The Transition from ESTB to EGNOS: Managing User Expectation

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1 Abstract

EGNOS, the European Geostationary Navigation Overlay Service, is being developed under the European Space Agency's ARTES 9 programme. This will be concluded with the Operational Readiness Review (ORR) in April 2004. Thereafter, the EGNOS Operator/Service Provider (to be nominated) is to take over and to lead EGNOS into providing a reliable signal-in-space and possibly more, all in support of safety-critical and a great number of other services.

The EGNOS System Test Bed (ESTB) has also been developed under the ARTES 9 programme as an EGNOS prototype, and has been providing pre-operational signals since February 2000. It has had a key role during the development phase, helping industry to shape the design, tune algorithms, and assess real-time issues using real data. It has also helped to prepare the market for EGNOS applications.

2003 is going to be a year of change, and we need to ensure a smooth transition from ESTB to EGNOS and to provide timely information to users and applications developers.

This paper will start by summarising the differences between the ESTB and EGNOS. It will explain why the EGNOS infrastructure is more extensive, the remarkable impact that this has on the expected performance, and its support for safety-of-life applications.

The transition from ESTB to EGNOS will then be presented from a user's perspective including: using the different geostationary satellites; the impact on users of switching from ESTB to EGNOS as the source of integrity and wide area differential data; the likely testing

that will take place; and the plans for SISNeT – providing the EGNOS signal-in-space over the Internet.

The paper will conclude by describing the level of performance that users can expect during the period up to ORR (April 2004), and identifying how they can get hold of the latest information.

2 Introduction

EGNOS is nearing completion. The system design started in 1997 and we are expecting EGNOS to be declared fully operational in April 2004 on completion of the Operational Readiness Review (see Figure 1).

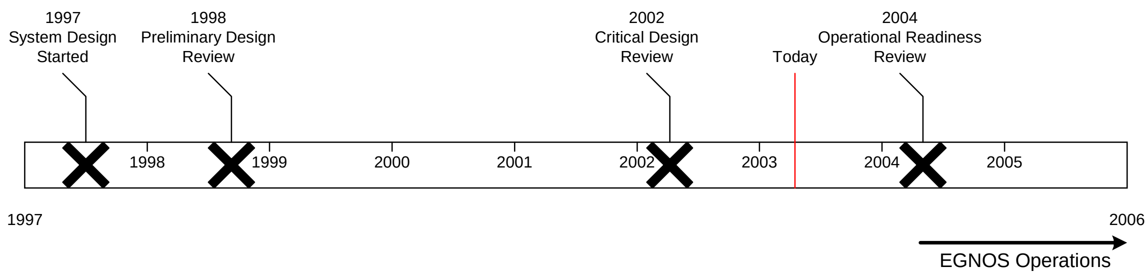

Figure 1: EGNOS Project Development

The ESTB was developed in parallel as an EGNOS prototype, and it has been providing pre-operational signals since February 2000. The ESTB has been invaluable helping industry to shape the design, tune algorithms, and assess real-time issues using real data. It has also helped to prepare the market for both EGNOS and Galileo applications.

So, 2003 is going to be a year of great change and we need to ensure a smooth transition from ESTB to EGNOS. User perception is driven by the signals broadcast by the geostationary satellites and the efficacy of the WAD and integrity data modulated on that signal. This means that we need to have an appreciation of the signal structure, the WAD and integrity data generation process and the delivery options using different geostationary satellites. Critically, we need to manage expectation during this transition process by providing timely information to users and applications developers.

This paper is the first stage in the expectation management process. In Section 3 we will give an overview of the two different systems, EGNOS and ESTB and summarise the key differences between the two systems. The transition to EGNOS is presented in Section 4 where we cover the signal structure, the use of the different geostationary satellites, RIMS deployment and SISNeT. This paper concludes in Section 5 by considering the user experience in terms of receivers, the expected level of performance, and where the latest information can be found.

3 EGNOS and ESTB

3.1 EGNOS

The European Space Agency, together with both the European Commission and Eurocontrol, is currently implementing EGNOS - the European contribution to the first phase of the Global Navigation Satellite System (GNSS-1). EGNOS augments GPS and GLONASS, providing and guaranteeing the availability of navigation signals for aeronautical, maritime and land mobile trans-European network applications. It will become operational in April 2004.

EGNOS users will benefit from improved performance, removing the need for local-area differential and commercial services in many cases.

- EGNOS has been designed to meet the demanding navigation performance requirements for aviation;
- accuracy is improved to about 5 meters vertical and 1 meters horizontal through the broadcast of wide-area differential (WAD) corrections;
- integrity (safety) is improved both through the high degree of redundancy in the system and by alerting users within 6 seconds if something goes wrong with EGNOS, GPS or GLONASS; and
- availability is improved by broadcasting GPS look-alike signals from three geostationary satellites.

EGNOS provides a European-wide, standardised and quality-assured positioning system suitable for a diverse range of applications. It is highly compatible with GPS, so a single antenna and receiver can process both the GPS and EGNOS signals eliminating the need for a separate radio to receive differential corrections. This will allow many users to dispense with their current local-area differential or commercial services.

The EGNOS architecture is highly redundant, generating wide-area differential corrections and alerting users within six seconds if something goes wrong (Figure 2).

Thirty-four Reference and Integrity Monitoring Stations (RIMS) are deployed to monitor the satellite constellation satellites. Each satellite has to be monitored by multiple RIMS before correction and integrity messages are generated. Four Mission Control Centres (MCC) process data from these RIMS to generate the WAD corrections and integrity messages for each satellite. Only one of these MCCs is active and operational, the other MCCs are hot spares that can be activated if a problem occurs.

Navigation Land Earth Stations (NLES) upload the corrections and integrity messages to the satellites, for onward broadcast to the users. The system will deploy two NLESs (one primary and one backup) for each of the three geostationary satellites, and a further NLES for test and validation purposes.

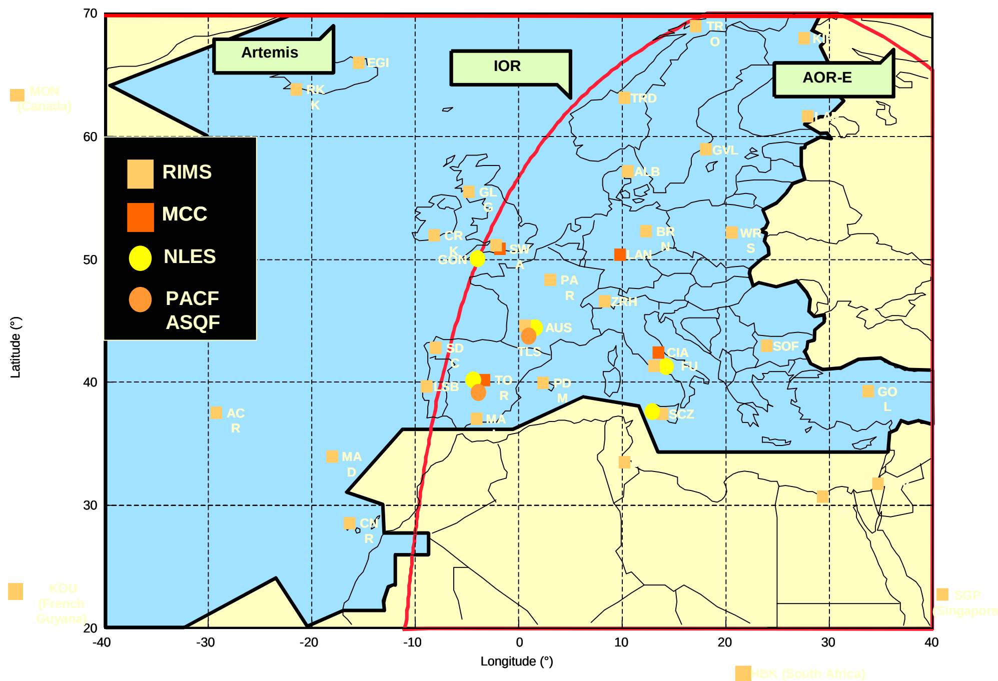

Figure 2: EGNOS Infrastructure

The EGNOS space segment comprises three geostationary satellites with global earth coverage. The EGNOS operational system is based on the use of two INMARSAT-3 satellites (Atlantic Ocean Region East – AOR-E - and Indian Ocean Region West AOR-E - IOR-W also known as F5), as well as the ESA ARTEMIS satellite (Figure 3).

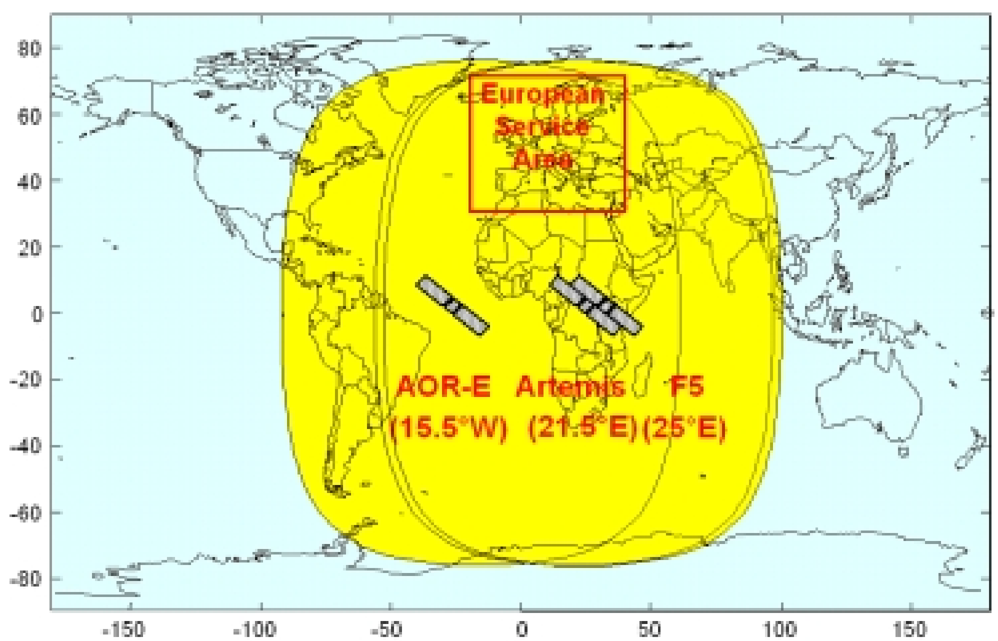

Figure 3: EGNOS geostationary satellite broadcast areas

EGNOS users should be able to track at least two geostationary satellites. It takes less than six seconds to notify users about a problem with one of the satellite constellations once it has been monitored by the RIMS network.

EGNOS provides different levels of service at different parts of the area covered by the geostationary satellites. Optimum performance is obtained within the core coverage area (Figure 3). There is degraded performance outside the core area, although there is some potential for improvement through interoperability with the Japanese, American and Canadian systems.

3.2 ESTB

A pre-operational service has been available from the EGNOS System Test-Bed (ESTB) since February 2000. Based on test signals, it is important to stress that the ESTB does not provide the same availability and integrity as EGNOS and hence cannot be used for safety or mission critical applications. The ESTB serves a European service area similar to that of EGNOS, using a much smaller number of RIMS (12 minimum) and only two geostationary satellites (see Figure 4). Accuracies of around 1 metre horizontal (95%) can be obtained in some parts of the coverage area but is limited by RIMS density.

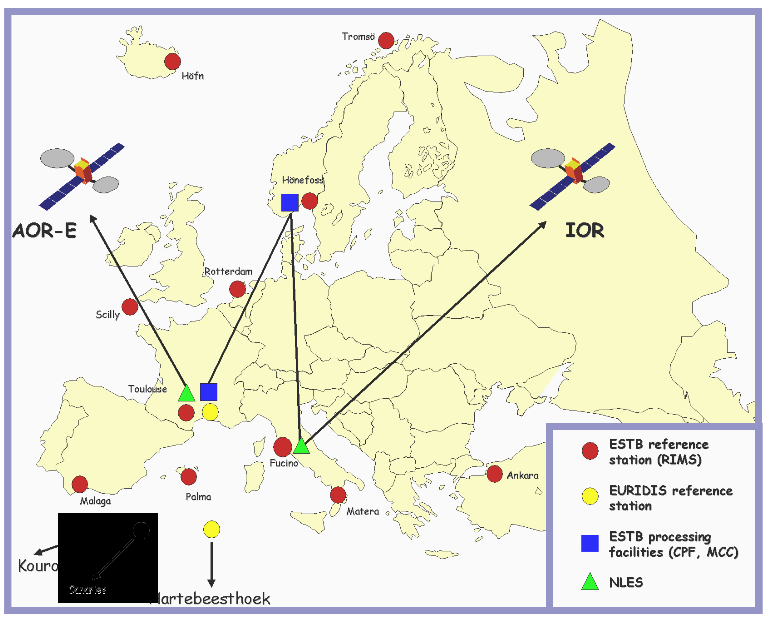

Figure 4: EGNOS System Test Bed

This provides a unique opportunity for validating and demonstrating new service and application developments in a realistic environment, not only preparing for the EGNOS operations from 2004 onwards but also in getting ready for the initiation of the Galileo system later this decade.

The key differences between the ESTB and EGNOS are summarised in Table 1 for the same European coverage area.

Parameter	ESTB	EGNOS
Number MCS	1	4
Number RIMS	12	34
Number NLES	2	6
Accuracy provided	1m 95% limited by RIMS density	1m 95% throughout the coverage area
Integrity provided	No	Yes
Service guarantee	No	Yes

Table 1: Key differences between ESTB and EGNOS

4 The Transition to EGNOS

User expectation is performance dependent (i.e. in terms of accuracy, integrity, availability and continuity) and user perception is driven by the quality of the WAD and integrity data modulated on the signals received from the geostationary satellites. The quality of the WAD and integrity data is itself dependent on the distribution and density of the RIMS network.

ESA intends to ensure continuity of the ESTB service at least until EGNOS is declared operational. At the same time, however, it needs to deploy and test EGNOS so that it can be brought into service in 2004. The limiting factor here is the number of satellites available for both systems, and hence it is vitally important that users understand which satellite is being used by which system (ESTB or EGNOS) and the performance provided so that they can configure their receivers appropriately.

4.1 Signal Structure

EGNOS uses the same frequency (L1 1575.42 MHz)) and ranging codes as GPS, but has a different data message format. Consequently, only slight hardware modifications are required for a standard GPS receiver to track EGNOS.

Integrity is provided at two levels every six seconds: coarse use/don't use for all satellites in view of the EGNOS coverage region (including the GEOs); and two parameters - σ^2_{UDRE} and σ^2_{UIVE} – that are an estimate of the satellite and atmospheric errors remaining after applying the WAD corrections. These are used to compute a certified error bound for the position solution in an integrity assessment.

The WAD corrections comprise terms to correct for each satellite's clock and ephemeris errors as well as errors due to the ionosphere. Fast and slow WAD corrections model the temporal decorrelation of the different error sources. The fast corrections model rapidly changing error sources include satellite clock errors. The slow corrections model more slowly changing error sources including long-term satellite clock drift and ephemeris errors. Ionospheric delays are provided at pre-defined grid points (Figure 5).

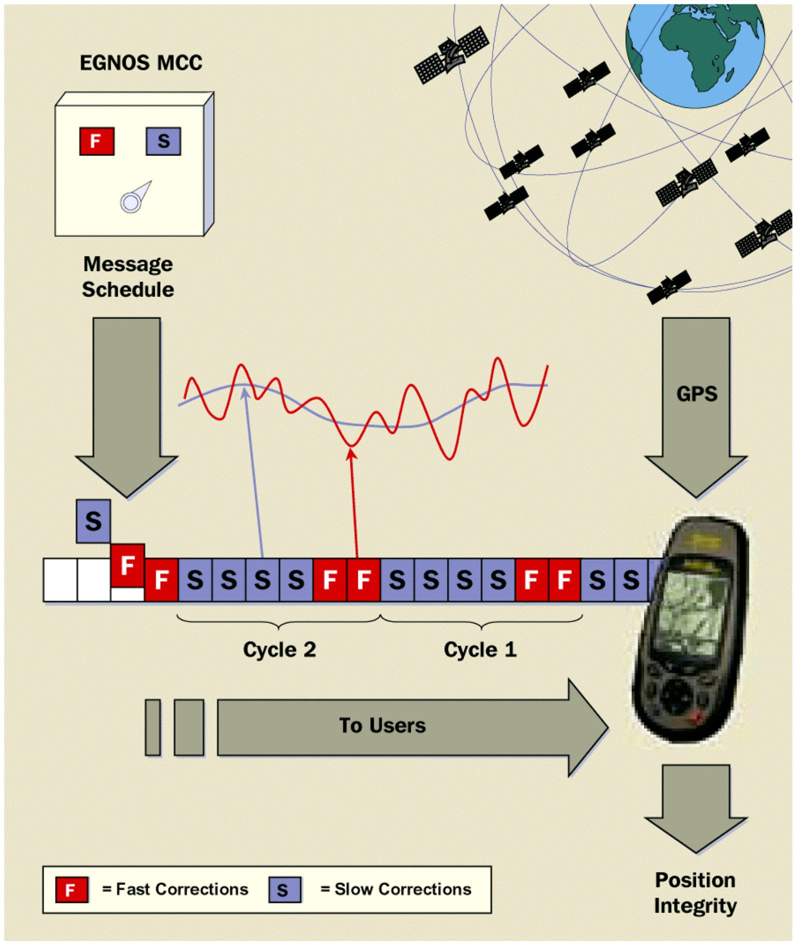

Figure 5: Delivering SBAS messages to users

Sixteen different message types have so far been defined to broadcast integrity data and WAD corrections (Table 2). The message schedule follows a 6-second duty cycle (Figure 5). This is structured both to prioritise the 6-second integrity time-to-alarm and to minimise the time for EGNOS initialisation.

Type	Comment	Type	Comment
0	Don't use this SBAS signal	17	GEO satellite almanacs
1	PRN Mask assignments	18	Ionospheric grid point masks
2-5	Fast corrections	24	Mixed fast/slow error corrections
6	Integrity information	25	Slow satellite error corrections
7	Fast correction degradation factor	26	Ionospheric delay corrections
9	GEO navigation message	27	SBAS service message
10	Degradation parameters	63	Null message
12	SBAS Network Time/UTC offsets		

Table 2: SBAS Message Types

The EGNOS signal has three key benefits:

- it is compliant with international standards for satellite based augmentation systems and so will be interoperable with similar systems in the US, Japan, Canada and India;
- the signal design is based on GPS and so a GPS receiver with minimal hardware modifications can track the EGNOS signal. This has two benefits: EGNOS provides additional range measurements that enhance availability; and EGNOS corrections can be used without purchasing a separate receiver; and
- it provides both enhanced accuracy and integrity (quality of service). The ESTB is delivering one-metre accuracy (similar to DGPS) that is independent of user/reference station distance. The EGNOS integrity information will give users additional confidence in the total system, alerting them within six seconds when something goes wrong.

SBAS interoperability has always been a pre-requisite for delivering a global seamless safety-of-life service. This was recognised early on by SBAS developers and air traffic services providers, and they have worked closely together to co-ordinate their activities at ICAO and in the Interoperability Working Group (IWG). One of the IWG's key activities has been to ensure that standards are available: Standards and Recommended Practices (SARPS) for system developers; and SBAS Minimum Operational Performance Standards (MOPS) for receiver manufacturers (DO229-C).

Despite all the efforts to co-ordinate standards, there has been some confusion during the initial test phase that has meant that some WAAS receivers could not process the EGNOS message. Two different test-warning messages are allowed in DO229-C but some receiver manufacturers only implemented one of them:

- in the first approach adopted by EGNOS, Message Type 0 is used to indicate that the system is on test and is not usable for safety critical applications. Receipt of a message type 0 normally results in the termination of the use of any ranging data and all messages; and
- in the second approach adopted by the WAAS, Message Type 2 data are transmitted in Message Type 0, indicating that the system is under test and optimising the use of the SIS bandwidth.

At 07:30 UTC on Tuesday 1st April the ESTB started to broadcast its signal using the revised Mode 0/2 format (the second approach), improving interoperability with other systems (WAAS and MSAS) and allowing all GPS/SBAS receivers to process the EGNOS test signal.

This new format allows *all* users equipped with GPS/SBAS receivers to benefit from the improved accuracy obtained when applying the differential corrections broadcast by both the WAAS in the USA and the ESTB in Europe.

4.2 Use of Geostationary Satellites

There are four geostationary satellites currently available to EGNOS/ESTB:

- Inmarsat Atlantic Ocean Region-East (AOR-E) at 15.5° W broadcasting with a PRN code of 120;
- Inmarsat Indian Ocean Region-West (IOR-W) at 25°E broadcasting with a PRN code of 126;
- Inmarsat Indian Ocean Region (IOR) at 65.5°E broadcasting with a PRN code of 131; and
- ESA ARTEMIS at 21.5° E broadcasting with a PRN code of 124.

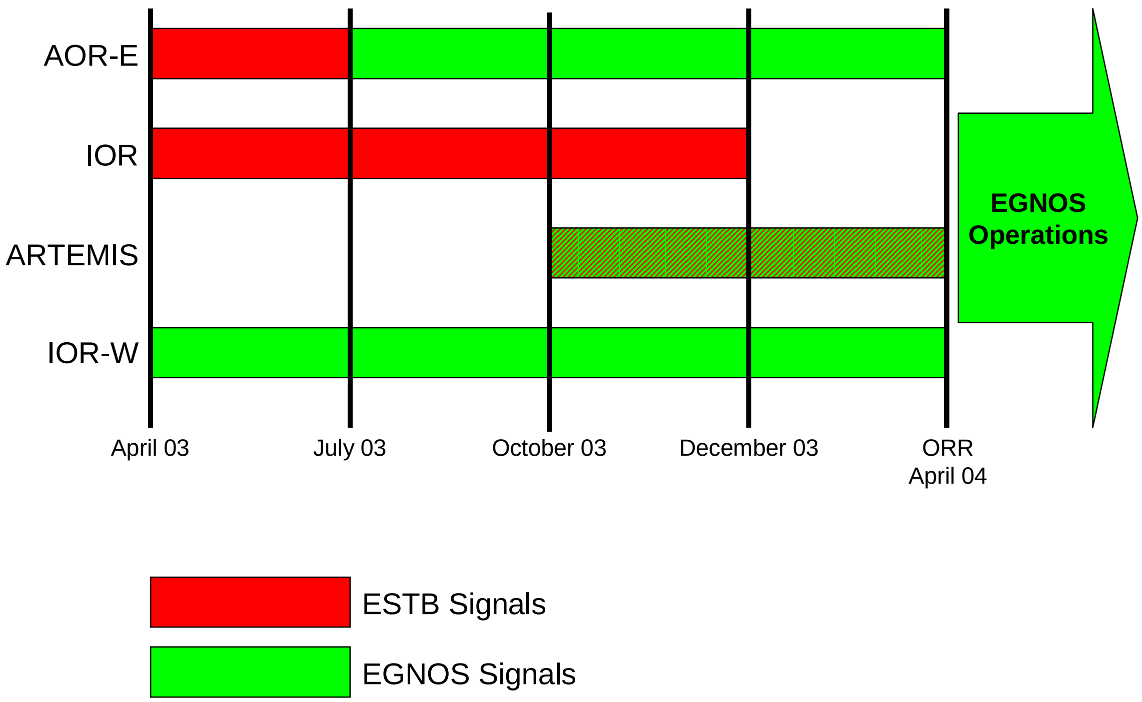

Figure 6: The preliminary EGNOS geostationary satellite strategy

The Inmarsat IOR satellite will cease to be available to EGNOS after December 2003 and so the preliminary geostationary satellite strategy is based on three satellites: AOR-E, IOR-W and ARTEMIS. AOR-E and IOR-W will be primary EGNOS satellites while ARTEMIS will fulfil a dual-role broadcasting either the ESTB or EGNOS signals.

4.3 RIMS Deployment

The quality of the WAD and integrity data is critically dependent on the number and density of the RIMS that provide the raw data. The EGNOS RIMS deployment has been designed to deliver incremental improvements in three stages:

- SIS-0 – comprises 6 RIMS, 1 MCC and 1 NLES with the signal being broadcast through the Inmarsat IOR-W satellite. The aim is to perform end-to-end tests, to demonstrate message format compliance, and the collection and analysis of data. There is no performance objective due to the small number of RIMS. The first SIS-0 signal was broadcast in April 2003;

- SIS-1 (Q3 2003) – comprising 10-15 RIMS, 1MCC and 1 NLES with the signal being broadcast through the AOR-E and IOR-W satellites. The aim is to meet the NPA/APV-1 performance associated with Level 2 performance.
- SIS-2 (Q4 2003) – comprising more than 25 RIMS, 2MCCs and 2 NLES with the signal being broadcast through the AOR-E and IOR-W satellites. This is the final step before the deployment of the remaining RIMS, MCCs and NLES that should occur in early 2004 for the ORR.

It is important to note that dates above are preliminary and indicative. Furthermore, we need to place a health warning on using these signals – they are all subject to system testing and should not be used operationally until after the ORR has been declared successful.

4.4 SISNeT

SISNet allows users to access the EGNOS signal-in-space over the Internet in real-time, improving the availability of EGNOS data in urban and other challenging environments.

EGNOS will broadcast through three geostationary (GEO) satellites, and the user has to maintain contact with at least one of them. This is fine for many users (e.g. aviation and maritime), but others (e.g. land mobile) may experience service outages in, say, urban canyons. This is particularly significant because ESA has shown that an EGNOS solution is more robust at higher mask angles, and that using the WAD corrections can deliver 10m accuracy (95%) with a high level of availability.

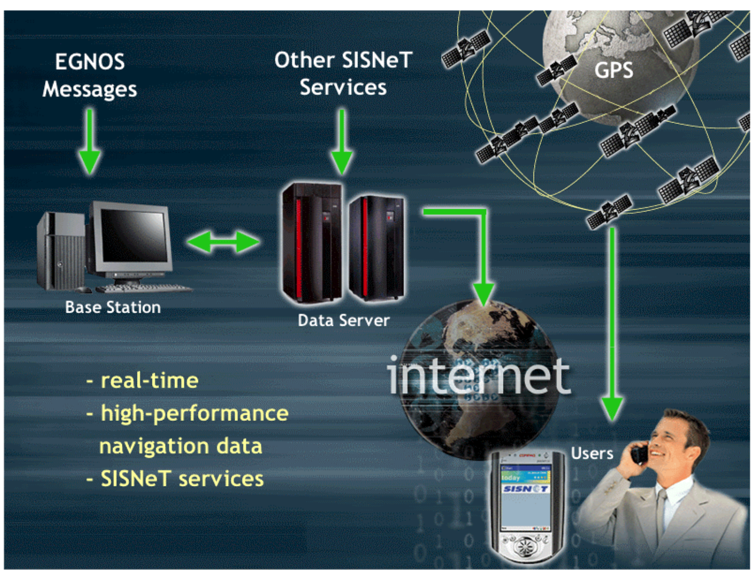

Figure 7: The SISNeT concept

Consequently, ESA is pursuing activities that aim to exploit fully the potential of EGNOS by investigating complementary transmission link options for EGNOS. SISNeT (Signal In Space through the interNeT) provides access to the ESTB messages over the Internet.

The SISNeT concept is illustrated in Figure 7 and comprises a Base Station, Data Server, Web Server and the User Applications. The Base Station can acquire the EGNOS messages either from an EGNOS receiver or from the ESTB Central Processing Facility. These are provided in real-time to the Data Server that implements all the extra services provided by SISNeT to users (e.g. text messages) and transmits these to a large number of connected users.

ESA has published a comprehensive SISNeT User Interface Document for those interested in developing SISNeT User Applications. The data rate is very small, typically 500 bit/s, and hence there is plenty of scope for embedding SISNeT on Personal data Assistants (PDAs) and other devices aimed at the land mobile market.

The real benefits of SISNeT are clear:

- the EGNOS signal is available even if GEOs are not visible;
- the SISNET data rate is less than 1 kbps, and hence can be accessed using GSM/GPRS;
- you no longer need an EGNOS receiver to obtain the EGNOS data - only a connection to the Internet is required; and
- pedestrian or land-mobile users will benefit from improved performance at higher mask angles.

5 The User Experience

5.1 Receivers

Recent investigations have shown that there are more than 120 receivers and 90 chipsets or boards on the market that are EGNOS compatible. If you buy a receiver that is compliant with the latest version of the GPS/WAAS MOPS (DO-229C), then you can be confident that your receiver will work with any SBAS signal. So, a receiver that is WAAS-compatible and compliant with DO-229C is also EGNOS compatible. However, it is important to note the following:

- if you are in the EGNOS coverage area, then your receiver will be able to track the GPS look-alike signals from other SBAS satellites (e.g. WAAS). Range measurements from the WAAS satellite are valid provided that the satellite is monitored by EGNOS. However, it is important to recognise that each SBAS optimises the WAD corrections and integrity data for its own coverage area, and hence only EGNOS WAD corrections and integrity information will be valid in the EGNOS coverage area; and

- your SBAS receiver will also work normally outside Europe. If you are in SBAS coverage, your receiver will track both GPS and GEO satellites and deliver the service provided by the operator. Otherwise, your receiver should functional normally in a GPS-only mode.

SBAS (i.e. EGNOS) data processing is more complex that GPS both because the messages have been designed to minimise the bandwidth requirements and because they need to account for updated GPS navigation information.

The receiver estimates corrections for satellite clock and ephemeris errors using the fast and slow satellite data messages. It has to account for both range-rate effects between successive fast corrections and performance degradation if a message is missed. The σ^2_{UDRE} term represents the residual range errors after having applied the fast and slow clock and ephemeris corrections.

The receiver then predicts ionospheric delays for each pseudo-range in three steps: it estimates where the satellite – receiver range pierces the ionospheric grid; the vertical delay at the pierce point is then interpolated from the surrounding grid points; and finally this is applied to the range measurement. The σ^2_{UIVE} term is applied to the range vector where it represents the residual ionospheric errors. Tropospheric errors may be mitigated using a simple model related to the receiver's position and the day number in the year.

Finally, EGNOS receivers compute a certified error bound for the position solution based on data broadcast by the GEO satellites, the user/satellite geometry, and the probability of integrity non-detection.

EGNOS will enhance GPS accuracy to around 1m (95%). It will also deliver an integrity service that provides a certified error bound for the GPS position solution, and alerts users within six seconds when out-of-tolerance events occur.

Prudent users with commercial or safety-related applications will value the added confidence provided by guaranteed EGNOS services.

5.2 What Level of Performance can I expect

The level of performance achieved will depend at any time on the geostationary satellite being tracked and whether the data are from EGNOS or ESTB. This is summarised in Figure 8 based. The ESTB currently delivers accuracies as good as 1m 95% but no integrity. EGNOS will deliver similar accuracies, but will also deliver integrity and availability to meet demanding safety and mission critical requirements.

The user needs to be able to select the most appropriate geostationary satellite for providing corrections during the transition period, and this is receiver specific. Once EGNOS has been declared operational following the ORR, it should deliver horizontal accuracies of around 1m 95% in the region shown in Figure 9 and APV-1 performance (equivalent to the current WAAS performance) in the region shown in Figure 10.

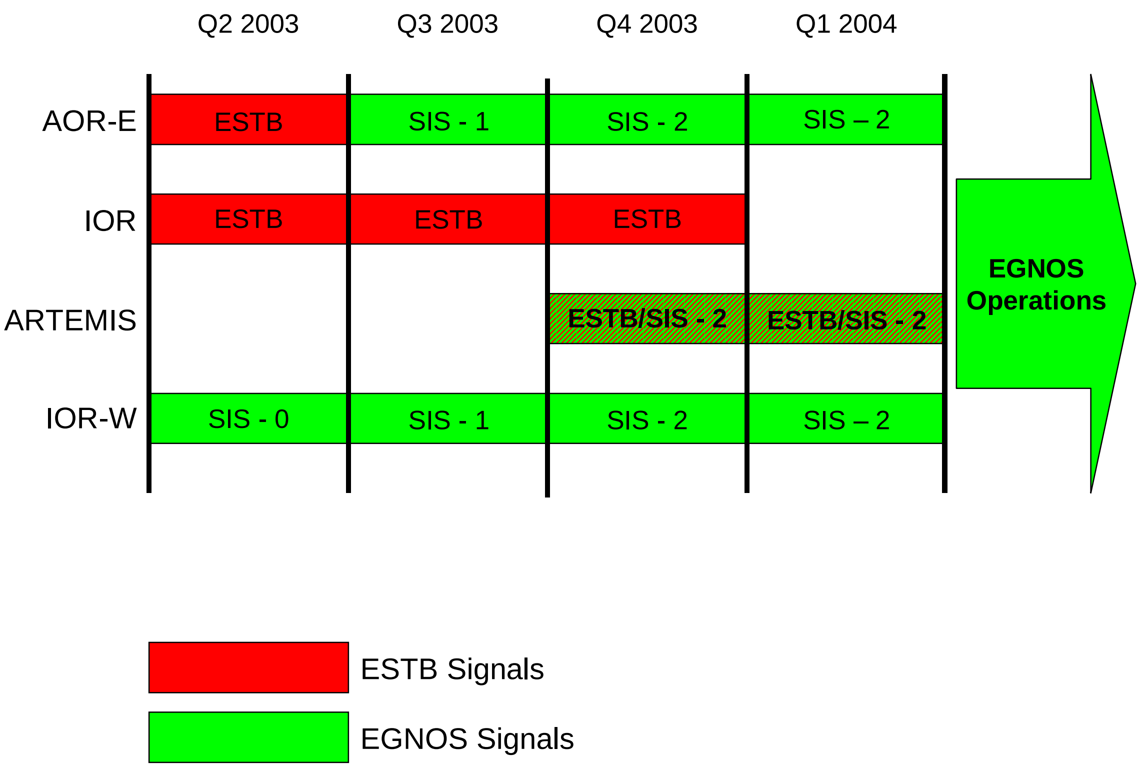

Figure 8: Expected performance during the transition process

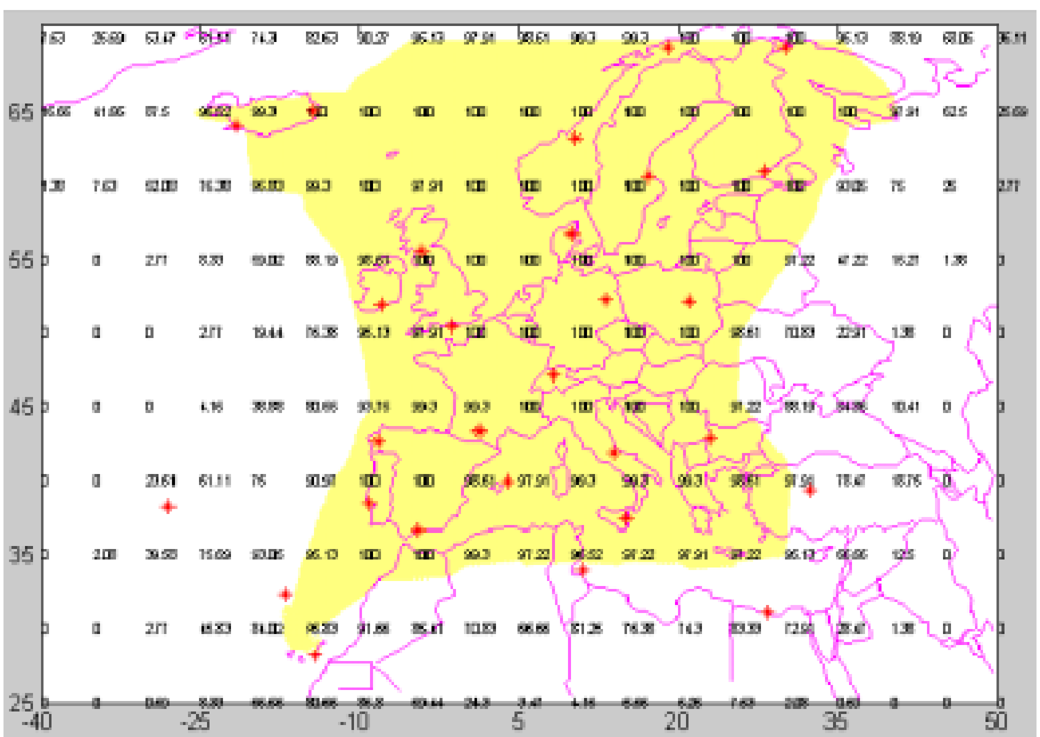

Figure 9: EGNOS expected coverage for high accuracy (1-3m) service

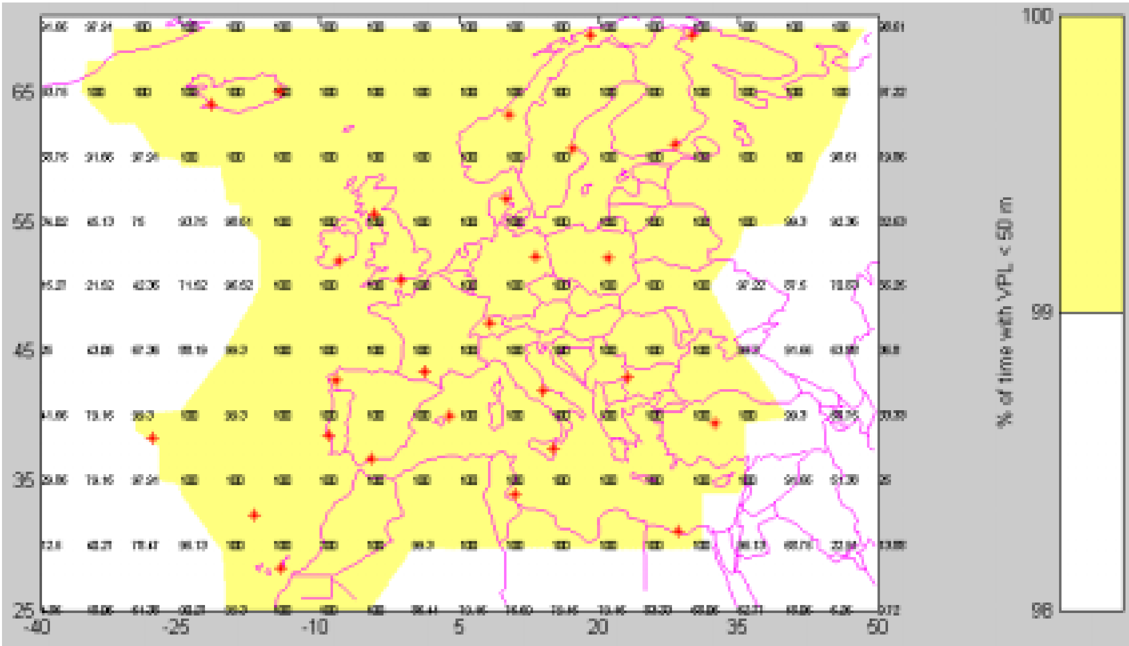

Figure 10: EGNOS expected coverage area for APV-1 (i.e. current WAAS) performance

5.3 Where can I find the latest information?

ESA has provided four main ways for users to receive reliable and timely information:

- the ESTB Helpdesk;
- ESA's ESTB web pages;
- the EGNOS Newsletter; and
- the EGNOS CD ROM, "Making EGNOS Work For You".

The ESTB (EGNOS System Test Bed) Helpdesk service was been launched in April 2001 with the aim of providing information and support to the general public and professional users of satellite navigation systems. It is accessed by email to estb@esa.int and addresses the following subject areas:

- general ESTB/EGNOS questions;
- system performance;
- system technical issues;
- system operational issues;
- user receiver issues;
- request for assistance with promotion, demonstrations or trials; and
- SISNET.

ESA's navigation web pages can be accessed at www.esa.int/navigation where there are links to the ESTB, EGNOS and Galileo. The ESTB web pages can be accessed at www.esa.int/estb. It contains a wealth of information including:

- system architecture;
- publications and documentation;
- information regarding the broadcast signals;
- EGNOS compatible receivers; and
- frequently asked questions.

Information about SISNeT can be found at www.esa.int/sisnet. Useful links and contacts are summarised in Table 3.

ESA Navigation Web Page	www.esa.int/navigation
ESA EGNOS Web Page	www.esa.int/EGNOS
ESA ESTB Web Page	www.esa.int/ESTB
ESA ESTB Help Desk	ESTB@esa.int
ESTB News	ESTB-News@esa.int
ESA SISNET	www.esa.int/SISNET

Table 3: Useful EGNOS related links

The EGNOS News (formerly the ESTB News) is published about three times each year and covers a wide range of activities:

- results from trials or demonstrations;
- tutorial articles;
- "Behind the Scenes" – ESTB and EGNOS system news;
- "News From Brussels";
- "Out and About" – EGNOS activities outside Europe;
- frequently asked questions;
- forthcoming events; and
- links and contacts.

The EGNOS News is made available in paper form at conferences, can be received in electronic format by subscribing to ESTB@esa.int, or can be downloaded from the ESTB web pages.

The EGNOS CD ROM has been designed to help users to understand how they can make EGNOS work for them. It does this by addressing four questions:

- Why use satellites for navigation?
- What is EGNOS?
- How does EGNOS work? And
- So what will EGNOS do for me?

The CD ROM uses a variety of multi-media tools supported by fact-sheets to provide information to users and contains a useful "jargon buster".