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5/22/2015

Docket Number DOT-OST-2015-0053
Complementary Positioning, Navigation, and Timing Capability;
Notice; Request for Public Comment

Locata Corporation Response to US DoT's Request for Public Comments on 'Complementary PNT Capabilities'

Locata Corporation (Locata)

Locata Corporation is a private company that has developed innovative new terrestrial GPS-like positioning technology. It provides a world-first capability by replicating all the functions of the GPS constellation, but in a specified "local" area. Locata produces this "local equivalent" of GPS signals *without* requiring satellites, atomic clocks, external aiding such as differential correction, or the complex ground segment infrastructure required for GPS (or eLoran, for that matter). The information available at a Locata receiver is functionally and technically the same as that supplied by a GPS receiver. Locata measurements are therefore fully complementary to the measurements derived from the satellite-based GPS system, so Locata can be thought of a "a Local Constellation" as opposed to "a Space-based Constellation". Although Locata is considered to be a very new emerging player in the Alternate Positioning, Navigation and Timing (APNT) space, our technology has already been taken up, and is being integrated, into products used by the crème-de-la-crème of the industry - including exemplary military reference users like the USAF, respected commercial manufacturers like Leica Geosystems, and many others.

Only a year after full commercial launch Locata is already delivering unprecedented capabilities for diverse applications in open-cut mining, machine automation, UAV's, autonomous cars, high-accuracy time distribution, robotics, port automation and more. Locata will also soon be releasing commercial product that delivers survey-grade positioning indoors, enabling GPS-like positioning for warehouse automation, etc. Because Locata is ground-based, it has a level of control, availability and signal power that is simply not possible from satellite-based systems. Locata's partners have validated the technology beyond question, with a user like the USAF installing permanent Locata networks over thousands of square miles of the White Sands Missile Range. At White Sands the USAF are completely jamming GPS and continuing to position their aircraft, *to the cm-level over that large area*, using Locata as the core component of their new Ultra High-Accuracy Reference System (UHARS). There are many industry magazine articles and white papers by respected companies that the DoT can refer to if they wish to learn more about Locata's new technology – two significant and informative recent articles are available from the links below[1, 2]. The USAF article at (1) is especially relevant to any discussion about complimentary PNT capabilities in GPS-denied environments.

1: http://bit.ly/1HnO5i1
2: http://bit.ly/1FtSLEX

Why Locata is submitting a response to the US DoT's Request for Public Comments

As a new entrant in this technology space, Locata clearly has a stake in any discussion about "backup to PNT" and is nowadays often mentioned in articles and conferences about this requirement. However, because Locata and eLoran technologies can both be described as "ground-based radiopositioning systems" many uninformed readers assume that *(a)* the technologies *compete* against each other in a commercial sense, and (b) that they fundamentally work in the same way. Neither of these statements is correct, however, so Locata wishes to go "on the public record" to briefly outline what we see as some of the benefits, challenges and major differences that characterize each system. We believe that, whilst the two technologies have small overlapping functionalities described below, Locata and eLoran are in fact two entirely different systems serving very different needs.

Most importantly - we wish to make it clear from the outset that ***we support the concept of eLoran being maintained as one of a range of GPS backup technologies***. eLoran is, in our assessment, the most appropriate technology available today to possibly supply *very long-range <u>coarse</u> solutions for traditional maritime and aviation uses*. In that respect, it is a useful fallback when or if GPS suffers an outage affecting these traditional applications. These transport sectors are very valuable to the nation and should have this fallback capability available to them, as part of the "public good" responsibilities of Government, when or if GPS is disrupted.

However, the contentious debate now raging about maintaining or extending the eLoran system *proves* there are many in the community that question the value of eLoran. Their concerns cannot be dismissed out-of-hand. We believe any reasonable observer of this debate must acknowledge that eLoran's critics are not simply being unreasonable or bloody-minded, and that they have raised valid concerns which must be recognized. Even Locata, whilst openly supporting the maintenance of eLoran, harbors concerns about eLoran's long-term viability for modern applications which require <u>much</u> better positioning accuracy than that which may be adequate in support of long-range maritime or aviation users. Critically, many of the claims made today about eLoran's capabilities <u>on land, in cities and indoors</u> concern us deeply because they clearly lack real-world proof and, in our view, truly independent technical validation. The old adage "there's many a slip between the cup and the lip" is very appropriate here - we often caution eLoran supporters during discussions to tone down their claims lest they turn around and bite them very badly in the future. Therefore, in the hope of advancing rational and clear-eyed discussion about eLoran within DoT and other Government agencies, we offer the following notes for consideration and contrast.

eLoran – the good and the bad

eLoran is best suited for very long range positioning and timing for marine and aviation uses, delivering what we (and many others in the GPS community) consider to be *very low accuracy (10's of meters) positioning* for those traditional transportation users. Alternatively, Locata is proven to provide extremely high-accuracy, *cm-level positioning suitable for **any** application*, but over smaller areas (e.g. a few hundred square miles around an airport or military facility, or within a harbor or port area). Both systems feature similar very high signal strengths (compared to GPS) over the areas they cover, hence both can be made very resistant to traditional GPS-style jamming. eLoran has been modernized now from its original Loran C roots to employ trilateration solutions from their synchronized transmitters, hence it now functions in a manner similar to both GPS technology (and to Locata).

It should be clear from the above paragraphs that eLoran has valuable complimentary uses to support GPS.

Nevertheless…. and this hesitation is for many the crux of their uncertainty about enthusiastically supporting eLoran… many in the industry believe that eLoran is not adequate – and probably never can be – as a backup for the requirements of most users today, and certainly not for most next-gen uses for personal and automation applications relying on GPS. This inherent lack of capability for most modern applications raises genuine concerns that we may all be collectively taking a backward step in this technology space. That's why we see many very committed and intelligent government officials and industry experts feeling torn about making this decision. That's why we are at this juncture today calling for public comments – trying again to assess if eLoran is worth advancing, despite a clear acknowledgement that is of use to a limited number of end users.

We believe that, in the end and on the balance of probabilities, a decision must of necessity be made to keep eLoran going. However, it will probably be a decision that is made grudgingly. It will be a pragmatic one based on a reality that "*we have little choice if the problem is one of providing at least some level of coarse functionality for marine and aviation users"*. It will not be a decision that "improves or extends GPS" to provide performance for modern automation, LBS and personal applications when GPS has problems.

Some specifics for industry and DoT deliberation

eLoran is acknowledged as well-suited to deliver backup PNT to maritime and aviation users during an extended GPS outage. However, any realistic assessment today will prove this demographic only represents *the vast minority* of the total PNT user population. Most PNT users are, in fact, on land. Many of them already require sub-meter accuracy, and, with growing requirements as diverse as indoor navigation or positioning robotic vehicles in industrial environments, many more high-accuracy uses are bound to follow. Simply put, eLoran cannot support this broad terrestrial user group. Hence eLoran cannot receive universal support from the industry. There's a nagging feeling that eLoran will let down many modern and emerging users (autonomous vehicles, robotics, machine control, mobile phone users, etc.) when or if the crunch comes.

Part of the problem arises because supporters of the technology are now often making public claims which are very difficult for an unbiased observer to support. They include:

- Regular statements to the effect (often repeated as mantra by the press) "that eLoran works underground, underwater and inside buildings" [http://www.insidegnss.com/node/4431] There are many reasons, which need not be gone into in depth here, why these claims should be taken with a huge grain of salt. We refer the DoT to the recent moves by South Korea to pull back from deploying an eLoran system on land until it could be demonstrated that the proposed deployment (including a very large number of terrestrial differential correction stations scattered across the country) could provide at least the 20 metre accuracy they expected [highlighted on page 13 of South Korean eLoran update document, attached as Appendix A]. We also refer the DoT to the excellent paper by **Dr. Wouter Pelgrum of Ohio University**, who delivered an excellent and balanced presentation at the recent 2015 Munich Satellite Navigation Summit that reiterated these eLoran limitations [Appendix B].

- Although eLoran high powered signals are more difficult to jam than GPS because of the extremely low frequencies involved (and hence its very long wavelength), they are still extremely sensitive to local electrical interference (the harmonics of electrical cables have been reported to badly interfere with eLoran's 100 kHz signals). The susceptibility of eLoran to local interference seems to be dependent upon receiver design; hard-limiting receivers tend to be more resistant to interference than linear receivers. However, the hard-limiting receiver also tends to be less accurate and slower to acquire desired signals, so there are considerable technical trade-offs which affect eLoran performance in built-up areas. Fortunately, in the environments for which eLoran is best-suited (maritime and aviation), there is less electrical interference present than say inside a building (unless the vehicle is generating its own interference, in which case it can be actively managed). So again, land-based personal and automation users will be less fortunate and subject to highly variable levels of local interference, further compromising the already degraded 10's of meters performance they may expect from eLoran.
- The number of correction stations required to deliver high accuracies across land areas is extremely high. The diagram below is taken directly from the South Korean eLoran document previously referenced as Appendix A.

Number of "differential eLoran stations" proposed by South Korea attempting to provide "20 m accuracy" (Page 9, Appendix A)

It should be obvious that if this density of ASF (differential correction) stations was to be projected onto a map of the USA to provide merely a 20-metre accuracy, then the costs and maintenance involved to deliver just this basic capability will become astronomical. This certainly flies in the face of the statements we often hear (from proponents *and* the press) "*that eLoran is cheap to deploy and run*". This statement is credible when discussing the coarse positioning which can be delivered to maritime and aviation users in a non-land-based applications. However it is not believable when discussing delivery of high-accuracy positioning which is actually required by the vast majority of users of GPS and PNT. Very careful consideration needs to be given to the real long term costs if the DoT expects anyone other than maritime and aviation users is to be serviced by eLoran.

- Finally, there is the serious but often avoided question of security of the transmitters. One of the real beauties of the GPS constellation satellites is that they are very difficult – if not almost impossible – to destroy in a situation of genuine wartime hostilities. This is absolutely not the case with eLoran. The massive antennas with their attached atomic clocks and infrastructure will make, we believe, an almost embarrassingly easy target in a real war. Then… *where is your "back-up"?* The fact that eLoran needs only a relatively small number of transmitter stations to cover vast areas actually makes the problem *far worse*. Taking out a small number of targets increases the probability of complete loss of that precious back-up capability, and is one reason why centralized and easily compromised infrastructure is the modern equivalent of the Maginot Line. A decentralized, easy-to-replace-and-deploy capability makes far more sense in modern systems, which is exactly why technology like the internet was invented.

There are other concerns which are relevant (e.g. the large antenna sizes required for reception of very low frequencies and how they could be incorporated into devices that need GPS like mobile phones) but going deeper into detail simply belabors the point. We believe Logan Scott, the respected cybersecurity expert, put the current situation into very clear and extremely concise perspective in an excellent article in the May 2015 issue of GPS World Magazine entitled ***Protecting Position in Critical Applications***, quote:

> "*While I strongly believe eLoran is an urgently needed augmentation for resilient wide area navigation, it is not capable of the centimeter-level precision required for machine control, for example ship-to-shore cranes and straddle carriers. High-precision local-area positioning systems based on optical systems, RFID and/or Locata-style systems may be the best approach for creating a defense in depth*."

We totally agree. So the fundamental take-away from Locata is that eLoran is a very helpful fallback for an important but extremely limited number of users. For that reason alone it must be considered by the nation as part of a concerted and intelligent beginning to solving the problem we now all see with GPS dependence. But don't let anyone kid themselves that this is *the answer*, because it is not. Not by a long way.

Like any harmful dependency, the first step is to admit you have a problem which must be faced, squarely and with resolve. ***We believe most of the nations on earth (not only the USA) have yet to take that first "AA" step and admit as a community that they now have to fix the dire satellite-based dependency we have all collectively created***. "The fix" will, like many engineering problems, be solved by *a system of systems approach* which will of necessity include eLoran, inertial units, chip-scale atomic clocks, and yes – Locata. eLoran may become that critical first step, but we should all acknowledge that nations and industry need to now commit *to the rest of the journey* and ensure non-satellite based positioning becomes a fundamental part of national infrastructure.

In Conclusion

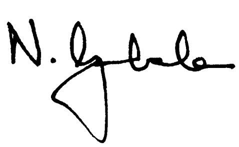
Despite our clear reservations about some eLoran claims and technical factors, we nevertheless believe the benefits of having *some* wide-area backup is worthy of our support. No technology is the panacea for the dependence which GPS has given the world, so weaning ourselves off this dependence will be a matter of "crawl, walk, run". **The most important thing I see here is that a conversation about the issues has begun**. We are encouraged that this may now truly be the first step towards actually solving the problem.

If the U.S. government truly desires a backup PNT system that can support critical transportation, homeland security, and other critical civil and commercial infrastructure applications within the United States, as well as to support emerging technologies which will require improved PNT capabilities--then eLoran represents only a very small piece of the solution.

A precise, non-GPS-based PNT system that services scalable land-based operations needs to be deployed as well. Locata is precisely the new technology advance which promises this level of high-accuracy positioning from a locally controlled network. **If the DoT wishes to see a cm-accurate, non-GPS based system working today over thousands of square miles when GPS is completely jammed, they need simply visit the White Sands Missile Range where the USAF's own 746th Test Squadron has already successfully deployed a very wide-area Locata network**. Our technology has been proven through the most stringent of independent testing, run by the USAF at their own facilities. Locata is a powerful step forward in the art of positioning and, when combined with eLoran's coarse ultra-long-range capabilities, truly does promise a local coverage that could "deliver it all, for everyone". For now let's start with eLoran, but then we must continue on to deliver resiliency and some level of comfort "to the rest of us".

Thank you for your time and consideration.

Respectfully,



Nunzio Gambale
(Locata CEO)

APPENDIX A

YONSEI UNIVERSITY

MINISTRY OF OCEANS AND FISHERIES

Update on the Korean eLoran Program

Jiwon Seo

Yonsei University, South Korea

Je-Bong Oh

Ministry of Oceans and Fisheries, South Korea

Resilient PNT Forum

Rotterdam, Netherlands

April 14, 2014

Intentional High-Power Jamming

[The Central Radio Management Office, South Korea]

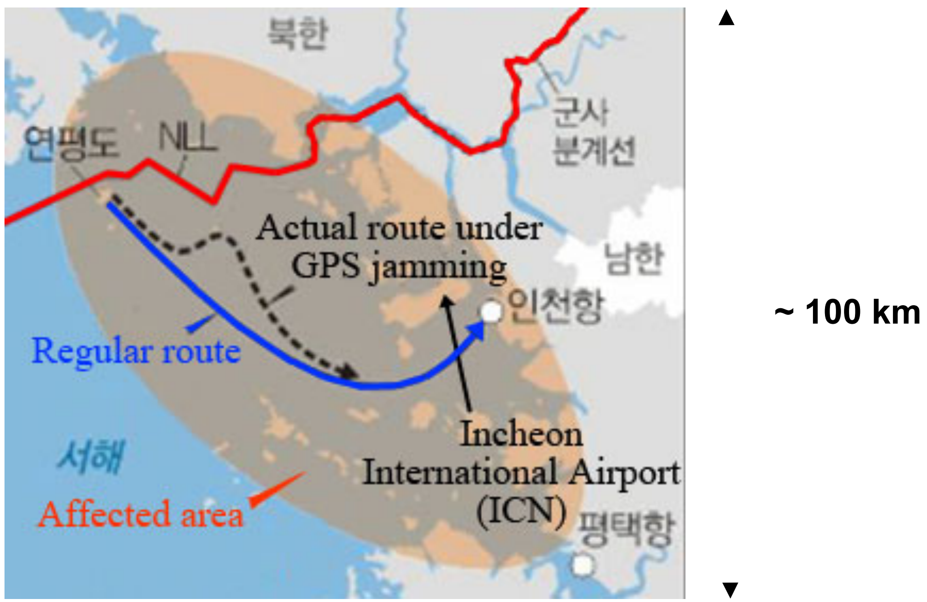
Dates	Aug 23-26, 2010 **(4 days)**	Mar 4-14, 2011 **(11 days)**	Apr 28 – May 13, 2012 **(16 days)**
Jammer locations	Kaesong	Kaesong, Mt. Kumgang	Kaesong
Affected areas	Gimpo, Paju, etc.	Gimpo, Paju, Gangwon, etc.	Gimpo, Paju, etc.
GPS disruptions	**181 cell towers, 15 airplanes, 1 battle ship**	**145 cell towers, 106 airplanes, 10 ships**	**1,016 airplanes, 254 ships**

[*NK News*, 25 June 2013] – based on a UN report

"Representatives from the North Korean front company Hesong Trading Corporation allegedly offered Mr. Ranger modern and vintage small arms and light weapons, **GPS jammers**, multiple launch rocket systems, and "extraordinarily," ballistic missiles with a range of up to 3,500 km."

Reported Navigation Problems

- South Korea experienced GPS disruptions for the past three years due to North Korean jamming attacks
- Reported navigation problems of fishing boats
  - Could not follow the regular route due to GPS outages because they heavily rely on GPS
  - [Sailors] “If visibility is low, fishing boats could crash each other and it is possible to cross the maritime border to the North Korea.” (translated)



[*Dong-a Ilbo Newspaper*, South Korea, 5 May 2012]

Reported Navigation Problems

- Reported navigation problem of a U.S. military plane
  - “A U.S. military reconnaissance aircraft made an emergency landing during annual South Korea-U.S. military exercises in March when North Korea jammed its GPS device”
  - “the RC-7B took off from its base at 8:30 p.m. on March 4 but had to make an emergency landing about 45 minutes later due to disruption of its GPS functions by jamming signals transmitted from Haeju and Kaesong in North Korea at intervals of five to 10 minutes that afternoon.”

N.Korea Jammed U.S. Reconnaissance Plane GPS

A U.S. military reconnaissance aircraft made an emergency landing during annual South Korea-U.S. military exercises in March when North Korea jammed its GPS device, it emerged Thursday.

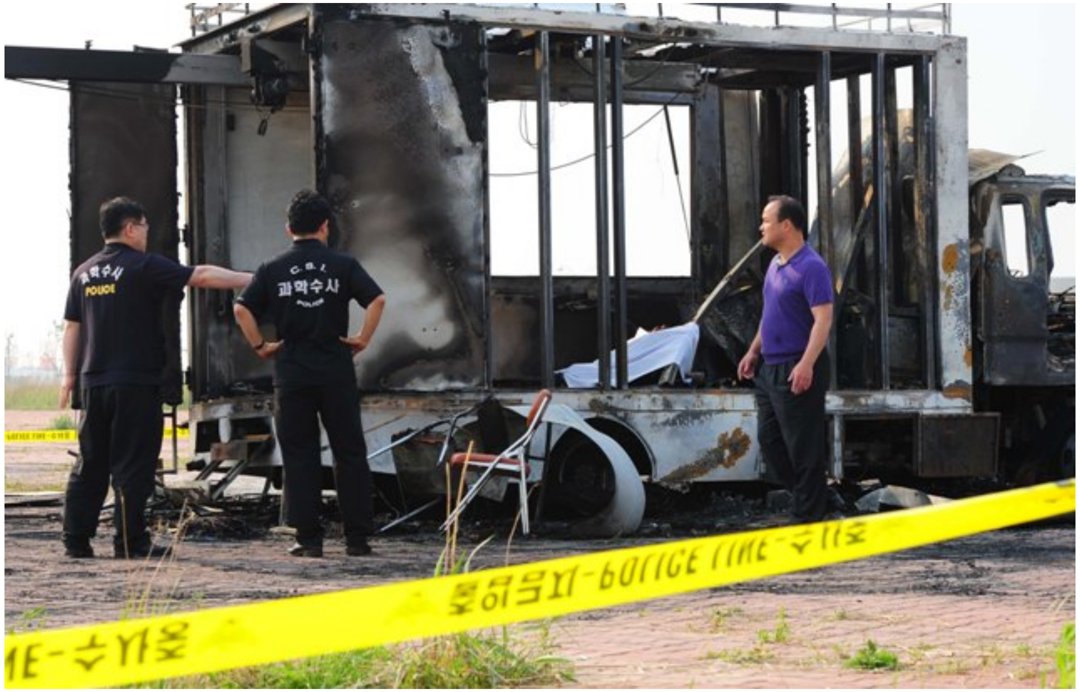
According to a report the Defense Ministry submitted to Democratic Party lawmaker Ahn Kyu-baek of the National Assembly's Defense Committee, the RC-7B took off from its base at 8:30 p.m. on March 4 but had to make an emergency landing about 45 minutes later due to disruption of its GPS functions by jamming signals transmitted from Haeju and Kaesong in North Korea at intervals of five to 10 minutes that afternoon.

U.S. soldiers get off Korean Air aircraft at the Korean Air Force Airport in Daegu to participate in the Key Resolve/Foal Eagle joint exercises on March 8.

[*Chosun Ilbo Newspaper (English Edition)*, South Korea, 9 September 2011]

Reported Navigation Problems

- Reported Schiebel S-100 UAV crash partly due to loss of GPS during the third jamming attack (Incheon, South Korea, May 10, 2012)
  - The S-100 crashed into their ground control station during tests (one engineer was killed and two others injured)
  - It is not confirmed whether the GPS loss was due to the jamming attack



[*Kyeonggi Ilbo Newspaper*, South Korea, 10 May 2012]

South Korea to Deploy eLoran

- South Korea’s decision to deploy eLoran was first announced at the European Navigation Conference 2013 (April 23, 2013)
  - Drew significant attention worldwide (second most-read article in the Inside GNSS website in 2013)

North Korea’s GPS Jamming Prompts South Korea to Endorse Nationwide eLoran System

Latest News • May/June 2013 issue

April 24, 2013

Inside GNSS, May/June 2013

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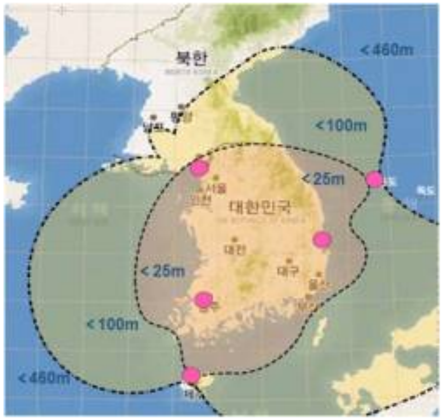


Projected accuracy and coverage of Korea's eLoran network. Ministry of Oceans and Fisheries of Korea *(Click image to enlarge.)*

GPS jamming attacks from North Korea that have increased in frequency and duration since they began August 2010 have prompted the South Korean government to implement an enhanced Loran (eLoran) systems that will cover the entire country by 2016.

The South Korean government completed design, development, and construction documents for the eLoran system in February and will procure the system infrastructure through international competitive bidding.

Inside GNSS
April 24, 2013

Governments confront rising threat to ships from signal jamming

Thu, May 30 2013

By Jonathan Saul

LONDON (Reuters) - Ships on the world's busiest waterways face growing threats to their satellite navigation systems, including jamming attacks, prompting Britain and South Korea to deploy back-up devices to avert potential disasters at sea.

South Korea has already experienced waves of signal jamming since 2010 on ships and aircraft, its officials said.

Vessels increasingly rely on systems that employ satellite signals to find a location or keep exact time, including the Global Positioning System (GPS).

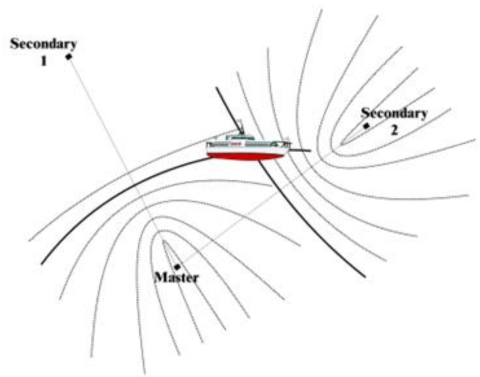
Reuters
May 30, 2013

Korea Loran-C Chain (GRI 9930)

[http://loran9930.go.kr]

The Korea Loran-C chain consists of

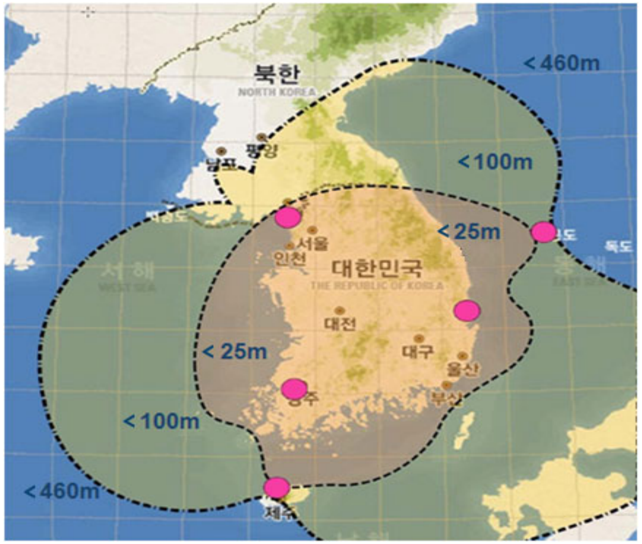
- 2 stations in South Korea
- 2 stations in Japan (scheduled to be discontinued in December 2014)
- 1 station in Russia



Korean eLoran Program – Initial Plan

- Decided to provide eLoran service without relying on other nations' infrastructure
- The Korean eLoran system was initially planned to consist of five transmitters
  - Two Loran-C stations in Pohang and Kwangju were planned to be converted into eLoran stations
  - Three new eLoran stations were planned to be built

Korean eLoran Program – Initial Plan



- 43 differential eLoran stations were planned to be deployed
  - To cover the whole country with a 20 m accuracy
- Initial Operational Capability (IOC) was expected in 2016
- Full Operational Capability (FOC) was expected in 2018

Korean eLoran Program – Milestones

- Korean eLoran program was initiated (October 19, 2011)
  - After the second jamming attack (March 4-14, 2011)
- RFP for Korean eLoran system design was released (February 9, 2012)
  - Then, the third jamming attack occurred (Apr 28 – May 13, 2012)
- The design of the Korean eLoran system was completed by ANSE Technologies, Korea (February 22, 2013)
  - The initial plan of the eLoran program was based on this design
- The Korean eLoran program was internationally announced at ENC 2013 based on this design (April 23, 2013)
- The Korean eLoran project was selected as one of the 140 national tasks of the Korean government (May 28, 2013)
  - Which demonstrates a very strong interest on this project from the current Korean government

Korean eLoran Program – Milestones

- The eLoran Advisory Committee of the Ministry of Oceans and Fisheries (MOF), Korea, was organized (June 18, 2013)
  - 15 committee members from universities and research institutes in Korea to support this program
- MoU on Technical Cooperation in the Field of eLoran between DfT of the UK and MOF of Korea was signed (December 12, 2013)
  - General Lighthouse Authorities of the UK and Ireland (GLA) are providing technical advices to MOF under this MoU


해양수산부

Department for Transport

Memorandum of Understanding

on Technical Cooperation in the Field of eLoran

between

the Ministry of Oceans and Fisheries of

the Republic of Korea

and

the Department for Transport of

the United Kingdom of Great Britain and Northern Ireland

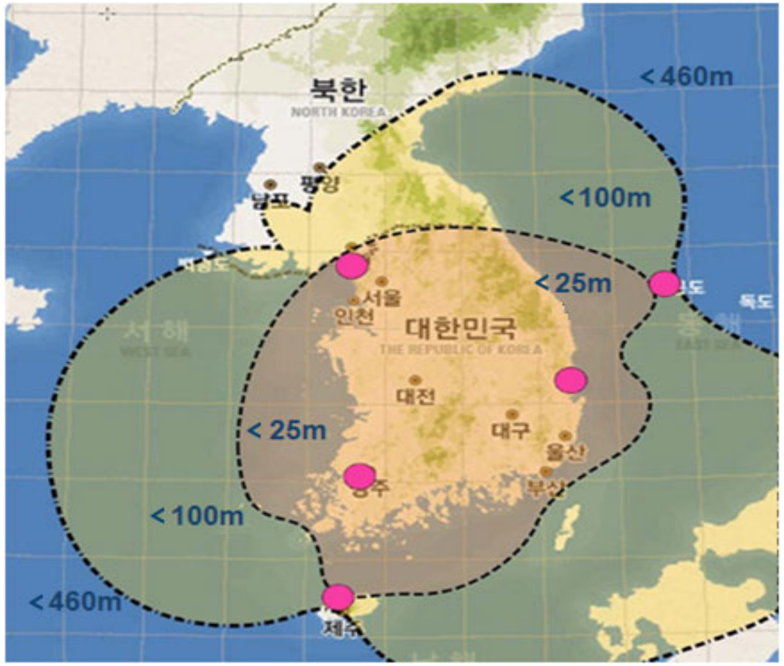
12 December 2013

Korean eLoran Program – Procurement

- Procurement process (international competitive bidding)
  - Tender document was released (September 30, 2013)
  - The first bidding in mid-November 2013 has failed
    - No bidder participated
  - The second bidding in late-November 2013 has failed
    - Automatically failed because only one bidder participated
  - eLoran Advisory Committee meeting was held (December 13, 2013)
    - To hear the voices of potential bidders (issues in the requirements)
  - The third bidding in January 2014 has failed
    - Still one bidder participated, but the proposal from the bidder was evaluated this time
    - After all, the proposal from the bidder was not accepted (I am not allowed to mention the details)

Korean eLoran Program – Procurement

- Issues in the system requirements in the tender document
  - 1,000 kW ERP (Effective Radiated Power) requirement given relatively short antennas (190 m, 145 m)
  - 20 m accuracy requirement for inland operations, which has not been demonstrated
  - 20 m accuracy requirement for maritime operations covering the EEZ (Exclusive Economic Zone)
  - And some other issues
- Extensive discussions, debates, and audits after the unsuccessful procurement
  - New direction of the program is recently decided



Korean eLoran Program – New Direction

- New direction of the program – ***First announcement***
  - Two-phase approach
    - First phase: Implement maritime eLoran for the West Sea of Korea with 3 transmitters and 2 differential stations by the end of 2015
    - Second phase: If demonstrated performance is satisfactory, more transmitters and differential stations may be deployed to cover other areas

    The program may not cover inland areas unless a 20 m accuracy on land is demonstrated by further R&D

Korean eLoran Program – New Direction

- New direction of the program – ***First announcement***
  - A new tender document with more reasonable requirements for the first phase is planned to be released in mid-May
    - Two Loran-C transmitters in Pohang (150 kW) and Kwangju (50 kW) will be upgraded to eLoran transmitters
    - An eLoran transmitter with 250 kW ERP will be deployed in Ganghwa
    - Two differential eLoran stations will be deployed, and the best locations for the differential stations will be proposed by the bidders
    - 20 m maritime accuracy is required within 30 km range from the differential stations
  - Multiple bidders are expected this time

Summary

- South Korea recognizes that “Global Navigation Satellite Systems (GNSS) have vulnerabilities to intentional and unintentional interference and that a complementary system is needed for resiliency”
- South Korea recognizes also that “eLoran is the only proven electronic system that can provide such resiliency”
- South Korea desires that “eLoran will become a cost effective backup for a wide range of applications that are becoming increasingly reliant on the position and timing information provided by GNSS”

  [Above three quotations are official words from the MoU between the UK and Korea]

- In conclusion, the procurement of the Korean eLoran system is unexpectedly delayed, but the Korean eLoran program is steadily moving forward

Thank you!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APPENDIX B

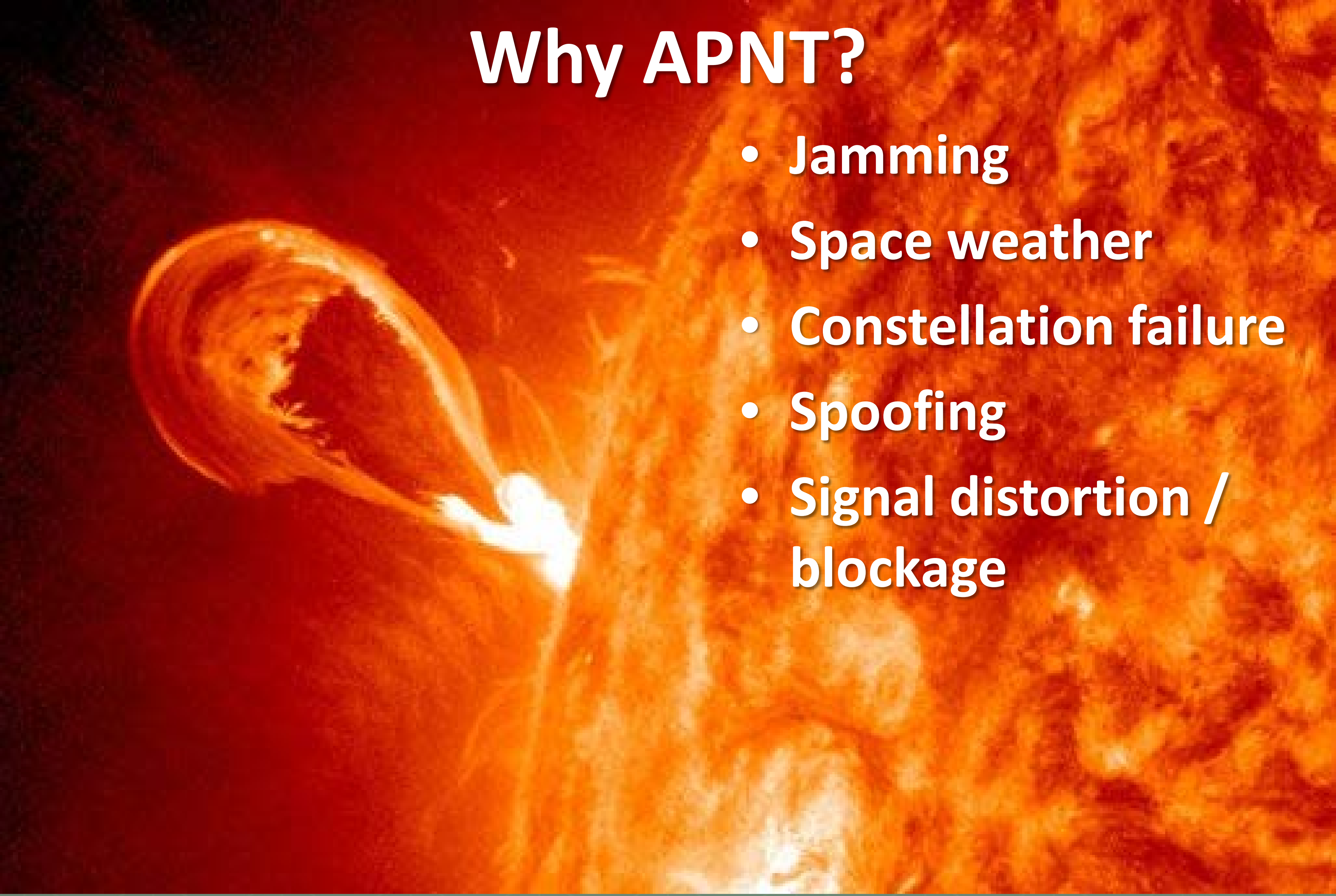
Alternative Positioning, Navigation, and Time

Wouter Pelgrum - Ohio University

Munich Satellite Navigation Summit
March 26, 2015

RUSS COLLEGE OF ENGINEERING AND TECHNOLOGY
Create for Good.

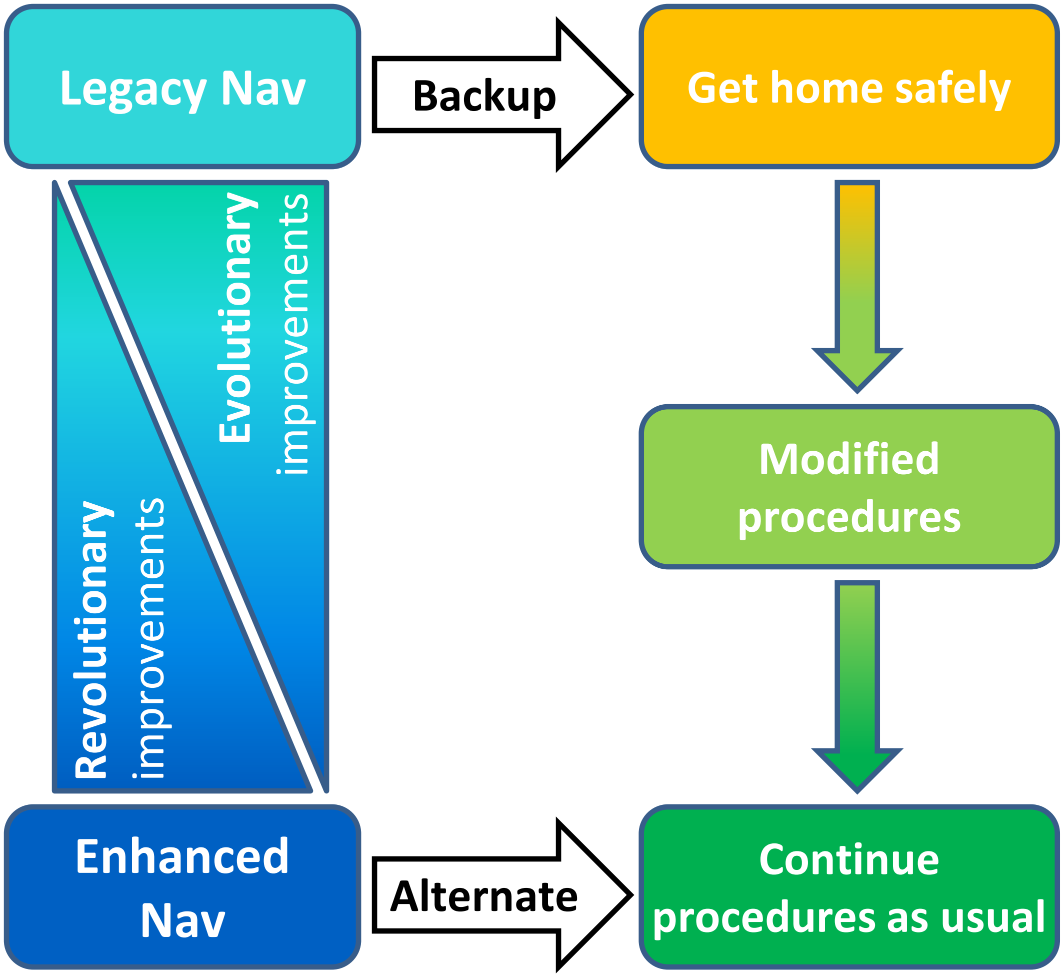
1804 OHIO UNIVERSITY



Why APNT?

- Jamming
- Space weather
- Constellation failure
- Spoofing
- Signal distortion / blockage

APNT CONOPS: Backup or Alternate?



Requirements:

- Accuracy
- Integrity: Risk Probability, Alert Limit, Time to Alert
- Availability
- Continuity
- Coverage
- Time
- Frequency
- Capacity
- Security: Authentication / Denial of Service

GNSS

Terrestrial | **Maritime** | **Aviation** | **Timing**

APNT

- UHF pseudolites
- WIFI positioning
- eLoran
- INS
- Atomic oscillator
- LF CW
- Odometry
- Map matching
- LIDAR
- DME
- EO
- RADAR
- ILS
- VOR
- IR

eLoran as APNT?

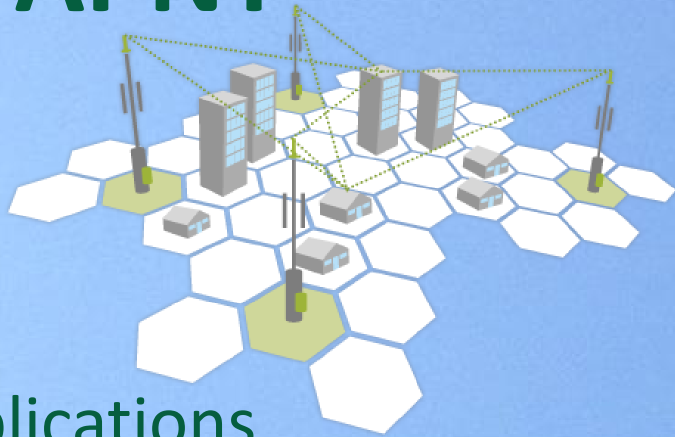
- High power, difficult to jam
- Sky-free
- Beyond line-of-site coverage
- High accuracy (<10 m) possible with ASF correction map and differential corrections
- Multi-modal
    1. Stationary timing
    2. Maritime positioning
    3. UAS navigation (also low-flying)
    4. Long-range data broadcast
    5. Aviation
    6. Terrestrial positioning

Is *e*Loran sufficiently *enhanced*?

- ***Current* Loran-C and eLoran:**
  - Sensitive to **local interference**
  - Suffers from **self-interference** (cross-rate)
  - **Cycle identification** can be challenging (early skywaves)
  - → **Highly advanced receiver signal processing** required, and
  - → **expert receiver installation**
- **Truly *enhance* Loran** by fixing shortcomings legacy system:
  - **Increase duty cycle** (more usable pulses per second)
  - **Orthogonal phase code** to mitigate cross rate
  - Maximize **steepness of rising edge** of pulse
  - → Simplify required receiver processing, allow **plug-and-play** installation, enable reception in challenging areas. Make it into **“a system that just works”**

Loran is gaining momentum, NOW is the time break with legacy and make the changes needed for the future.

Terrestrial APNT



Commercial applications
Search & Rescue (E911 / E112)

→ High accuracy and availability, cold start performance, also indoors

- High-density network of UHF pseudolites
- Co-located with cell towers
- LTE / NextNav / Locata / ?

Aviation: Considerations & Constraints (1)

- Meet APNT **performance requirements** (Accuracy, Integrity, Continuity, Capacity, Coverage, Time/Frequency, etc.)
- Resilient against **jamming** and **spoofing**
  - The more complex a system is the more attack surfaces it has
- "**Space-free**" solution and independence of GNSS
  - APNT independent position solution not sensitive to (severe) space weather (ionosphere) and GNSS interference, jamming, spoofing, constellation and/or control errors
- APNT should **not be isolated from GNSS**
  - The best performance/protection should result from an integration of APNT resources and GNSS (and INS when available).
  - APNT should be capable of an independent position solution, but not limited to that
  - APNT could provide GNSS augmentation information or ARAIM information
  - APNT should be useful for combating spoofing as well as maintaining capability during a denial of service attack
- **International harmonization**
  - Architectures that are not scalable (up or down) to provide a globally applicable solution are not viable

Aviation: Considerations & Constraints (2)

- Focus on **proven technologies** to reduce risk
  - Challenging APNT time line restricts development of new technologies
- **Legacy compliance**, compatible with current national and international specifications & requirements
- Minimize required changes **avionics** (antenna, cable, impact on other boxes, FMS, training, maintenance, etc.)
  - Incremental benefits to forward fit and affordable retrofit
- Minimize required changes to **ground infrastructure**
  - Avoid 3rd party (non-FAA) ground sites if possible
  - Avoid precise time synchronization if possible
- Collect significant **operational data** to avoid surprises (**flight testing**)
- Solicit **industry support** (Ground equipment, Avionics)
- Solicit **user support**
  - Must quantify user cost-benefit and schedule
  - Need positive business case or mandate
  - Architectures that provide benefits to non-aviation market segments have an easier business case

INCREASED APNT PERFORMANCE

RNAV 1.0 | 0.6 | RNP 0.3 | < 0.3

W IRU | W/O IRU

Hybrid
- ADS-B 1090-ES pseudoranging
- UAT APNT data broadcast
- UAT pseudoranging
- LDACS pseudoranging

eDME
- Precise Time Transfer
- Synchronize beat signal to UTC
- Optimize pulse shape and TOA determination
- Add monitoring and alerting
- Stabilize carrier phase
- Add beat signal
- Add data channel
- Increase performance interrogators (> TSO-C66c)
- Optimize troposphere correction
- Increase performance transponders (> E2996)

NextGen DME/N
- Fill coverage gaps
- Remove critical DMEs
- Better survey transponders

DME/N
- RNAV-1 with DDI
- TSO-C66c & E2996

INCREASED COST

Add 1090ES

Add UAT / LDACS

Synchronize ground stations

Add eDME functionality & performance

Update/re-certify avionics

Update/re-certify transponders

Add transponders

Add / relocate transponders