EGNOS System Testbed Status and Achievements

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BIOGRAPHY

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Norbert Suard is an Engineering Specialist in the CNES Ground Segment Development Division where he has over 15 years of experience in development and studies of navigation system augmentation (CE-GPS, EURIDIS, and EGNOS ESTB).

ABSTRACT

Europe is fully engaged in the development of EGNOS, the European Geostationary Navigation Overlay Service, aimed at augmenting GPS and Glonass navigation services in terms of precision, data integrity and continuity and availability of services. EGNOS is now a reality as a test bed - a simplified version of the fully-fledged system has been readied in January 2000 by Alcatel Space Industries, the prime contractor leading the international industrial team that is developing the system.

Thanks to this test bed system, an EGNOS-like signal has since mid-February 2000 been transmitted from space, providing users with a GPS augmentation signal and enabling them to compute their positions to an accuracy of a few metres. The EGNOS test bed signal is currently available in the coverage area of the AOR-E satellite, and in the current of year 2001 it will be also available in the coverage of IOR satellite.

ESA is responsible for the technical management and the overall operations of the EGNOS System Test Bed and, in performing this role, is working in close co-operation with the French space agency CNES and the Norwegian Mapping Authority (NMA) which have also made in-kind contributions to development. Development of the EGNOS System Test Bed was managed by Alcatel Space Industries, ESA prime contractor for EGNOS and by the subcontractors GMV (E), Racal (UK), Seatex (N) Astrium (D) and DLR (D).

The EGNOS System Test Bed (ESTB) is also a unique tool for the analysis and design of EGNOS. As such, the ESTB is an integral part of the ESA EGNOS programme. During 2000, the ESTB activity has mainly focused on the improvement of the SIS availability and the performance.

The paper will present:

1. An overview of the ESTB implemented architecture and a recall of the main features,
2. The way the system is being operated, the "Help desk" organisation and the SIS availability status
3. An overview of the on-going developments such as the evolution of the standard, the addition of news reference stations, and the expansion mode outside ECAC
4. A description of the achievements and WAD results obtained so far, in particular results on accuracy of the positioning and integrity.

Finally, it will be concluded by an overview on demonstrations and applications that are now possible with the ESTB.

INTRODUCTION

The ESTB (EGNOS System Test Bed) is a real-time prototype of EGNOS. It provides the first continuous

GPS augmentation service within Europe, and constitutes a great step forward for the European strategy to develop the future European Satellite Navigation Systems: EGNOS and Galileo.
The ESTB has been developed with a set of objectives including:

- The support to EGNOS design: In particular, algorithm design benefits from the ESTB experience in design and usage.
- The demonstration of the capabilities of the system to users: The ESTB constitutes a strategic tool for the ETG (European Tripartite Group, formed by ESA, EC and Eurocontrol). The ETG plans to promote the use of EGNOS and analyse its capabilities for different applications. In particular, ESTB availability will allow Civil Aviation authorities to adapt their infrastructure and operational procedures for future EGNOS use when it becomes operational.
  A specific workshop sponsored by ESA aimed at fostering the use of ESTB and analysing the needs of potential users was successfully organised on July 6-7, 2000 with a very large number of participants covering a variety of different users and countries world-wide.
- The analysis of future EGNOS upgrades.
- To serve as a backbone for continuous EGNOS experimentation and design improvement process.

1. ESTB ARCHITECTURE

The ESTB architecture is presented in figure 1; it has been driven by high performance objectives in order to be able to assess the operational capabilities of EGNOS.

Also, in order to reduce the development time of the ESTB and to optimise the overall ESTB effort, a number of existing assets have been taken into account to build up the ESTB:

- from NMA in Norway, based on the existing SATREF system,
- from CNES, based on the EURIDIS ranging system (EURIDIS was implemented in order to provide the GPS ranging capability on the INMARSAT III AOR-E navigation payload),
- From ENAV, based on the MTB (Mediterranean Test Bed) composed of one NLES for broadcast on IOR and two reference stations located in Fucino and Matera.

The following paragraphs detail the ESTB design and elements, highlighting the contributions of the IKD providers:

- A network of reference stations (RS) sized to a number of 10, expandable in the future, and which are permanently collecting GPS/GEO/GLONASS data. Two additional RS provided by AENA (Spain) will be connected around mid 2001 (located in Palma de Mallorca and Gran Canaria).
- A Control and Processing Facility (CPF) generating the WAD (Wide Area Differential) user messages. This CPF is located in Honefoss (Norway), and supported by SATREF™ platform.
- Three EURIDIS reference stations for the purpose of the Ranging function. These RS are located on an intercontinental basis in order to provide a wide observation base for the GEO. They are also collecting GPS/GEO data.
- A EURIDIS processing centre located in Toulouse (France), devoted to the generation of the GEO ranging data, and which also acts as a node for the transmission of the user message.
- Two Navigation Land Earth Stations (NLES) are used in the ESTB. The NLES located in Aussaguel, close to Toulouse (France), is part of the EURIDIS Ranging system and transmits through INMARSAT III AOR-E satellite; the other NLES is placed in Fucino (Italy) providing access to the INMARSAT IOR satellite.
- A real-time communication network based on frame-relay links, allowing the transfer of the RS data to the processing centres, and of the navigation messages from Honefoss to the NLES.
- Independent User receivers to test the system and perform demonstrations.
- Post processing tools to analyse the ESTB performances.

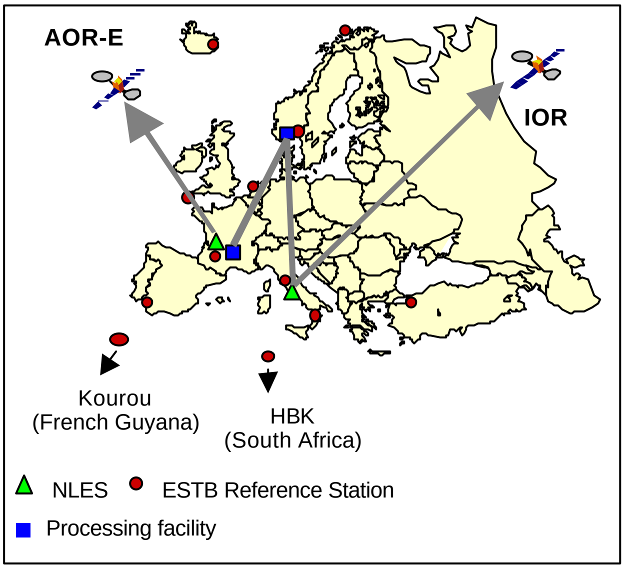

Figure1: Ground elements location

2. ESTB OPERATIONS AND USERS SUPPORT

2.1. Operations Team

ESA plans to operate the ESTB continuously until EGNOS becomes operational. The ESTB ground segment is controlled on working hour's basis, but the system is able to run continuously unless there is no hardware failures.

The operational tasks are under ESA responsibility. Different parties contribute to the daily operations, either under a contract with ESA or through co-operation agreements:

- CNES (French Space Agency) for the Ranging ground segment (Euridis) operations, the AOR-E signal generation and the overall ESTB co-ordination
- the Norwegian Mapping Authority (NMA), for the operations of the reference stations and the CPF processing facility in Honefoss
- Telespazio, for the MTB operations including the IOR SIS generation
- Thales for the Frame Relay network operations

2.2. SIS robustness: providing a 24h service

The SIS availability (% per month) is shown in figure 2. In March 2001 the SIS availability was:

- with GPS corrections: 84%
- with ranging only: 2%

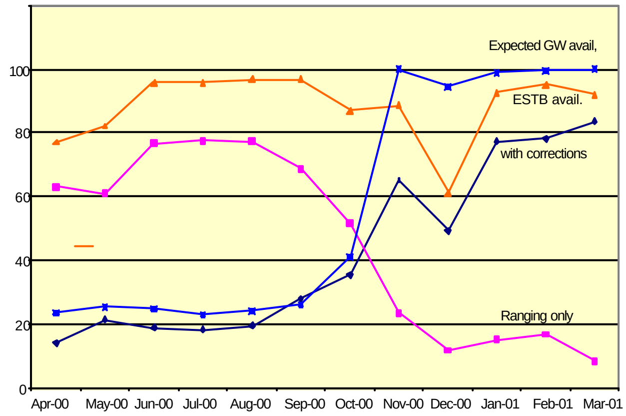

Figure 2: SIS availability (% per month)

Major losses of availability are due to interruptions during week-end (NLES long Loop and CPF interruptions). To reach a target of 95% availability before end 2001, ESA has planned some improvements of the CPF processing and of the NLES long loop with automatic restart capability. Also, to avoid interruptions when industrial tests are performed, a redundancy Platform of the CPF processing will be provided at Honefoss.
The broadcast schedule for IOR and AOR-E can be found for each month on the EGNOS web site with address http://www.esa.int/EGNOS.

2.3. Experimenter's support: ESTB users Helpdesk

The ESTB provides a unique opportunity for validating and demonstrating new service and application developments in a realistic environment, in preparing for the EGNOS operations from 2004 onwards but also in getting ready for the initiation of the Galileo system later this decade. To support these initiatives, the European Space Agency has set-up an ESTB Helpdesk e-mail service (ESTB@esa.int).
The ESTB Helpdesk e-mail service is available for all current or future ESTB users as well as anyone else with an interest in state-of-the-art satellite navigation. The ESTB Helpdesk will respond to questions on the ESTB architecture and performance, EGNOS receivers, ESTB Signal in Space (SIS) status and on ESTB evolutions. Moreover, it will try to assist potential users in every possible way on how to exploit the ESTB for their specific application or service developments.

3. ONGOING UPGRADES

Even after very satisfactory results, the ESTB is still evolving. In particular, since March 2001:

- ♦ The ESTB is able to broadcast SIS in compliance with the updated MOPS DO229A
- ♦ The ESTB-CPF embraces capabilities for providing an enhanced navigation service. Expansion Service is aimed at providing a controlled service out of the nominal service area. Different concepts and architectures have been investigated depending on the relative location of the secondary service area and EGNOS primary service area. Only one CPF, as currently designed, is sufficient to provide WAD corrections and integrity to both areas simultaneously.
- ♦ The processing of the ionospheric vertical delay has been developed and verified for low latitude ionosphere conditions (ionosphere equatorial crest region, a zone of enhanced electron density at both sides of the geomagnetic equator).

3.1. Signal specifications: MOPS DO229A

The ESTB SIS is conform to the MOPS DO229A [ref.2]. Differences are only applicable to receivers used within expansion areas (usage of message type 27).

- Type 27 message will broadcast *ESTB UDRE Increment Indicators*.
- Only one type 27 message with up to 7 regions will be broadcast.
- The *ESTB UDRE Increment Indicator* will be the same for all regions included in message type 27. Moreover, such a value will be a configuration parameter.
- ESTB users within the designated region will translate the broadcast *ESTB UDRE Increment Indicator* to *ESTB UDRE Increment Factor* by means of a table different from the table A-20 of Ref.
- ESTB users will translate the broadcast *ESTB Region Radius Indicator* to degrees by means of a

table different from the table A-21 of Ref. [2] and provided in figure 4.

Region radius indicator	Region radius in degrees
0	5
1	10
3	15
4	25
5	30
6	35
7	40

Figure 4: Table for MT27

3.2. Expansion service: ECUREV project

3.2.1. Objectives

The major objectives of the ECUREV project (awarded by the European Commission to GMV) were:

a) to design and develop a Test Facility, composed of a portable monitoring station (RIMS) with autonomous communication means, and a User Monitoring Unit (UMU tool) for performances monitoring. The Portable RIMS has been designed for an easy transportation and installation. In order to avoid any dependency from local communication means, each RIMS is equipped with a VSAT (Very Small Aperture Terminal). The User Monitoring Unit, consist of one receiver compatible with ESTB SIS plus some SW tools that support the specific implementation of message type 27 in ESTB-CPF. These tools are also intended for the performance analysis of collected data. User Monitoring Unit has been designed to remain static, though future upgrades for a mobile platform environment will be possible with minimum changes.

b) to design and develop the necessary software changes in the Central Processing Facility (CPF) of the ESTB aiming at providing APV-I performance over an expansion area located out of Europe. The major changes are:

- **Ionospheric Corrections Module:** Implementation of modelling supported by a-priori information.
- **UDRE Computation Module:** It is necessary to degrade UDRE in the Expansion Service area while maintaining the values in the nominal service area, by means of message type 27. The expansion service area is defined through the use of such a message. For the sub-areas identified in this message, a particular UDRE increment common to all satellites can be defined, thus ensuring integrity over the expansion service area. The definition of an appropriate "UDRE increment" is one of the key issues for the service expansion.
- **Message Selection and Generation Module:** Usage of message type 27, and optimise the available GEO payload bandwidth (this specially affects to ionosphere corrections and GIVE over the expansion service area).

c) To conduct a test campaign in Canary Islands, in order to analyze the possibilities of expanding the EGNOS service outside of Europe, and to prove the correct performance of the changes implemented in the ESTB-CPF.

A portable RIMS has been deployed at Tenerife Sur airport and linked to the ESTB-CPF.

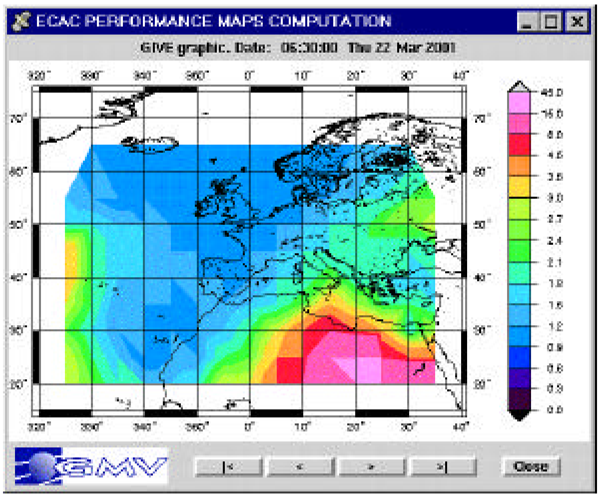

Figure 3: GIVE estimates (ECUREV scenario, 9 RIMS)

Figure 3 shows a map with the GIVE obtained in ECUREV expansion scenario. This figure, when considering the RIMS location, shows the high dependence of the ionospheric delay quality determination on the RIMS geometry, resulting in lower errors in the estimation and, hence, lower GIVE values.

By ordering additional RIMS units, ESA and the European Commission will be then in a position to conduct tests in different areas, to show to interested parties the augmentation navigation capabilities provided by ESTB.

4. CURRENT TYPICAL PERFORMANCES

4.1. Integrity availability

The current ESTB typical performances measured on different point of the ESTB service area with 8 Reference stations (without using the GEO ranging capability) are as follows:

- for APV-II service (VAL=20m), the achieved availability reach 93%

- for APV-I service (VAL=50m) the achieved availability is very close to 100%.

These results are illustrated by the diagrams introduced by the Stanford University where VPE (in horizontal) and VPL (in vertical) pairs as computed every epoch are plotted. Figures 5 and 6 shows the VPL versus VPE and HPL versus HPE performances computed with 10 RS in Toulouse on 24 hours (15 March 2001)

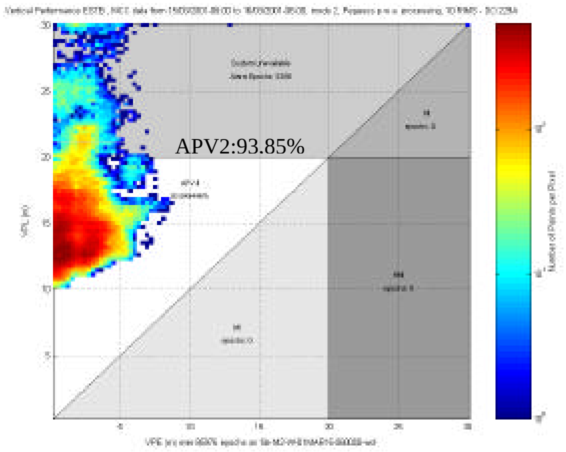

Figure 5: VPL vs. VPE (24 hours duration)

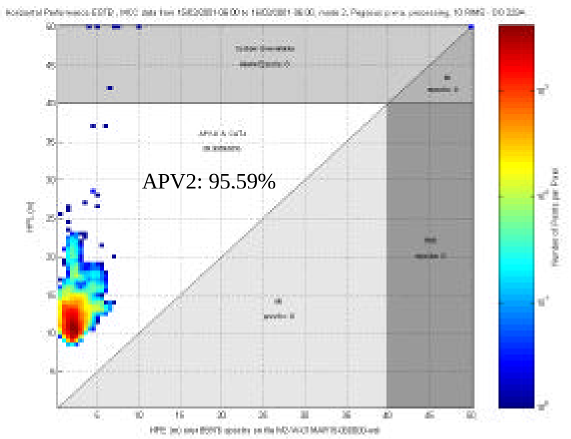

Figure 6: HPL vs. HPE (24 hours duration)

4.2. Accuracy performances

The typical accuracy achieved within the ESTB service area is (without using the GEO ranging capability):

- HNSE: 3m 95%
- VNSE: 6m 95%

The average estimated VNSE with 10 ESTB reference stations connected (including the MTB) is shown in figure 6.

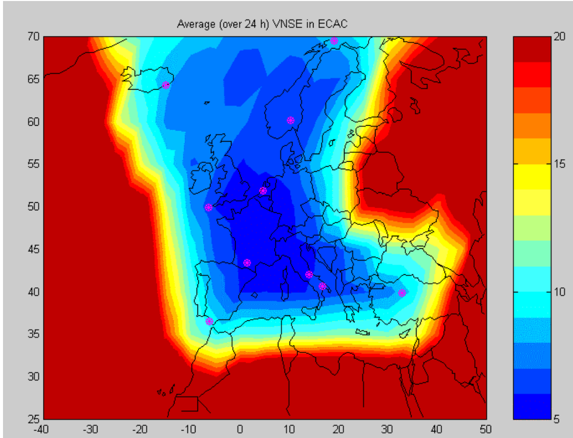

Figure 6: average VNSE with MTB Stations

5. CONCLUSIONS

The ESTB is now providing a pre-operational signal in space, allowing a high level of positioning accuracy above Europe. It supports four main domains:

1. Industrial activities for the development of EGNOS: assessment of the overall system and the mission performances to establish confidence in the system design and that the final accomplishment of the mission requirements can be reached.
2. Validation of algorithms during EGNOS implementation phases, including subsystems testing with real data.
3. Preparation of the EGNOS operational phase: In the year 2000, the ESTB was used for static and in-flight data collection activities, and for 2001 new operational activities are scheduled.
4. Demonstrations: the ESTB will also continue to play an important role in demonstration activities not only for aviation but also to prove EGNOS functionality for other modes of transport. Multi-modal trials have already been performed involving land, maritime, and rail users (see Ref7):
   - Maritime demonstration was made during February 2000 in Genoa Harbour.
   - road demonstration in Turin during November 2000
   - maritime demonstration in Greece during March 2001

REFERENCES

[1] Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment. “Change No. 1 to RTCA/DO-229” July 15, 1997.

[2] Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment. RTCA/DO-229A June 8, 1998..

[3] Draft GNSS Standard and Recommended Practices (SARPs) corresponding to GNSSP/3, Montreal. May 12-23, 1999.

[4] EGNOS System Test Bed: Achievements and Ongoing Upgrades, A. Cruz et al, GMV. ION GPS 2000, Salt Lake City, USA, September 2000.

[5] ECUREV. EGNOS Expansion Concepts and Implications on ESTB, I. García et al., GMV November 1999

[6] ESTB/SIS - User Interface Description (E-TN-ITF-E31-0008-ESA), N. Suard, H. Secretan

[7] ESTB News, Issue 1, May 2001