSS receivers.

## WHAT IS ELORAN?

eLoran is the latest in the longstanding series of low-frequency (LF), LOng-RAnge Navigation (LORAN) systems. It meets the accuracy, availability, integrity, and continuity performance requirements for maritime harbor entrance and approach maneuvers, aviation En Route and Non-Precision Approaches, land-mobile vehicle navigation, and location-based services. It is a precise source of time (phase) and frequency. eLoran also provides user bearing (azimuth), even when the user is not moving, and it has built-in integrity. Of equal importance is that the eLoran signal includes one or more Loran Data Channels that are available to provide one-way, low data rate, "Short Message Service" information.

### eLoran Performance

eLoran operates in the internationally protected 90 to 110 kHz spectrum. It is built on internationally standardized Loran-C and provides a high-power PNT service for use by all timing and navigation users. International eLoran standards are expected in 2018.

eLoran uses pulsed signals at a center frequency of 100 kHz. The pulses are designed to allow receivers to distinguish between the groundwave and skywave components in the received composite signal. This way, the eLoran signals can be used over very long ranges without fading or uncertainty in the time-of-arrival (TOA) measurement.

Megawatt transmitters are used for the eLoran signal, compared to the 10-100W transmitters in satellites. The propagation characteristics for the 100 kHz long wave signal from eLoran are very different from the L-band signals from satellites. Signal power is about 62 dB or approximately 100,000 times greater than GNSS.

eLoran delivers information comparable to that GNSS, but with much, much different phenomenology. It is a very high-power, long wave, pulsed transmission, whereas GNSS is low-power, microwave, spread spectrum. eLoran is literally at the other end of the spectrum from GNSS.

Although eLoran is based upon Loran-C, it has key differences:

- All transmissions are synchronized to UTC (like GNSS)
- Time-of-Transmission versus TOA control
- The ability to use differential corrections
- Receivers use "all-in-view" signals
- Includes one or more Loran Data Channels that provide low-rate data messaging for added integrity, differential corrections, and other communications messages.

A modern receiver can detect eLoran, Chayka, or Loran-C signals and use all available, though the benefit of signal synchronization to UTC is only available from an eLoran signal.

Even receiving signals from one transmitter is useful. A single signal provides an authenticated time source for stationary timing users, and a single LOP or azimuth to add to location calculations for positioning and navigation users.

## Spoofing and Jamming

Spoofing and jamming eLoran is exceptionally difficult and is nearly impossible at a distance. Just as equipment required to spoof and jam GNSS must mimic small, relatively low powered GNSS transmitters, spoofing and jamming eLoran requires large, high power transmitters. With megawatt transmitters and 700-foot towers for primary eLoran transmission sites, equipment needs alone to disrupt eLoran over a significant area would be almost prohibitive for any actor other than a nation state engaged in open conflict. This is the reason that an independent assessment by researchers at Stanford University described eLoran as," for all practical purposes, unjammable" across any significant area. A MITRE paper concluded: "The analysis shows a very low probability of successfully producing operationally significant interference."

## eLoran Traceability to UTC

A key requirement for interoperability between PNT solutions is synchronization of their underlying timing reference. In the United States, GPS satellite transmission timing is synchronized to UTC from the U.S. Naval Observatory (i.e., UTC(USNO)). This was also the case for Loran-C. eLoran transmissions are also synchronized to UTC, thereby ensuring optimum usability, integration, and interoperability. Just as each GNSS satellite is independently synchronized to UTC for maximum accuracy, each eLoran transmission is independently synchronized to UTC.

Synchronization is derived from the national time source where the eLoran transmission site is installed. In the United States, it would derive from the Naval Observatory (USNO), like GPS. In other countries, timing might come from a single national time source (e.g., NPL in the UK, BIPM in France or KRISS in Korea) and then be distributed to each of the transmitting sites.

A standardized eLoran transmission site has local and remote time scales that allow it to operate in sync with the national time scale, or in case that source or the link to it fails, to maintain synchronization for exceptionally long periods of time. The transmission site time distribution solution uses the Local Time Scale (LTS) as its core. The LTS consists of an "ensemble" of at least three atomic primary reference sources (PRS). Three PRSs allow for majority voting in the case of an anomaly.

The Remote Time Scale (RTS) collects time from one or more external references selected by the service provider (usually the national time scale). RTS inputs are not directly coupled to the LTS and are monitored and weighted to determine their usefulness as observables to the LTS. Examples of RTS references include GPS, GNSS (e.g., Galileo), Two-Way Satellite Time Transfer (TWSTT), Two-Way Low-Frequency Time Transfer (TWLFTT), direct fiber, microwave, and "hot clock."

An eLoran transmission site with a cesium-based PRS LTS can maintain its local time reference within tens of nanoseconds of UTC for at least 70 days with no access to any RTS. With a higher performing PRS, such as a hydrogen maser or quantum clock, the time between accessing a remote time synchronization signal increases significantly, and the LTS can be held more tightly to UTC, for a longer period, without a reference input.

TWTT is a well-known means of transferring time, typically between a UTC source and Stratum-1 time sources, such as GNSS satellites and Loran transmission sites. However, TWLFTT can also be used to transfer time at the nanosecond level between Loran transmitting sites, and without the need of satellites.

## eLoran Limitations

The timelines for deployment and geographic coverage for eLoran are uncertain. However, recent actions by the US Congress to mandate PNT alternatives to GPS, coupled with growing awareness of the vulnerabilities of GPS/GNSS in general, are setting expectations that eLoran will be re-instituted in the USA. In addition, actions in the UK and other nations indicate they are on a similar course.

After the US and/or the UK begin activation, other countries, such as Canada and European countries are expected to follow suit. Several other countries, such as South Korea, Saudi Arabia, China, and Russia, support their Loran systems and are considering upgrades.

eLoran will probably be deployed first for timing applications, then for positioning. Because only a single station is required to determine timing, many users can benefit immediately while additional transmitting sites are established.

When eLoran is used as a sole-source for positioning, a minimum of three eLoran transmission sites are needed to calculate a 2D PNT solution. 2D solutions are sufficient for many users, including many aviation users and a vertical component can be added with a simple barometric altimeter.

Interference is a potential problem for all RF signals. eLoran signals may face interference issues from other LF radio sources near the receiver. Power lines, older style fluorescent lighting, motors, and switching power supplies can be a problem. Most navigation users and timing applications are rarely affected. Land-mobile and handheld applications are the most likely to encounter these temporary noise sources.

## SIGNAL COMPARISON

| Resilient PNT – A Holistic Approach | | | | |
|---|---|---|---|---|
| | **GNSS** | **STL** | **eLoran*** | **Differential eLoran*** |
| **Timing accuracy to UTC** | ~ 20 ns | ~ 200 ns | ~ 300 ns | ~ 30 ns |
| **Positioning Accuracy** | ~ 3 meters | 30-50 meters | 50 meters | < 10 meters |
| **Commercial Availability** | Today | Today | Future | Future |
| **Time to First Fix** | ~ 100 seconds | *Timing:* few seconds *Position*: few secs to within 500 km; ~10 minutes to converge | < 20 seconds | < 20 seconds |
| **Fast Moving Platforms** | Yes | With IMU integration | Yes | Yes |
| **Anti-Spoof** | GNSS: military only<br>Galileo: PRS - future | Yes. Authenticated signal, encryption available. | Yes. Authenticated signal, encryption available. | Yes. Authenticated signal, encryption available. |
| **Anti-Jam** | Weak signal – easily jammed | Yes. 30-40 dB stronger | Yes.** ~ 62 dB stronger | Yes.** ~ 62 dB stronger |
| **Coverage** | Global<br>Precision degrades at poles<br>GLONASS – better at high Lat | Global<br>Coverage increases at poles | Continental (1200 km radius from transmitter) + coastal waters (1800 km radius from transmitter) | Timing, terrestrial positioning: ~ 30 km radius around differential site. Aviation positioning: ~ 165 km. |
| **Indoor** | With supplementation | Yes | Yes | Yes |
| **Underground** | No | No | Yes ~ 30 m | Yes ~ 30 m |
| **Underwater** | No | No | Yes. Depth typically ~ 20 m | Yes. Depth typically ~ 20 m |
| **Embedded Data/Comms Channel** | No | Yes, low rate<br>Higher rate satcom possible via same antenna | Yes, low rate | Yes, low rate |
| **Sovereign** | Three nations & EU only | Subscriber/provider partnership | Subscriber/provider partnership | Subscriber/provider partnership |

*eLoran demonstrated by General Lighthouse Authority of the UK and Ireland, and by US DHS Wireless Precise Time CRADA 2012 – 2018. Loran-C is currently in use in Russia, China, S. Korea, Saudi Arabia, and Iran. A single eLoran signal (usable for time and one LOP) is currently operating in the UK.

**At 1,000 km from medium power eLoran transmitter.

## CONCLUSION

It is hard to imagine any business being able to function at a fraction of its current level without the continuous wireless PNT services they have come to rely upon. The governments of the United States and United Kingdom have shown that PNT is essential for critical infrastructure, national security, and economic wellbeing. The European Union has called for complementary and backup systems for traditional GNSS.

Yet no PNT system, including GNSS, is perfect. Nor can one system provide the trust, resilience, performance, and security that individuals, businesses, and national critical infrastructure demand. Putting the user first requires a more holistic approach - a resilient architecture that can always be trusted to deliver accurate information. The pillars of that architecture are GNSS in medium Earth orbit, STL in low Earth orbit, and eLoran with its feet planted firmly on the ground. This trusted, resilient suite will be more than sufficient for the great majority of users, but can easily be supplemented if needed by other sensors.

A comprehensive, holistic approach to trusted, resilient PNT is the only way to ensure that modern economies can be sure to keep the lights on and their business and populations thriving.

## CONTRIBUTORS

**John Fischer -** Vice President of Research & Development for Orolia, John has worked with global navigation satellite systems (GNSS), wireless, positioning navigation and timing (PNT) and specialized systems for more than 15 years.

Prior to joining Spectracom, he specialized in wireless telecom as a founding member of two startups: Aria Wireless in 1990 and Clearwire Technologies in 1997. At Clearwire, he served as Chief Technology Officer, creating wireless broadband equipment for Internet connectivity.

Early in his career, John worked as a systems engineer in radar, EW and command and control systems. He graduated with a master's degree and bachelor's degree in electrical engineering and computing engineering from the State University of New York at Buffalo.

**Dr. Michael O'Connor --** CEO of Satelles. Dr. O'Connor is a recognized pioneer in the booming field of precision agriculture. As a graduate student at Stanford University, Michael led the team that invented the world's first farm tractor steering control system using GPS. Upon graduation, Dr. O'Connor co-founded IntegriNautics (now Novariant, Inc), where he established the AutoFarm business and brought the first products based on this technology to market. This work formed the basis for what is now a $1B+ global market.

In recognition of his visionary work, Michael has been honored by Technology Review Magazine as one of the world's Top Young Innovators and was included in *GPS World Magazine*'s inaugural list of 50 Faces to Watch in GPS. Dr. O'Connor has also been inducted into the Space Technology Hall of Fame.

Michael received his bachelor's degree in avionics from M.I.T., and his master's and Ph.D. in aeronautics and astronautics from Stanford University.

**Charles "Chuck" Schue –** Founder, President, and CEO of Ursa Navigation Solutions, Inc. (UrsaNav), Chuck is a recognized expert in positioning, navigation, and timing systems. His contributions have led to major critical infrastructure and safety-of-life system improvements in the United States and abroad. Chuck is also a founder/owner of three other advanced engineering firms, with products as diverse as in-space electric propulsion and pre-shot sniper detection.

Chuck holds three master's degrees and is a senior member of the American Society for Quality and the Institute for Electrical and Electronics Engineers. He is active in the Institute of Navigation, a fellow of the Royal Institute of Navigation, a founding member of RTCM Special Committees 127 and 131, and SAE Systems Management Council Committee on PNT.

## ABOUT OROLIA

Orolia is a world leader in Resilient Positioning, Navigation and Timing (PNT) solutions that improve the reliability, performance and safety of critical, remote or high-risk operations. With expertise in government, maritime, aviation and enterprise applications, Orolia provides virtually fail-safe GPS/GNSS and PNT products and solutions for their customers' most mission critical needs. Orolia's US headquarters is in Maryland, with commercial presence in more than 100 countries worldwide. www.orolia.com

## ABOUT SATELLES

Satelles provides unique timing and location solutions delivered over the Iridium® constellation of 66 low-earth-orbiting satellites. These timing and location signals are available today, anywhere on Earth, without the need for local infrastructure. Unlike standard GPS, these high power signals can reach into many building structures. In addition, the signal-in-space provides a location-specific signature that can reliably prove (or authenticate) the time and location of a user, while being virtually impervious to spoofing and other attacks. www.satelles.com

## ABOUT URSANAV

UrsaNav is the global leader in Low-Frequency (LF) position, navigation, and timing (products and solutions such as Loran-C, Enhanced Loran, Chayka, eChayka, and LFPhoenix.™ UrsaNav's "sky-free" PNT technology is fully interoperable with, yet completely independent of, GPS/GNSS. UrsaNav is committed to improving the operational capabilities of its clients and providing exceptional value to the worldwide users of its technology. We strive every day to make the world a safer and more prosperous place. www.ursanav.com