eLoran in Korea
– Current Status and Future Plans

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Location Privacy Concern

- Location privacy issue receives more attention as GPS tracking devices are widely available
  - “A Spy-Gear Arms Race Transforms Modern Divorce”
    - The Wall Street Journal (October 6, 2012)
      - “In suburban Atlanta, a private investigator said that his firm, which is handling roughly 80 spousal investigations, is currently tracking about five cars using GPS.”
      - “LandAirSea sells a GPS Tracking Key—a matchbox-size, magnetized gizmo that can stick to cars—for $179 online”
PPDs for Sale Over the Internet

• How to protect location privacy?
  • Personal Privacy Devices (PPDs): small-size low-power GPS jammers


[Dong-a Ilbo Newspaper, South Korea, 1 June 2011]
GPS RFI at Newark Airport

* A well-known example of GPS interference due to PPDs
GBAS Site at Newark (Near Freeway)

- Heavy Traffic (> 100,000 veh/day)
- RR 1: ~100 m from Heavy Traffic
- RR 2: ~130 m from Heavy Traffic
- RR 3: ~75 m from Heavy Traffic

Courtesy: Sam Pullen
GPS Anti-Jam Technology such as CRPA (Controller Reception Pattern Antenna)

- **Direct beams to all GPS satellites**
- **Null to jammers**
- **Safety information from GBAS**
- **Positioning from GPS**

*CRPA is effective under moderate-power jamming*

[J. Seo, Y.-H. Chen, et al., 2011]
Intentional High-Power Jamming

GPS disruptions for the past three years due to North Korean jamming

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

[The Central Radio Management Office, South Korea]

* Note that the durations of jamming have continuously increased
Intentional High-Power Jamming

The Electronics and Telecommunications Research Institute (ETRI) of South Korea observed and analyzed North Korean jamming in L1, L2, L5 bands.

* Under this intentional high-power jamming, the benefit of anti-jam technologies such as CRPA is very limited.
## Expected Capabilities of eLoran

- **Time**: UTC synchronized with an accuracy of 50 ns
- **Frequency**: Achieves Stratum 1 quality  
  i.e., maximum drift: $1 \times 10^{-11}$ or less  
  (fractional frequency offset)
- **Navigation**: Satisfies the HEA & NPA requirements

<table>
<thead>
<tr>
<th></th>
<th>Accuracy</th>
<th>Integrity</th>
<th>Availability</th>
<th>Continuity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harbor Entrance and Approach (HEA)</td>
<td>20 m, 2drms</td>
<td>3×10⁻⁵/h</td>
<td>99.7%</td>
<td>99.85% over 3 hours</td>
</tr>
<tr>
<td>Non-Precision Approach (NPA)</td>
<td>307 m</td>
<td>10⁻⁷/h</td>
<td>99.9-99.99%</td>
<td>99.9-99.99% over 150 seconds</td>
</tr>
<tr>
<td>eLoran (expected)</td>
<td>8-20 m</td>
<td>10⁻⁷/h</td>
<td>99.9-99.99%</td>
<td>99.9-99.99% over 150 seconds</td>
</tr>
</tbody>
</table>

[eLoran Definition Document, 2007]
[S. Lo, et al., 2007]
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
The South Korean government recently completed the design development and construction documents for the Korean eLoran system in Feb 2013

* This talk is the first introduction of the Korean eLoran program at an international conference

- The Korean eLoran system will consist of five transmitter stations
  - Two Loran-C stations in Pohang and Kwangju will be upgraded to eLoran stations
  - Three new eLoran stations will be constructed
  - Control station will be at Pohang
• Simulation result of the expected accuracy and coverage of the Korean eLoran system
  • Demonstrates satisfactory coverage including major harbors
  • Not the ideal best-case geometry, but a realistic alternative with minor performance degradation
Purpose of the Korean eLoran System

- To provide better than 20 m accuracy over the country including land, air, and sea as an effective complementary navigation system
  - Not just the HEA and NPA
  - Should be able to provide a 20 m accuracy inland as well
  - Conventional eLoran error mitigation techniques such as differential corrections and ASF maps will be utilized for land areas as well
ASF (Additional Secondary Factor)

• Primary Factor (PF)
  • The term that accounts for the time of propagation of the Loran signal through the atmosphere rather than the vacuum
  • RTCM SC127 decided to use the index of refraction in atmosphere to be 1.000338
  • Then, the speed of light in the atmosphere is 299,691,162 m/s
ASF (Additional Secondary Factor)

- Secondary Factor (SF)
  - The term that accounts for the difference in propagation time from a Loran signal propagating over an \textbf{all seawater path} rather than through the atmosphere

- The Brunavs model accounts both the primary factor and secondary factor

\[
\text{Brunavs}_{PF+SF}(m) = -111 + 98.2D + (13.0D + 113.0)e^{-\frac{D}{2}} + \frac{2.277}{D}
\]

[S. Lo, \textit{et al.}, 2009]
**ASF (Additional Secondary Factor)**

- **Additional Secondary Factor (ASF)**
  - The term that accounts for the extra delay on the time of arrival of the Loran signal due to propagation over inhomogeneous land path rather than all seawater path
  - **ASF can vary significantly spatially and temporally**

[S. Lo, et al., 2009]
Once spatial ASF variations are surveyed over a region—this is a one-time effort—eLoran receivers store the spatial ASF variation maps and apply the information as spatial corrections. Grid size of 500 m is generally acceptable for maritime users. Land users would experience more local variations due to re-radiation and bending of eLoran signals. A denser grid size may be necessary.
Temporal ASF Correction by dLoran

- Temporal ASF correction by differential eLoran (dLoran) corrections
  - Account for the residual ASF not corrected for by the ASF map
  - Also account for other slowly varying errors such as the residual errors from our PF and SF models as well as some transmitter errors

- 43 differential eLoran stations would be deployed over the country
  - 30 km coverage of each differential station is assumed
  - Differential corrections are broadcast via eLoran Data Channel (LDC)
Current NDGPS Infrastructures

- South Korea provides National DGPS (NDGPS) service since 2009
  - 17 DGPS reference stations and 17 integrity-monitoring stations
  - Some dLoran stations plan to be collocated with the NDGPS stations

* DGNSS Central Office in Daejeon, Korea
Roadmap of the Korean eLoran Program

- 2013
  - Three sites for new eLoran stations in Gangwha, Jeju, Ulleung and 43 sites for differential eLoran stations have been selected, which will be secured by 2013

- 2014
  - Two legacy Loran-C stations in Pohang and Kwangju would be upgraded to eLoran stations
  - A new eLoran transmitter would be installed at the Gangwha station
  - 27 differential eLoran stations in Pohang, Kwangju, and Gangwha areas would be deployed
  - A prototype eLoran system would be ready with total 3 transmitter stations and 27 differential stations
Roadmap of the Korean eLoran Program

- **2015**
  - Two more eLoran stations would be ready in Jeju and Ulleung
  - Remaining 16 differential stations would also be deployed

- **2016**
  - ASF maps for 5 transmitters would be ready by 2016
  - The Initial Operational Capability (IOC) of the Korean eLoran system is expected in 2016

- **2018**
  - After two years of test operations in 2016 and 2017, the Final Operational Capability (FOC) would be declared in 2018
Summary

• A complementary PNT service is necessary in South Korea especially due to the repeated GPS jamming from North Korea
  • A terrestrial high-power radio navigation system, eLoran, is selected as the best candidate for South Korea
• The South Korean government has recently completed the design development and construction documents of the Korean eLoran system
  • The system consists of 5 transmitters and 43 differential stations
  • The system plans to provide better than 20 m accuracy over the country
• The system will be procured through International Competitive Bidding (ICB)
  • Interested vendors are welcome to participate
• The IOC is expected in 2016 and the FOC is expected in 2018
Thank you!

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