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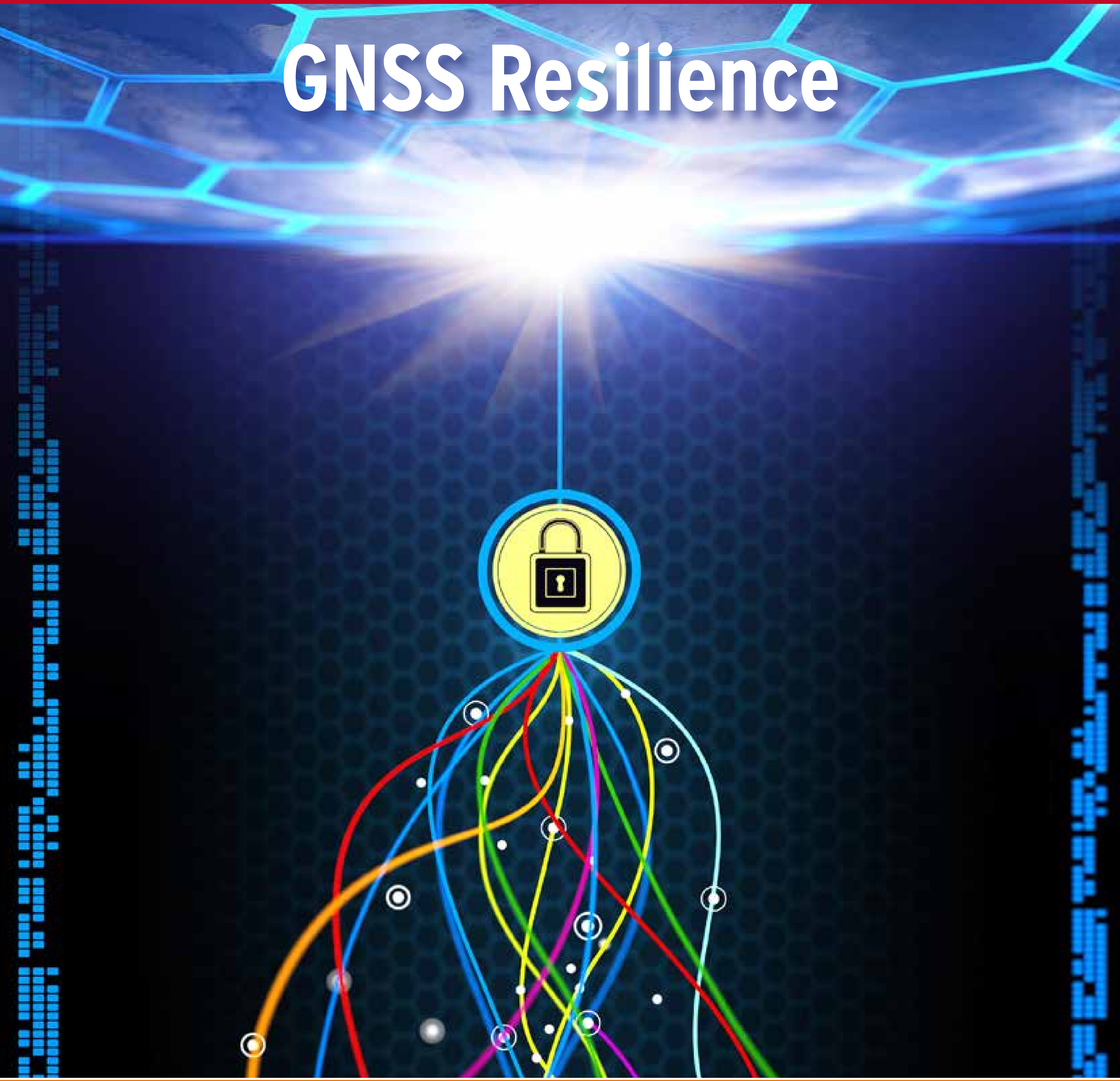
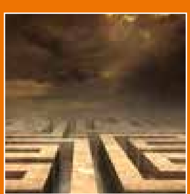


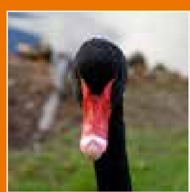


The Navigation of Navigation

How we got to where we are with GNSS

Resilience Has A Name

Its name is eLoran



The Black Swan and the SENTINEL

Mitigating against the unexpected

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Resilience Has a Name

By Charles Schue FRIN

Today, Global Navigation Satellite Systems (GNSS)*, such as the systems GPS and GONASS, are seen to provide carefree position, navigation, and timing (PNT). GNSS has yielded tremendous benefits in safety, security, and productivity. Less recognized is what happens when GNSS is not there. In a world of intentional and unintentional interference, jamming, spoofing, and faking, which component of our nation's GNSS-dependent critical infrastructure are we willing to live without: electricity, telecommunications, or navigation?

The Problem: Vulnerabilities

On Friday, April 24, 2009, a seemingly innocuous navigation problem created tense moments in Washington, DC. The White House and Capitol Hill were evacuated when a small airplane strayed into restricted airspace because the pilot's GPS stopped working. The posture of US Government agencies is that 'if GPS fails, there are other systems that back it up' Where were those back-up systems when two fighter jets and two United States Coast Guard helicopters were dispatched to intercept the aircraft? The aircraft did not have an alternative navigation receiver on board. In the US, this is likely because of inconsistent policies on Loran and enhanced Loran (eLoran) that have deterred industry from developing, and pilots from investing in, the only technology that is independent, complementary, interoperable, multi-modal, and has diverse failure modes from GPS. eLoran is the only co-primary solution available to GPS.

The reality is that GPS is ingrained in our lives like time, electricity, and water. It touches our lives every day in ways we might not even realize. An interruption to GPS service could have a significant negative impact on a nation's economy and, possibly, the safety of its citizens. The list of vulnerabilities for GNSS includes signal anomalies and failures, signal blockage, spectrum competition, and intentional and unintentional interference. There is an escalating quantity and sophistication to jamming, spoofing, and now faking technology. Economic constraints also impact the availability of GNSS: escalating satellite system costs, program funding delays, and satellite launch problems. In the US, we categorize public sectors of the Critical Infrastructure / Key Resources that may be compromised by these, and other, vulnerabilities into 16 areas. A common theme across 15 of these 16 categories is a dependence on precise timing.

The Need: Resilience

When faint, far-away GPS signals can't be received, people start to feel the impact immediately. Usually these outages have minimal impact because they are localized and short-lived. Often they occur because the user is temporarily in an area without a good view of the sky. More and more often, though, they are because of the presence of one of a growing number of people with jamming devices (aka 'Personal Privacy Devices'), many of which also block mobile phone frequencies. Inexpensive, easy to obtain, and illegal in many nations, use of jammers is nevertheless increasing as people become more concerned about privacy and being tracked by their employer, spouse, government intelligence agencies, and others.

Resilient PNT is achieved through co-primary Soluttions

If a navigation satellite outage became widespread and lasted more than a few hours, most authorities agree that the impacts would quickly become catastrophic. Transportation would immediately become much less efficient and more dangerous (even many city traffic lights are coordinated using satellite timing). Telecommunications, financial, electrical delivery and other sectors would also soon begin to fail as their back-up timing systems lost synchronization with each other. Power grids would lose synchronization, and outages might occur as transmission points became overloaded. More than speculation, these problems have been well documented in academic papers, and proven in government tests in the US and UK. Most dramatic were the impacts of North Korea's multiple rounds of intentional jamming of South Korea.

Even more insidious is the problem of spoofing. The world's pre-eminent spoofer of satellite navigation receivers, Professor Todd Humphreys of the University of Texas at Austin, has demonstrated how easy it is to take control of unmanned aircraft and autopilots by sending just a slightly stronger navigation signal, making the receiver think it is somewhere other than where it really is. He has postulated if time stamps on automated financial transactions could be altered through spoofing one could reverse the buy-sell equation at a stock exchange, allowing someone to sell at a higher price before buying at a lower one.

So, what does it take to get a jammer? Not much. Although they may be illegal to purchase, own, or operate (depending on national laws), they are easily ordered off the internet. Anyone with a degree in engineering, or even a technical bent, can find the plans and parts to build one. And they need not be certified – no IEC testing performed. In fact, poor designs end up jamming more than just GNSS.

Perhaps of greatest concern is that so many users unquestioningly rely on satellite navigation and timing signals. Ships have run aground, aircraft have overshot their landing sites, and drivers have been led astray. The high availability and accuracy of GNSS lures many users into complacency where they are unable to detect spoofing, jamming, or a malfunction before it results in an accident.

One valuable feature of pairing GNSS with a second, independent signal is that it can alert users when something might be wrong, concept put forth by GPS security expert Logan Scott and referred to as 'proof of position' or 'proof of time'.

Some navigation and timing users have resorted to a variety of methods, such as sophisticated clocks and local systems, to tide them over during interference events and other outages. Telecommunications companies, for example, typically place multiple, expensive primary reference clocks, such as cesium reference standards, in their cell systems for just such eventualities. But even the best backup clocks lose synchronization with each other, and older forms of navigation can't meet the needs of modern transportation systems. And that's for users who have made provisions and trained for outages. Many have no plans or capability at all.

Resilience provides a measure of safety and security that stops the domino effect from spreading. GNSS resilience has a name, and it is eLoran.

The Solution: Co-Primary GNSS and eLoran

If not for the overwhelming success of GNSS, there would be little discussion of vulnerabilities. No system is perfect, and even if it were, the manner and environment in which that system operates and is used is not controllable. What we can do is recognize that resilience helps overcome vulnerabilities.

Since GPS reached Full Operational Capability in 1995, and after the 1996 Presidential Commission on Critical Infrastructure expressed concern on the over-reliance on GPS sole means, varying solutions have been proposed as alternatives. Over the past 19 years, no one system has been identified that can fully replace GPS's considerable capabilities. GPS's only truly equivalent solutions are other global satellite systems, such as Russia's GLONASS. The Chinese Navigation Satellite System (CNSS) and Europe's Galileo will also be equivalent once they become fully operational, around 2020. However, all GNSS have similar failure modes resulting from shared spectrum and extremely low power signals.

Where GNSS is available and trusted, it will almost always be the first choice for PNT. In areas where it is not available, or when it cannot be trusted, then government, academic, and industry reports and studies unanimously agree that eLoran is the most cost effective, wide-area alternative. eLoran is a co-primary PNT solution to GNSS. It is not a holdover solution, like inertial sensors or oscillators. eLoran is not a backup. It is a complementary, independent, and interoperable alternative that works along-side GNSS and provides the fail-safe resilience that our critical infrastructures demand. eLoran is not an augmentation like WAAS, LAAS, EGNOS, or MTSAT. A failure of GNSS does not cause loss of eLoran functionality, and vice versa. However, eLoran is an augmentation when used in the context of Dr Brad Parkinson's Protect, Toughen, and Augment (aka 'PTA') program.

eLoran: The Basics

The eLoran system is often confused with its predecessor, Loran-C, considered by some to be obsolete World War II technology, just like radar and sonar. Essentially, eLoran is Loran-C on vitamin supplements. It is built on all the good things learned from operating Loran-C around the world for over 60 years, both for military and commercial purposes. eLoran provides a high level of PNT service over a wide area, and an even more precise level of service within range of a Differential eLoran Reference Site, a concept similar to Satellite Based Augmentation Systems, or Ground Based Augmentation Systems like DGPS or EGNOS. Modern eLoran receivers use any and all transmitting sites in view (because they are all synchronized to UTC), and can combine terrestrial transmissions with satellite transmissions in an integrated solution. Finally, eLoran is more digital than analog, with a built in data channel that provides real-time update messages to receivers that include UTC synchronization, and corrections for propagation effects. The US alone spent over $160 m to research, develop, and test the technology and concepts that evolved Loran-C to eLoran. Millions more have and are being invested by other nations and private industry.

Images courtesy of ctstechnologys.com

eLoran transmit site technology is 21st century and exists today. All of the equipment is modular, fully-redundant, hot-swappable, software configurable, and requires almost no maintenance. Everything is smaller, lighter, requires less input power, and generates significantly less waste heat. Similar advances apply to Differential eLoran Reference Site and Control and Monitor Site technologies. It is affordable to acquire and to operate.

eLoran user equipment is available today. Receivers, and associated E- and H-field antenna technology is constantly evolving. Modern eLoran receivers are really software defined radios and are backward compatible with Loran-C and forward compatible through firmware or software changes. As more eLoran services come on line, the technology will improve at a more rapid rate and Size, Weight, Power, and Cost will decrease. eLoran receivers can be stand-alone, or integrated with GNSS, Inertial Navigation Systems, Gyros, Chip-Scale Atomic Clocks, Signals of Opportunity, etc. Capabilities are only limited by the user's imagination.

The Tipping Point: Time and Frequency

Under the auspices of a Cooperative Research and Development Agreement with the US Government – to look at wide-area wireless time and frequency transmission - UrsaNav started several projects to demonstrate the capability of eLoran alongside GPS.

GPS is used in both synchrophasors and frequency disturbance recorders, key to maintaining the efficiency and reliability of the grid. Working with the University of Tennessee and the SmartGrid community, UrsaNav setup in its Bedford, MA, facility 311 miles NE of the transmitting site in Wildwood, NJ, a test bed. It included an atomic time scale, time interval counters and two Frequency Data Recorders, one with GPS, and the other modified with an eLoran receiver replacing its internal GPS receiver. No other changes to the Frequency Data Recorders were made.

Using only 'raw' eLoran, that is with neither differential corrections nor continuous receiver antenna calibration, frequency and phase angle comparisons were measured. The eLoran performed on par with the GPS. In fact, when the testing started, an urgent email arrived from the university laboratory: 'That is great. Now we can see the data from the two Frequency Data Recorders, units 905 and 913. Could you tell me which unit is using eLoran now?'

Having proximity to, and several transmitter options at, Wildwood, NJ has allowed for extensive timing tests. Currently there are installed receivers in Washington, DC, at our Leesburg, VA office due west of DC, and our Bedford office in Massachusetts. Additionally, there is a two way satellite time transfer system (TWSTT) between the US Naval Observatory (USNO) in Washington, DC and the Loran transmitting site at Wildwood. The variation between an UrsaNav UN-152B eLoran timing receiver, installed at the USNO, and the Master Clock measured over a two week period had a standard deviation of 29 ns at a distance from Wildwood, NJ of 118 miles. During the same period, a timing receiver at Leesburg, VA versus a 5071A cesium yielded a standard deviation of 36 ns at a distance of 143 miles. The data showed high correlation between phase differences at Leesburg and at the USNO. It is clear that differential corrections would have a significant positive effect in accuracy improvement over distances such as that between the Leesburg and the USNO, in this case 25 miles.

On the other side of the Atlantic, where eLoran signals are on-air continuously, UrsaNav set up a similar timing test from our office near Bertem, Belgium. Time is provided at a closest distance of almost 500 km from the transmitting site at Lessay, France with a standard deviation of 14 ns. A local Differential eLoran Reference Site, say located in Antwerp, would further improve the Positioning and Timing precision for at least 30 miles in all directions, which would include Brussels and Bertem. Furthermore, a plot of the Maximum Time Interval Error (a measurement of wander, or time stability) shows that an eLoran timing receiver performs as well as, or better, than a GPS gold standard timing receiver that is used by the telecommunications industry.

While there is a critical need today for alternate timing sources, as new advanced mobile networks roll out, the need for resilient and robust synchronization will only increase.

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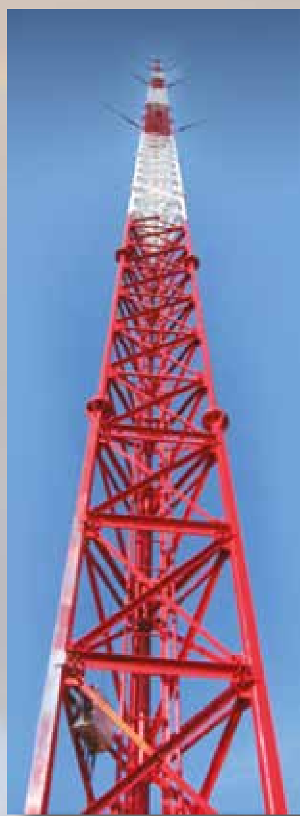

From transmission to reception, the technology exists today and is constantly evolving.

Covering Our World With eLoran

Eleven nations continue to operate Loran-C, Chayka (Russian equivalent of Loran-C), or eLoran, and/or have established programs to migrate to eLoran. Several countries are leading the way in developing or implementing eLoran capabilities to provide the resiliency necessary to protect their critical infrastructures. In the UK, for example, eLoran will also provide the ability to meet eNavigation requirements, while simultaneously generating cost savings for mariners. Where leadership in this field once rested in the US, it is now agencies such as the General Lighthouse Authorities (GLA) of the United Kingdom and Ireland that are in the forefront.

New Differential eLoran Reference Site equipment for the GLAs.

Another country that has selected eLoran to improve resiliency nation-wide is the Republic of Korea, who is in the process of implementing an independent, sovereign eLoran capability, while continuing to operate in collaboration with their neighbors. The Kingdom of Saudi Arabia is pursuing a strategy of upgrading their existing Loran-C transmitting sites to eLoran, and possibly adding one or more new sites. India has budgeted for, and is considering, several options for implementing an eLoran solution. In their initial assessment, the emphasis was on maritime positioning, and data and time over the subcontinent. India previously operated six low-power Loran-C stations in two systems. Russia has signaled that it is upgrading its Loran-C equivalent, known as Chayka, to a modern version called Skorpion. It appears Iran also sees the value of resiliency, and sovereign independence of GNSS, with their newly proposed Land-Based Positioning System.

A Way Forward in the United States?

Ever since the US terminated its Loran-C program in 2010, which included its nascent eLoran program, there have been efforts to resurrect it. Most recently a proposal for a Public-Private-Partnership was put forth by UrsaNav. Although no formal decisions have been made, there is considerable interest within the legislative and executive branches of the government. Additionally, there is a lot of buzz from industry, both from potential market segments, such as telecommunications, first responders, finance, and electrical providers, and from receiver manufacturers. The premise is to use existing assets to begin rebuilding a Continental United States (CONUS) eLoran PNT capability, with the initial focus on the provision of wide-area timing and frequency.

An initial configuration must include at least four transmitting sites. With each additional site, timing and frequency service would improve from single to double, triple, or even quadruple coverage. eLoran adds resiliency to the CONUS critical infrastructure, a requirement that the US President has imposed on the Departments of Transportation and Homeland Security. Outside of CONUS, the US Department of Defense is on record as encouraging the development of overseas eLoran capability.

The end goal is to resurrect the entire 19-station CONUS constellation of transmitting sites, which would provide an extremely robust timing and frequency coverage. A similarly robust positioning service would also result from the 19-station constellation.

The US started the race towards eLoran, and then fell off the horse. In doing so, they abdicated their leadership role in global terrestrial PNT. They need to get back on the horse, and get back in the race.

A Final Thought

The 'low number of users of Loran' is an insufficient argument for not moving to eLoran as a co-primary solution to GNSS, and as a component of a robust, sovereign, multi-level resilient PNT solution. How do we estimate the number of users of critical infrastructure in any nation? I suspect they are a significant majority of the overall population. Once administrations promulgate stable policy, commit to funding, and commit to performance, industry will step up to provide the latest technology and users will benefit.

GPS is ingrained in our lives like time, electricity, and water. Without it, there could be chaos in many sectors simultaneously. Filling gaps in GPS service for the public and private sectors using eLoran is a necessary component of our ability to always be prepared. Where GNSS is not enough, eLoran as a co-primary solution will provide the resilience required for todays interconnected systems.

eLoran is not an insurance policy, although its cost is so small compared to any portion of a GNSS. We should be providing assurance of PNT, not insurance for PNT, so that we can rely on PNT to be available, accurate, reliable, and trustworthy.

About the Author

Charles 'Chuck' Schue is co-founder and President of UrsaNav, Inc., an advanced engineering and IT firm with principal offices in the United States and Belgium. UrsaNav provides products and services to customers in almost every state, including Alaska, Hawaii, and insular areas of Puerto Rico and Guam, and in over 32 countries worldwide. Low Frequency solutions, including eLoran, constitute one of four core businesses at UrsaNav.

You can read more about Chuck and UrsaNav at www.ursanav.com or www.ursanav.eu.

*Note: * GNSS and GPS are used interchangeably in this article. As of the time of this writing, only GPS and GLONASS are fully operational.*

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