eLoran in Korea – Current Status and Future Plans

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***Abstract* – After the annual GPS jamming attacks from North Korea started from August 2010, the South Korean government realized the importance of a complementary navigation and timing system. Among various options, a high-power terrestrial radio navigation system, eLoran, was considered as the most effective candidate. The South Korean government has recently completed design development and construction documents for the Korean eLoran system in February 2013. The current status and future plans of the Korean eLoran program are detailed in this paper based on the design development and construction documents. The purpose of the Korean eLoran system is to provide better than 20 m accuracy over the country. Eventually, the South Korean government hopes to expand eLoran coverage to the entire Northeast Asia in close collaboration with Russia and China. The Initial Operational Capability (IOC) of the system is expected in 2016 and the Final Operational Capability (FOC) is expected in 2018. The eLoran system will be procured through International Competitive Bidding (ICB). This is the first article presented at an international conference regarding the recent decision made by the Korean government.**

BIOGRAPHIES

Jiwon Seo is an Assistant Professor in the School of Integrated Technology at Yonsei University in Korea. He received his B.S. in mechanical engineering (division of aerospace engineering) from KAIST (Korea Advanced Institute of Science and Technology) and received M.S. degrees in aeronautics/astronautics and electrical engineering from Stanford University. He received his Ph.D. in aeronautics/astronautics from Stanford in 2010. He was a Postdoctoral Scholar at Stanford until January 2012. Professor Seo is currently working closely with the Ministry of Oceans and Fisheries of Korea for the Korean eLoran program.

Mincheol Kim is a Deputy Director of the Maritime Safety Facilities Division in the Ministry of Oceans and Fisheries, Korea. Dr. Kim is in charge of the Korean eLoran program.

I. INTRODUCTION

For the past three years, North Korea has repeatedly jammed GPS signals in South Korea. As in Table 1, it was reported that 1,016 airplanes and 254 ships in South Korea experienced GPS disruptions during the 16 days' North Korean jamming in 2012. It is a significant concern that the durations of the North Korean GPS jamming have continuously increased from 4 days in 2010 to 16 days in 2012.

Table 1: GPS disruptions for the past three years due to North Korean jamming (reported by the Central Radio Management Office of 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, Mountain 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

For the 2011 jamming, the Electronics and Telecommunications Research Institute (ETRI) of South Korea analyzed the jamming signals and reported that all the L1, L2, and L5 bands were affected. The ETRI observed high-power continuous-wave (CW) jamming signals in the L1 band. For L2 and L5 bands, multiple CW-type jammers swept the whole bands by moving their center frequencies. It was also noticed that North Korea seemed to test their jammers with various transmission powers, frequencies, and jamming intervals. Figure 1 shows a summary of the North Korean jamming in 2011 and 2012 from a different report [1].

Considering the continuous threats from North Korea and the critical infrastructures of South Korea relying on GPS, the South Korean government has recently decided to deploy a high-power terrestrial radio navigation system, eLoran [2,3], as a complementary navigation and timing system. The Ministry of Land, Transport and Maritime Affairs (currently, the Ministry of Oceans and Fisheries) of South Korea initiated the plan in October 2011 and recently completed design development and construction documents for the Korean eLoran system in February 2013 [1]. The documents are prepared by a governmental contract with ANSE Technologies in Korea. The following sections detail the decision made by the South Korean government and the current status and future plans of the Korean eLoran program.

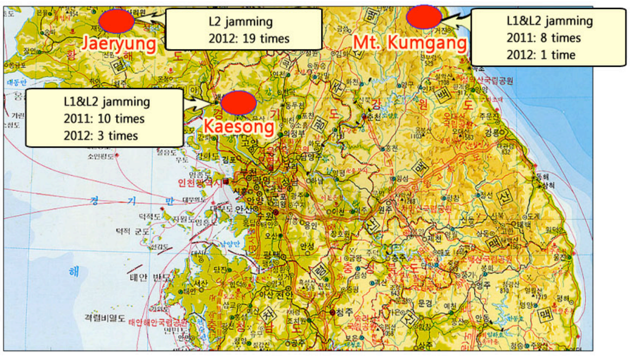

Figure 1: North Korean GPS jamming and jammer locations in 2011 and 2012 [1]

II. LORAN-C AND NDGPS INFRASTRUCTURES IN KOREA

South Korea currently operates two Loran-C stations in Pohang and Kwangju for the Korea Loran-C chain (GRI 9930). The control station of the chain is in Daejeon, Korea. The Korea chain consists of two Loran-C stations in Korea, two stations in Japan, and one station in Russia. However, Japan plans to discontinue Loran-C in December 2014. The Russian station at Ussuriysk does not yet operate. As a result, the Korea chain will not have a sufficient number of transmitters to provide Loran-C service in the region.

Because of the evident necessity of a complementary radio navigation system, the South Korean government decided to change the current Loran-C system to the enhanced Loran (eLoran) system without relying on other countries' infrastructures. Specifically, South Korea plans to convert the current two Loran-C stations into eLoran stations and build three more eLoran stations. In a comparison, the UK operates a prototype eLoran system using signals from a new eLoran station at Anthorn, UK and existing Loran-C stations of other countries [4].

South Korea provides National Differential GPS (NDGPS) service. The Korean NDGPS system consists of 17 reference stations, 17 integrity-monitoring stations, and the DGNSS Central Office in Daejeon (Figure 2). This NDGPS system has been operating since 2009. For differential eLoran service, 43 differential eLoran stations schedule to be deployed over the country. Some of these differential eLoran stations plan to be collocated with the existing NDGPS stations. Section III.C explains the differential eLoran service in detail.

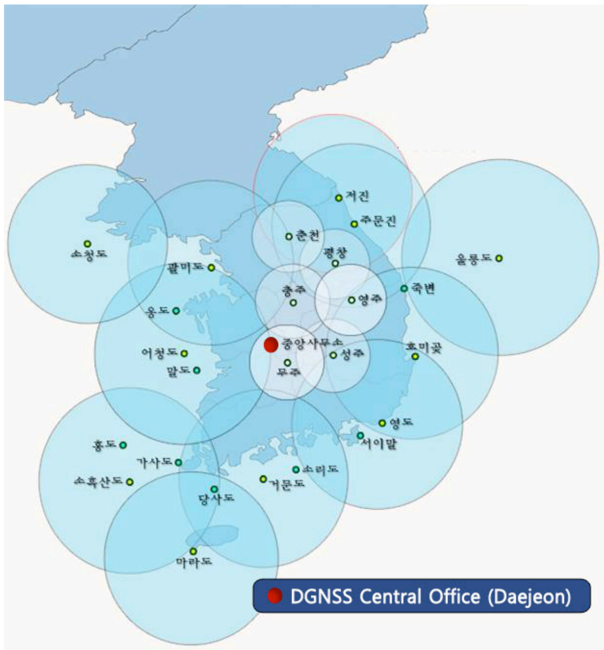

Figure 2: Korean NDGPS stations and coverage [1]

III. THE KOREAN E-LORAN SYSTEM

A. Main Performance Requirement of the Korean eLoran System

Since the continuous GPS jamming threats from North Korea mainly affect the land of South Korea as well as the sea and sky, the purpose of the Korean eLoran system is not limited to maritime applications. A generic eLoran system is expected to satisfy the accuracy, availability, continuity, and integrity requirements of the Harbor Entrance and Approach (HEA) and Non-Precision Approach (NPA) [2]. In addition to this capability, the Korean eLoran system should be able to provide better than 20 m accuracy, which is the accuracy level required for the HEA, over all regions of South Korea including land areas in order to be an effective complementary navigation system. Further, the South Korean government hopes to expand eLoran coverage to the entire Northeast Asia in close collaboration with Russia and China in the near future.

In order to achieve this required 20 m accuracy for land mobile users in South Korea, the conventional techniques to mitigate eLoran errors in harbor areas [5,6] would be adopted for land areas as well. Enough number of differential eLoran stations would be deployed inland to mitigate temporal errors (Section III.C). Additional Secondary Factor (ASF) maps with a dense grid size for land areas would be generated to mitigate spatial errors (Section III.D).

Differential eLoran service and ASF maps have been applied to provide better accuracy in limited harbor areas [7-10], but they have not been utilized to cover a whole country. South Korea hopes to become the first country to provide better than 20 m accuracy nationwide using the eLoran technology.

B. System Architecture

As briefly mentioned in Section II, South Korea has two legacy Loran-C stations in Pohang and Kwangju. These stations plan be converted into eLoran stations. In addition, three new eLoran stations would be built in Ulleung, Ganghwa, and Jeju (Figure 3). Total five stations can provide radio navigation service in the entire region of South Korea.

Figure 3: Selected locations for the eLoran transmitter stations [1]

The locations of these new transmitters are selected based on the coverage and accuracy simulation results using two independent eLoran simulation tools which are not developed by the authors. There is a better geometric configuration of the transmitters than Figure 3 according to the simulation results, but it is almost impossible to secure those sites to achieve the best coverage. The configuration in Figure 3 is a realistic alternative and its coverage degradation compared to the best geometry is not significant.

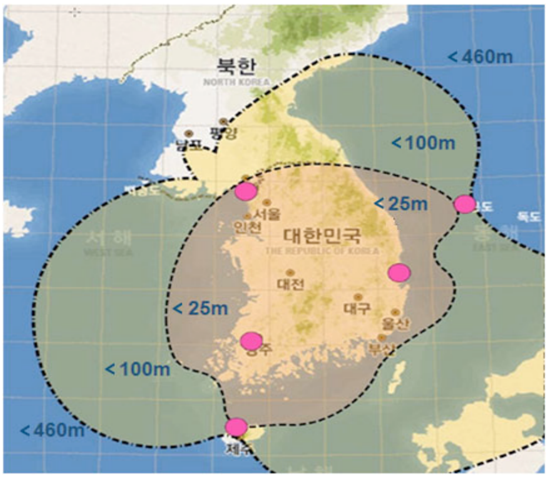

Figure 4: Simulation result of the expected accuracy and coverage of the Korean eLoran system provided by ANSE Technologies [1]

Figure 4 shows the expected accuracy and coverage obtained from a simulation tool. This configuration would provide a good accuracy over the land and major harbors of Korea shown in Figure 5. This simulation result is not from the authors but from the documents [1] which are prepared by ANSE Technologies under a contract with the Ministry of Land, Transport and Maritime Affairs (currently, the Ministry of Oceans and Fisheries).

Figure 5: Major harbors in South Korea [1]

The control station of the Korea Loran-C chain is currently located at the DGNSS Central Office in Daejeon. Due to the very limited space of the DGNSS Central Office, the control station of the Korean eLoran system will be located at the Pohang transmitter station instead.

C. Differential eLoran Stations for Temporal Error Mitigation

Differential eLoran service is necessary to provide better than 20 m accuracy. One differential eLoran station is assumed to provide reasonable temporal error mitigation in a 30 km range. A less than 30 km separation between a differential station and a vessel would be necessary for HEA [11], but the effective mitigation coverage of a differential eLoran station for land areas has not been completely studied. Nevertheless, ANSE Technologies assumed a 30 km coverage in Figure 6 and the locations of the 43 differential eLoran stations to cover the country are initially selected. If the effective coverage is less than 30 km, more differential stations would be necessary to achieve the required accuracy level over the country.

Figure 6: Selected locations for the 43 differential eLoran stations [1]. The radius of each circle is 30 km.

The Regional Maritime Affairs and Port Administration offices plan to host 13 differential eLoran stations. Six differential stations will be collocated with the NDGPS stations in Figure 2. Seven stations will be located in major cities. The locations of remaining 17 stations are selected to provide nationwide coverage. District offices at these locations will host those stations.

The differential eLoran corrections generated by the differential stations are broadcast using the eLoran data channel (LDC). Thus, eLoran receivers can utilize the differential corrections and improve their position accuracies without extra antenna or hardware.

The 43 differential eLoran stations are grouped into five areas in Figure 6. The transmitter station of each area is responsible for delivering differential corrections generated by the differential stations in the area. Actual implementation of delivering corrections via LDC can be different from this idea.

D. ASF Maps for Spatial Error Mitigation

The ASF is the largest error source in eLoran. The spatial variations of ASF cannot be effectively mitigated by the differential eLoran corrections alone. In order to mitigate this spatial error, ASF maps are utilized [12-14]. 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. ASF maps with the grid size of 500 m are generally acceptable for maritime users [3].

Land users experience more local variations due to re-radiation and bending of the eLoran signals [6,15]. The effect of re-radiation due to metallic objects is generally more significant. Thus, the expected eLoran position accuracy in cities is worse that the expected accuracy in open country. In this sense, the major difference of land users compared to maritime users is greater spatial ASF variations.

ASF maps will be generated over South Korea including land areas. A denser grid size than 500 m may be necessary to provide the required 20 m accuracy for land users. Before performing ASF survey when eLoran transmitters are ready, an optimal grid size for land users in Korea needs to be carefully studied.

IV. FUTURE PLANS

As of this writing in April 2013, the Final Operational Capability (FOC) of the Korean eLoran system is expected in 2018. The detailed plans are as follows.

Three sites for new eLoran stations in Ulleung, Ganghwa, and Jeju have been selected, and the lands will be secured by 2013. The 43 sites for differential eLoran stations have been selected as well. The 19 sites at the Regional Maritime Affairs and Port Administration offices and the NDGPS stations are already secured, and other sites will be secured by 2013.

In 2014, two legacy Loran-C stations in Pohang and Kwangju would be converted into eLoran stations, and a new eLoran transmitter would be installed at the Ganghwa station. Differential eLoran stations would be deployed at the 27 sites in Pohang, Kwangju, and Ganghwa areas.

While testing these stations, two eLoran transmitters would be installed at the Ulleung and Jeju stations in 2015 and the remaining 16 differential stations would also be deployed. The Initial Operational Capability (IOC) of the Korean eLoran system is expected in 2016.

The Korean eLoran system with the five transmitter stations and 43 differential stations plan to be tested during 2016 and 2017. The ASF maps for the five transmitters schedule to be generated by 2016. If necessary, more differential eLoran stations would be deployed during this period. After operating the system for two years, the FOC would be declared in 2018.

V. CONCLUSIONS

The repeated GPS jamming from North Korea is a significant concern to South Korea. In order to provide a complementary radio navigation service, the South Korean government has decided to deploy the Korean eLoran system. The system architectures and future plans of the Korean eLoran system are presented in this paper based on [1] which is the result of a governmental contract with ANSE Technologies. The main purpose of the Korean eLoran system is to provide better than 20 m accuracy over the country with the help of differential eLoran stations, ASF maps, and any other possible technologies. An eLoran system satisfying this main performance requirement will be procured through International Competitive Bidding (ICB). The IOC of the system is expected in 2016, and the FOC is expected in 2018.

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