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Development of the EGNOS Pseudolite System

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Abstract. In order to access the Satellite Based Augmentation System (SBAS) service, the end user needs to have a direct line of sight to at least one of the Geostationary Earth Orbit (GEO) satellites transmitting the augmentation messages. This requirement is critical for users in environments such as city canyons, valleys and fjords since high buildings and mountains in the vicinity of the end user can easily block the lines of sight to the GEO satellites. The situation becomes worse at high latitudes because of the low elevation angles to the GEO satellites. Even a very low obstacle can block the lines of sight to the GEO satellites. This limitation reduces SBAS Signal in Space (SIS) availability significantly at high latitude especially for land applications. This paper presents a solution of transmitting the European Geostationary Navigation Overlay Service (EGNOS) SIS using a pseudolite. The EGNOS pseudolite functions in a similar way as a GEO satellite. It will provide not only a terrestrial-based solution for transmitting the EGNOS SIS, but also a ranging measurement for the navigation solution. The EGNOS pseudolite system mainly consists of a Master Control Station, an EGNOS Data Server, EGNOS pseudolites and the user terminal. A preliminary test on a surveyed site has been carried out to verify the functionalities of the system. The data set collected from the test has been processed with two scenarios: one with four GPS satellites, while the other with three GPS satellites plus an EGNOS pseudolite. Both data processing scenarios have similar satellite geometries. The test result shows that the positioning accuracies are similar for both scenarios.

Keywords: EGNOS, Pseudolite, SBAS

1. Introduction

EGNOS (European Geostationary Navigation Overlay Service) is a European Satellite Based Augmentation System (SBAS). Consisting of three GEO (Geostationary Earth Orbit) satellites and a network of Ranging and Integrity Monitoring Stations (RIMS), the EGNOS system provides the end users with differential corrections, integrity information, and additional ranging measurements from the GEO satellites to improve the positioning accuracy, availability and integrity.

However, the low elevation angles to the GEO satellites have caused a lot of difficulties for accessing the EGNOS SIS at high latitudes because even a very low obstacle can block the lines of sight to the GEO satellites (Chen, 2003). This limitation reduces the EGNOS SIS availability significantly in Nordic countries especially for land applications. Although the situation in central Europe is better than that in Nordic countries, there are still many locations, such as city canyons, valleys and downhill ski centres that do not have good visibilities to the EGNOS GEO satellites.

Non-GEO transmission of the EGNOS SIS has been investigated in order to improve the EGNOS SIS availability. These implementations include the EGNOS TRAN (Terrestrial Regional Augmentation Network) solution (Redeborn *et al.*, 2003), ESA's SISNeT (Signal In Space over the Internet) solution (Toran *et Al.*, 2002a) and EDAS (EGNOS Data Access System) solution (Toran and Ventura-Traveset, 2005).

The EGNOS TRAN solution augments the GEO transmission of the EGNOS SIS by using terrestrial transmission technologies such as GPRS (General Packet Radio Services), LORAN-C, and VHF (Very High Frequency) (Redeborn *et al.*, 2003).

The ESA's SISNeT technology offers one of the terrestrial dissemination means for dissemination the EGNOS SIS (Toran *et al.*, 2002a, 2002b; Chen *et al.*, 2003, 2004). In particular, it allows accessing the EGNOS SIS through the Internet in real time. The SISNeT server can be accessed free of charge, only requiring setting up a free access account (which can be requested through SISNET@esa.int) (Toran *et al.*, 2002a, 2002b). As the user can fetch EGNOS messages whenever he or she needs without waiting for it from the GEO satellites, therefore it is possible to reduce the initiation time for providing the first EGNOS-corrected coordinates from minutes to tens of seconds over a GPRS connection.

The EDAS solution extends the SISNeT concept with a wider sense including more services, more secure and efficient data transmission links, more stable data server and more flexible for adopting new services to the system (Toran and Ventura-Traveset, 2005).

All solutions mentioned above cover only the dissemination or re-transmission of the EGNOS SIS. The EGNOS pseudolite solution will provide not only a terrestrial-based dissemination solution for the EGNOS SIS, but also an additional ranging measurement. The ranging capability is one of the significant advantages of the EGNOS pseudolite solution comparing to the TRAN, SISNeT and EDAS solutions. Furthermore, the EGNOS pseudolite solution can serve an unlimited number of users within the radio coverage area of the pseudolite because it works in a broadcast mode. This is another advantage over the GPRS solution, which can support only a limited number of active data calls simultaneously to one base station. Furthermore, the end user does not need to pay any air-fee for receiving the EGNOS SIS by using the EGNOS pseudolite solution. This advantage makes it possible to utilize the solution for hot-spot like applications that have a large number of users within a small area. The last, but not least, advantage of the EGNOS pseudolite solution is that end users do not need any additional terminal or device to receive the EGNOS signal because the signal will be received by an EGNOS enable receiver. However, the navigation software in the user terminal has to be modified in order to take the advantages of the modified EGNOS SIS transmitted by the EGNOS pseudolite.

The only disadvantage of the EGNOS pseudolite solution is its limited radio coverage. A network of pseudolites will be required if a large service coverage area is required. However, the ranging capability from such a network of pseudolites will be beneficial for improving the positioning geometry in the degraded environments such as city canyons, fjords, and locations with difficult terrains.

2. The EGNOS Pseudolite System

The EGNOS pseudolite system consists of the following components: the EGNOS data server, the Master Control Station (MCS), the pseudolites and the user terminal as shown in Fig. 1.
The EGNOS Data Server is the component that provides the EGNOS SIS of a particular GEO satellite. It can be connected either to an EGNOS receiver or to the client component of the EDAS system. For the first case, the EGNOS SIS is obtained from the GEO satellite, while for the second case, the EGNOS SIS can be directly obtained from the EDAS over a terrestrial data communication link.

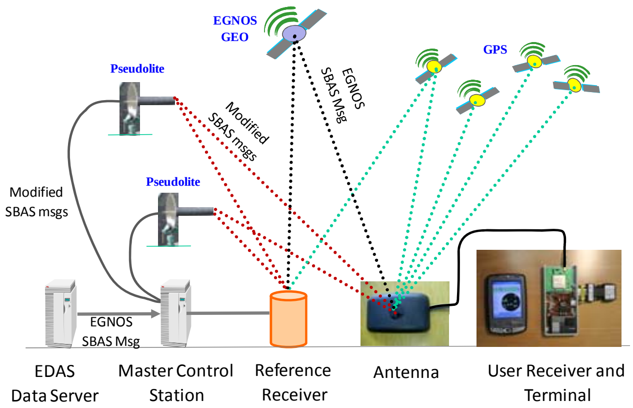

Fig. 1. Overview of the EGNOS Pseudolite System

The EGNOS pseudolite transmits a SBAS compatible signal that including augmentation contents for the corresponding EGNOS pseudolite. In order to generate this new SBAS signal, the Master Control Station needs to:

- Estimate the clock offset of the pseudolite and synchronize the clock of the pseudolite to EGNOS network time;
- Encode the clock offsets and other parameters in the SBAS format;
- Modify the corresponding SBAS messages; and
- Send the modified SBAS messages to the pseudolites from which the SBAS messages will be broadcasted to the end users.

An EGNOS pseudolite is an RF (Radio Frequency) transmitter that will transmit a SBAS compatible signal that includes augmentation contents for the corresponding EGNOS pseudolite.

The user terminal will receive the SBAS data streams and the ranging measurements from pseudolites, GPS and GEO satellites, and calculate the navigation solutions.

2.1. The EDAS Data Server

The main functions of the EDAS Data Server are: 1) to obtain the EGONS SIS either from EDAS or from the GEO satellites and 2) to send the SBAS messages in real time to the MCS. The SBAS messages will be processed in the MCS rather than in the EDAS Data Server.

2.2. The Master Control Station

An EGNOS pseudolite will be functioning in a similar way as a GEO satellite. It transmits a SBAS compatible signal and provides an additional ranging signal for positioning. However, the EGNOS pseudolites will not be monitored by the EGNOS ground segment, thus, the EGNOS pseudolites have to be monitored and operated independently. The Master Control Station is the component in the system to carry out this task.

The MCS configures the system and monitors its performance. The MCS contains a server to allow remote connections. This service enables clients to connect to the MCS remotely over the Internet for configuring the MCS settings and monitoring the system performance remotely. Fig. 2 shows the main functions of the MCS.

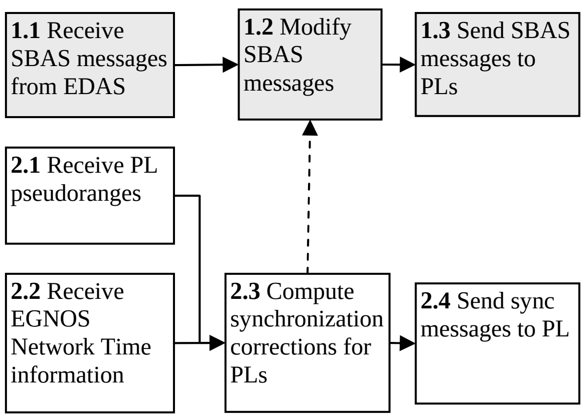

Fig. 2. An overview of the main tasks of the control station.

One of the main tasks of the MCS is to modify the SBAS messages received from EDAS before forwarding them to the EGNOS pseudolite for re-transmission. Most part of the new EGNOS compatible SBAS signals for the EGNOS pseudolites are based on the original EGNOS signal. However, any information related to the EGNOS GEO satellite in the original EGNOS signal has to be replaced with the corresponding information of the pseudolite *e.g.* clock corrections and integrity information of the pseudolite and coordinates of the antenna of the pseudolite. The message types that are needed to be modified include: MT-1 for the PRN mask, MT 2-5 and MT-24 for the fast corrections and integrity information, MT-6 for integrity information, MT-7 for fast correction degradation factors, and MT 9 messages for position of the antenna of the pseudolite. The MT 9 messages from the original EGNOS signal of a GEO satellite will be replaced by the new MT 9 messages for the pseudolite. The user terminal will decode the coordinates of the antenna of the pseudolite from the MT-9 messages and apply it for the navigation solutions. Therefore, this is a plug-and-play solution without manually inputting the coordinates of the pseudolites by the users. Table 1 shows the messages types that might need to be modified.

Fig. 3 shows the modification process of the SBAS signals to be transmitted by the EGNOS pseudolite.

In addition to the modification of the EGNOS messages, the MCS is also responsible for monitoring the connected pseudolite signals. This task is two-fold: 1) the MCS needs to perform integrity checks, verifying whether the system is performing as expected, *e.g.* the characteristics and correctness of the signal; 2) the MCS also handles the synchronisation of pseudolite transmission to EGNOS Network Time. The synchronisation task is done based on the input from the reference receiver. The clock of the pseudolite is firstly synchronized to the GPS time using the receiver as shown in Fig. 4, and then to EGNOS network time by applying the correction information in the MT-9 messages of the EGNOS signal.

Table 1. Message types required to be modified

Content to be modified	Message Type to be modified/added	Reason for the modification
PRN mask	MT1	Add PRN mask for pseudolites
Fact Corrections	*MT2-5, MT 24*	*Add fast clock corrections for pseudolites.*
UDRE	MT 2-5, MT 24, MT 6	Add integrity information for pseudolites
Fast Correction Degradation Factor	MT 7	Add Fast Correction Degradation Factor for pseudolite
Ephemeris parameters	MT 9, MT 17	Add WGS-84 coordinates for the EGNOS pseudolites.
clock offset and drift	MT 9	Corrections to EGNOS Network Time for the pseudolite.

The clock offset Δt^p of the pseudolite from the GPS time can be estimated as:

$$\rho = r + \Delta t^p - \Delta t_m \qquad \Rightarrow \qquad \Delta t^p = \rho - r + \Delta t_m$$

where ρ is the pseudorange measurement to the pseudolite, r is the known distance between the phase centres of the antennae of the pseudolite and the reference receiver, Δt_m is the estimate of the clock offset of the reference receiver from the GPS time plus the corrections for the cable lengths.

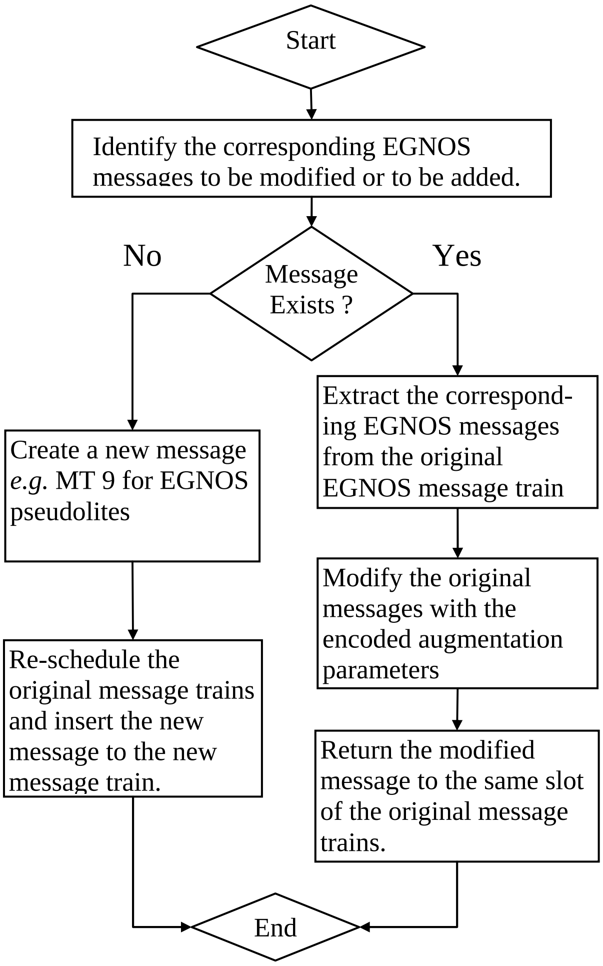

Fig. 3. General processing logic of modifying or adding an EGNOS message.

Fig. 5 shows the synchronization accuracy in meters. The pseudolite is synchronized to GPS time using a very low cost GPS module (iTrax03) as the reference receiver. The synchronization accuracy is ±2.3m for a 24h observation session. The clock offset of the pseudolite is estimated once per second, encoded in the SBAS messages and transmitted to the end users via the pseudolite.

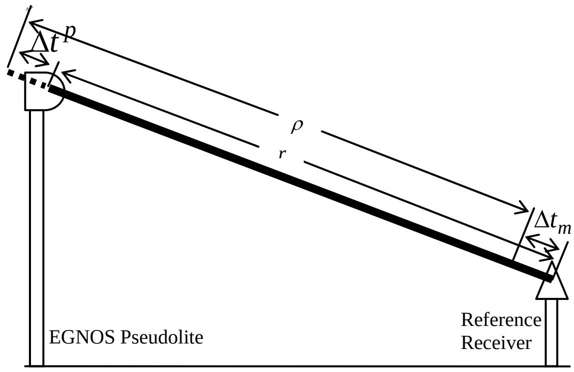

Fig.4. Synchronizing the clock of the pseudolite to the GPS time with a reference receiver.

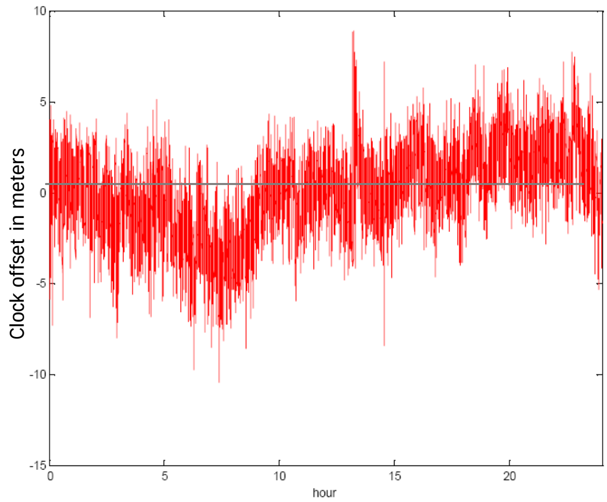

Fig.5. Accuracy of the time synchronization between the pseudolite and GPS

2.3. The EGNOS Pseudolite

A pseudolite is an RF transmitter installed on the ground. It is called GPS pseudolite when it transmits a GPS-like signal (Cobb, 1997). GPS pseudolites are used in many positioning and navigation applications (Wang, 2002). As our pseudolite transmits an EGNOS-like signal, therefore it is called EGNOS pseudolite (Chen *et al.*, 2006) as shown in Fig.6.

The EGNOS pseudolite is based on the GSG-L1E signal generator from Space Systems Finland. It consists of two separate modules: a digital module and an RF module. The digital module contains a CPU and a digital circuit for generating the PRN code. The embedded software running on the CPU controls the digital circuit and handles the communications towards the MCS. Using the communication protocol the embedded software receives and processes *e.g.* the navigation messages that will be modulated onto the EGNOS signals.

The RF module generates the L1 carrier and modulates it with the C/A code and the navigation message generated by the digital part. The pseudolite is optimized for high resolution on the frequency, which is required for synchronizing its clock to the EGNOS Network Time with a high precision.

2.4. The User Terminal

The user terminal is a Pocket PC based device holding the navigation software for exploring the functionalities of the EGNOS pseudolite system. It works together with a COST (Commercial of The Shelf) receiver unit with a modified firmware that can track multiple pseudolites as shown in Fig. 7.

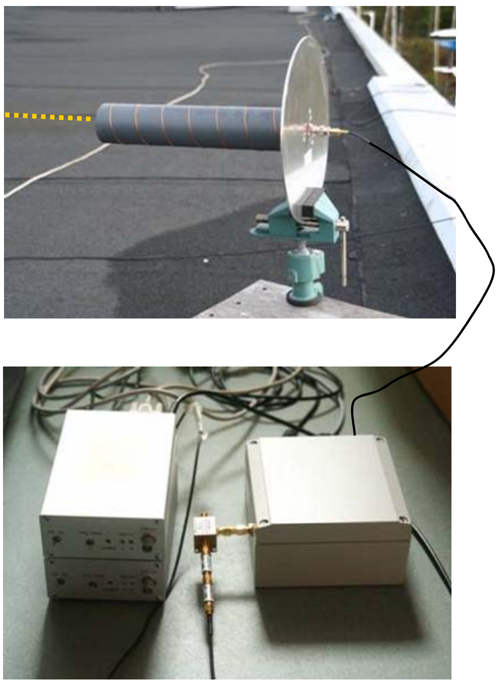

Fig. 6. The EGNOS pseudolite developed by Space System Finland Ltd.

Fig. 7. User terminal of the EGNOS pseudolite system.

In order to explore the functionalities of the EGNOS pseudolite, the receiver unit should be able to

- Track the GPS satellites, the GEO satellites, and the EGNOS pseudolites, and
- Send the following raw data to the user terminal over a Bluetooth data communication link for navigation processing:
  - GPS ephemeris and pseudoranges;
  - The raw bit streams (500 bps) containing the SBAS messages from the EGNOS psedolites and/or the GEO satellites (whenever visible); and
  - Ranging measurements to the pseudolites.

As the GPS module is a low cost one that has limited processing power. It can decode only one SBAS data stream in real-time. In our case, it is required to decode multiple SBAS data streams from the GEO satellites and pseudolites. Therefore, the decoding process for multiple SBAS data streams is implemented in the user terminal side (Pocket PC).

Furthermore, the navigation software in the user terminal should distinguish the EGNOS pseudolites and the GEO satellites and apply no ionosphere corrections to the ranging measurements of the EGNOS pseudolites as these ranging signals do not go through the ionosphere .

Fig. 8. Components of the EGNOS pseudolite system.

The navigation software in the user terminal has the functionalities of real-time positioning, data logging and play-back function. While running in a real time mode, every single bit across the serial cable can be logged to the user terminal in binary format. By using the play-back function of the terminal software, the user can re-process the same data set with different positioning modes. This function is convenient and important for system testing and performance evaluation. Fig. 8 shows all the components of the EGNOS pseudolite system.

3. Preliminary Test Results

A preliminary test has been carried out on a surveyed site on the roof of the official building of the Finnish Geodetic Institute. The objective of the test was to verify the functionality of the system. The data set collected from the test was processed in two scenarios: one with four GPS satellites while the other with three GPS satellites plus one pseudolite. The satellite geometries for both data processing scenarios are similar as shown in Fig 9. All EGNOS GEO satellites are masked out for the test. The EGNOS pseudolite installed on the same roof was employed in this test. It transmitted the modified SBAS messages and provided a ranging measurement for the positioning solutions. No SBAS corrections were applied for both data processing scenarios.

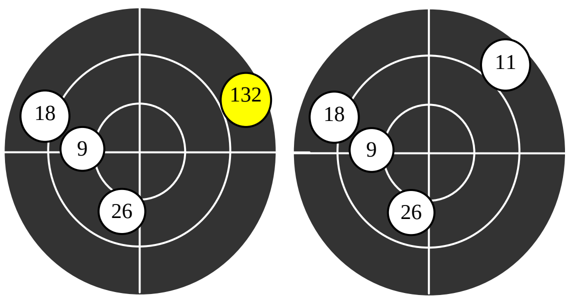

Fig. 9. Sky plots for two data processing scenarios.

Fig. 10 shows the differences of the positioning accuracies of these two data processing scenarios. It is obvious that the positioning accuracies of both scenarios are similar.

4. Conclusions

The EGNOS pseudolite system brings two benefits to the GNSS users: additional ranging measurement(s) and the SBAS corrections. A preliminary test has been carried out at a surveyed site for testing the functionalities of the system. The data set collected from the test has been processed with two scenarios: one with four GPS satellites, while the other with three GPS satellites plus an EGNOS pseudolite. Both scenarios have similar satellite geometries. The test result shows that the positioning accuracies are similar for both scenarios. To evaluate the performance of the system and the benefits of the SBAS corrections, further tests are still needed.

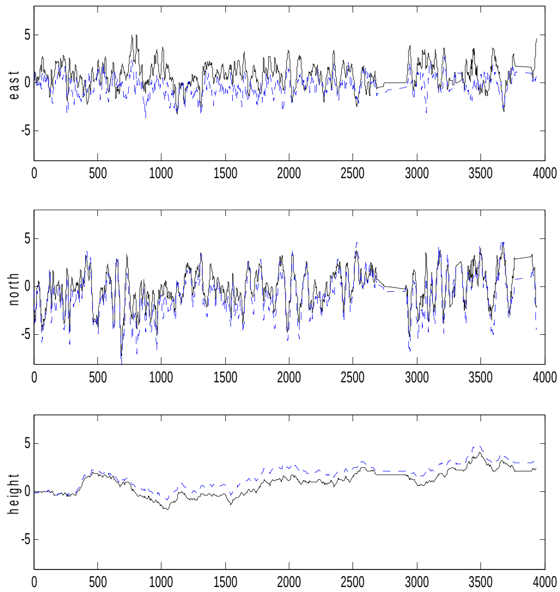

Fig. 10. Positioning accuracy of two data processing scenarios. Solid line: for the scenario with 4 GPS satellites, dotted line: for the scenario with 3 GPS satellites + 1 pseudolite.

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