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EGNOS Status, performances and Planned Evolutions (2006-2010)

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1. Introduction

The European Tripartite Group (ETG)[1], (ESA – EC – EUROCONTROL) has implemented, via the EGNOS project, the European SBAS contribution to the Global Navigation Satellite System (GNSS-1). The European Space Agency (ESA) has been in charge of the system design, development and qualification of an Advanced Operational Capability (AOC) of the EGNOS system (also known as EGNOS V1).

At the time of writing (July 2005), EGNOS has reached major key milestones through the formal technical qualification process (known as ORR--Operational Readiness Review) and the formal start of initial operations. This two events mark a success completion of more than 8 years of intensive work by ESA and European industry.

In this article, we provide first some detailed information on the EGNOS V1 Project status, information on the formal technical qualification, and the start of initial operations.

Next, this paper will provide information on EGNOS V1 measured and qualified performances, showing they are excellent, exceeding in several cases the expected requirements.

In parallel to the start of EGNOS V1 operations, and similarly to the WAAS US Systems, EGNOS V1 will be subjected to modernised versions, the so called EGNOS V2 and EGNOS V3. These are aiming at enlarging the service area; provide additional services; further improve performances and to follow SBAS standard evolutions, which may result as a consequence of GPS modernisation and the introduction of the European Galileo system. Current views on the EGNOS Infrastructure evolution plans will also be described here.

[1] A formal agreement based on article 228 of the EC treaty was signed between the European Community, EUROCONTROL and ESA, for the development of the European Contribution to the first generation Global Navigation Satellite System (GNSS-1).

2. EGNOS Status

At the time of this writing (July 2005), the deployment of the EGNOS infrastructure is essentially completed, with all the four Master Control Centres (MCC) and all the six Navigation Land Earth Stations (NLES) deployed. A total of 31 out of 34 Reference stations (called RIMS) are installed, and all 3 EGNOS Geostationary satellites (Inmarsat 3 AOR-E, Inmarsat-3 IND-W and ESA's ARTEMIS satellite) have already transmitted successfully EGNOS signals since December 2003, when test transmissions were started.

The EGNOS formal qualification process (ORR), which is the final milestone in the EGNOS V1 development programme, was held May/June 2005. A thorough review was performed, with more than 60 peers, including ESA, Civil Aviation, GJU and Eurocontrol reviewers. A formal Board was held on 16 June 2005 concluding that:

- EGNOS Technical qualification is successful, subject to the completion of review actions and recommendations;
- EGNOS AOC requirements have been verified and are largely met;
- the system is ready to enter into Initial Operations as EGNOS V1.

The ORR marks a success completion of more than 8 years of intensive work by ESA and European industry and allows now starting initial operations, for which a technical kick-off has already been held with the ESSP EGNOS operator in June 30, 2005, and for which the formal Contractual kick-off, and formal start of initial operations, is now scheduled to take place end July 2005.

The main objectives of this operational phase are the following:

- To initiate and stabilise operations of the EGNOS GS (Ground Segment) and SF (Support Facilities);
- To qualify operations of the GS and SF; and
- To arrive at the Operations Qualification Review (OQR) +1 day with an operationally qualified system providing safety-of-life services (e.g. aviation).

At the time of writing (July 2005), EGNOS GEO Transmissions per PRN GEO satellite are organised as follows:

- PRN 124 ESA ARTEMIS satellite is permanently used by the EGNOS operator (ESSP) as part of the EGNOS initial operations and to allow reaching EGNOS operations stability in 6 months from now.

- PRN 126, Inmarsat IND-W is currently run by EGNOS Industry Contractor, implementing some post-ORR complementary tests as requested by the ORR board. These are planned to be concluded end September 2005.

- Finally, PRN 120 Inmarsat AOR-E is operated under direct ESA control, aiming at maintaining a stable EGNOS Test bed transmission, until the EGNOS operations ram-up phase is concluded and SIS stabilisation is reached, early 2006.

3. EGNOS measured Performances

The main objectives of the ORR just held was to confirm that the EGNOS system has been adequately qualified with respect to technical and safety requirements. A dedicated performance review panel was held, concluding that "all EGNOS system performances for Level 2 and Level 3, when extrapolated to the fully deployed system conditions, are confirmed to be duly qualified." This section aims at providing some information on the actual qualified performances in terms of accuracy, integrity and availability.

Figure 1 provides the HNSE and VNSE 95% ***accuracy*** as measured at 9 different European cities during the performance qualification phase. Horizontal and vertical performances in the order of 1m and 1-to 2 meters, respectively, have been measured confirming ESA expectation of 1-3 m HNSE and 2-4m VNSE, and well beyond the formal EGNOS requirements of 7.7m for both HNSE and VNSE.

Place	Paris	Toulouse	Madrid	Brussels	Geneve	Palma de Mallorca	Lisbon	Cork	Berlin
HNSE (95%)	1.0	1.0	1.1	0.8	0.9	1.1	1.1	1.3	1.1
VNSE (95%)	1.3	1.6	1.4	1.6	1.5	1.5	1.7	1.9	1.6

Figure 1: HNSE 95% and VNSE 95% EGNOS performances

Figure 2 provides the cumulative ***availability*** as measured at ESA EGNOS P.O. in Toulouse form the period Feb 11 to Feb 25th 2005, in which EGNOS performance qualification campaign was conducted. An APV-1 availability figure of 99.94% has been measured and above 95% for APV-2, exceeding formal requirements 99% for APV-1 and of 95% APV-2.

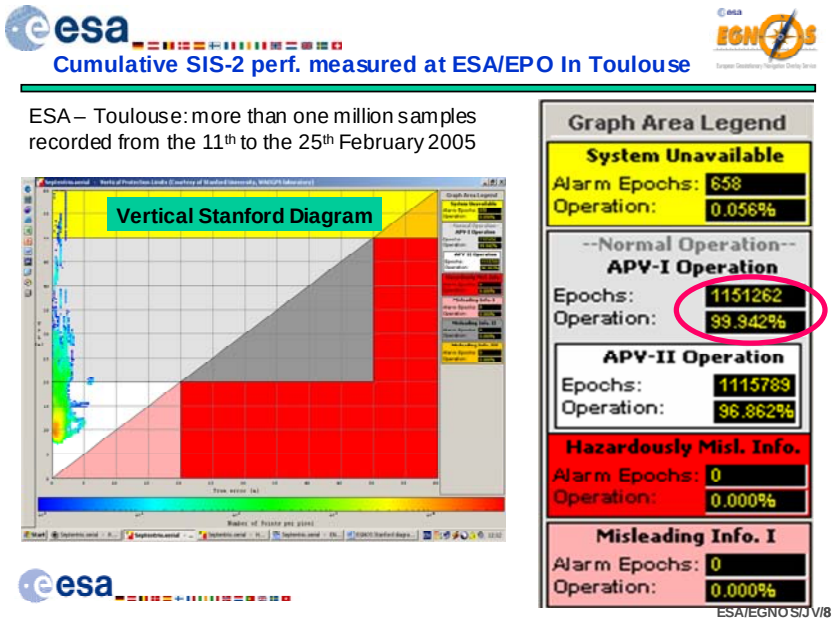

Figure 2: EGNOS APV availability figures measured

Concerning ***Integrity***, this has also been assessed in some detail during the EGNOS qualification campaign, by both ESA (through what is known as the ESA IMAGE Project) and Industry post-processing campaigns, leading to the following common main conclusions:

- No single MI event in user domain at any location in Europe (over 20.000.0000 samples analysed);
- Comfortable safety margins;
- No pseudorange underbound events;
- Results of deployed system in line to factory results at user and pseudorange level.

In the context of integrity, it is worth to note here a specific complementary analysis performed with EGNOS during the severe solar storm occurred at the end of October 2003, affecting the propagation of radio waves through the ionosphere. The relevance of this assessment is that this storm is one of the largest occurred during the last solar cycle, and one of the worst ionospheric storms ever recorded. Through this analysis it has been shown that in these limiting conditions, EGNOS had been able to provide a reliable service over the whole service region, as well as vertical guidance capability (APV). A total of 17 locations (see Figure 3) were carefully analyzed showing no MI or HMI event at user level, and no MI or HMI at GIVE pseudorange level, neither (please refer to [2] for more details). This is an extremely encouraging result that reinforces the confidence on the EGNOS safety design and algorithmic conception.

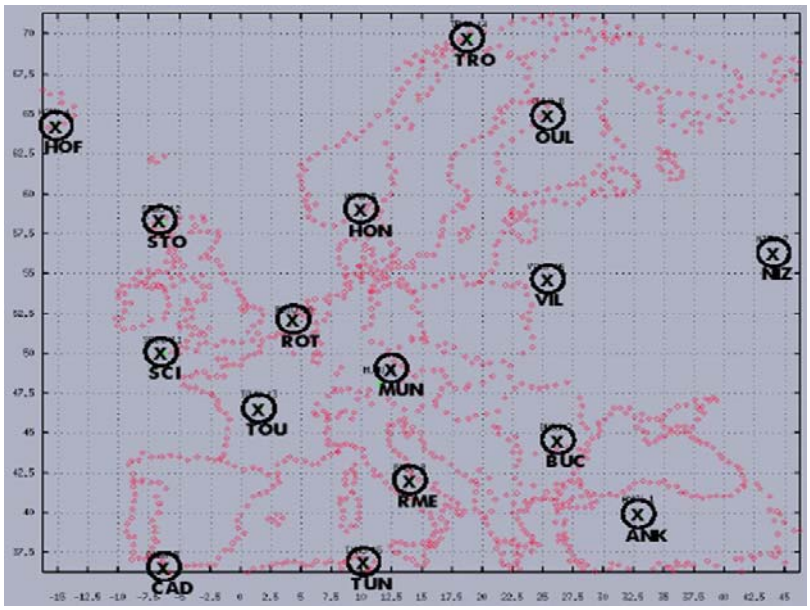

Figure 3: EGNOS Users analysed during October 2003 iono storm

Aiming at providing more information on actual achieved EGNOS performances, and aiming at supporting EGNOS application development, ESA has created an experimental EGNOS Real Time Performance dedicated website (which may be access through the ESA website EGNOS for Professionals Portal at www.esa.int/navigation/egnos-pro) In which EGNOS performances are updated in real time at several European cities every hour (see Figure 4)

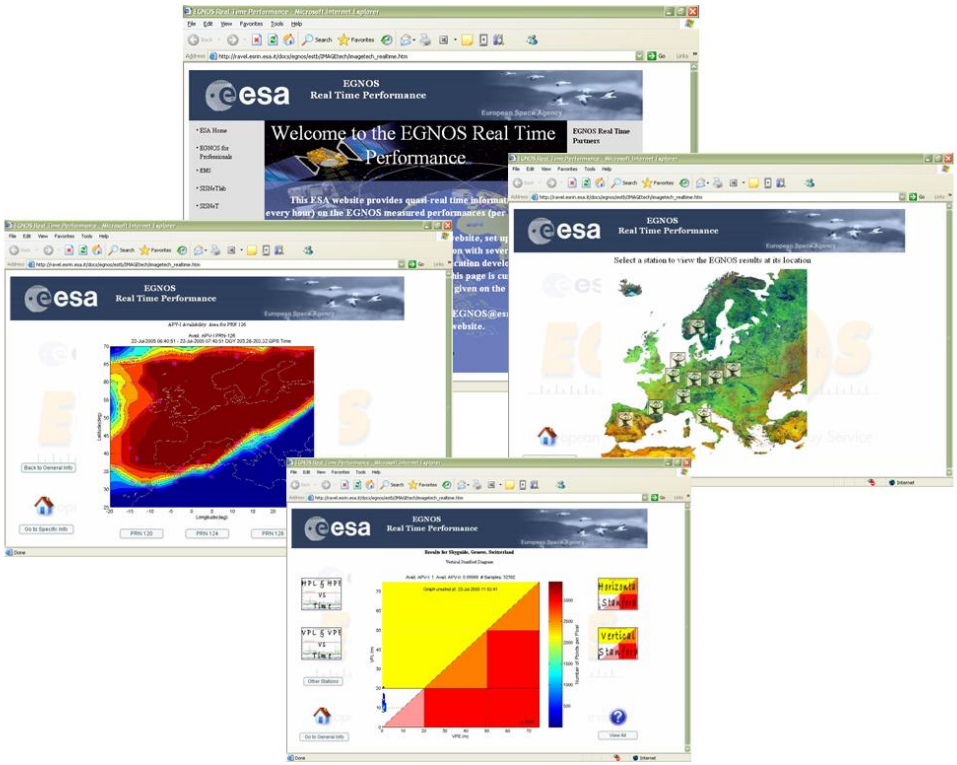

Figure 4; EGNOS Real time website

4. EGNOS Evolution: Context

Since 1998, when the original EGNOS mission requirements were set, the GNSS environment considerably enlarged with the launch of the Galileo program and the planned modernisation of the GPS (e.g. with the introduction of GLPS L5 civil frequency) and WAAS systems.

In this world-wide context, the Council of the European Union confirmed in June 2003 that:

- EGNOS is an integral part of the European Satellite Navigation policy;
- EGNOS will be adapted as need be to follow the SBAS ICAO (International Civil Aviation Organisation) international standard upgrades;
- EGNOS services should be extended determinedly to other parts of the World on a long term basis.

In addition, several studies indicate that modernised SBAS systems (e.g. including GPS L5 integrity) in combination with the European Galileo services, could open the path for GNSS as being the positioning "sole mean" even for the most demanding safety of life applications.

Aiming at responding positively to this GNSS dynamic context, a support program has been defined by ESA and the European Commission. This ***"GNSS Support Program",*** has been defined in two steps: **Step 1**, covering the 2005-2006 timeframe, and **Step 2** to cover the 2006 – 2010 timeframe, to further maximise GNSS benefits to European citizens, and in particular to define and implement the more appropriate evolutions of the EGNOS system to best open the path for the future Galileo services to be available from 2009 onwards.

The drivers to the envisaged EGNOS evolution plan are highlighted in Figure 5.

Figure 5: EGNOS Evolution Mission Drivers

These are essentially the following ones:

- The EGNOS extension beyond the ECAC service area;
- The follow-up on of International standards, so that EGNOS remains always interoperable to WAAS and MSAS
- Targeting “sole-mean” positioning for safety of life applications, when combined with Galileo;
- To foster Galileo multimodal services penetration;
- To maintain European Industry excellence on GNSS SBAS technologies.

5. EGNOS Infrastructure Evolution Plan

ESA has just launched (June 2005) an EGNOS evolution definition phase aiming at finalising an EGNOS evolution Infrastructure development plan, so that the identified desirable EGNOS mission evolutions may be implemented in the time frame 2006-2010.

Current views of this EGNOS Evolution Plan 2006-2010, and possible EGNOS versions are summarised in Figure 6.

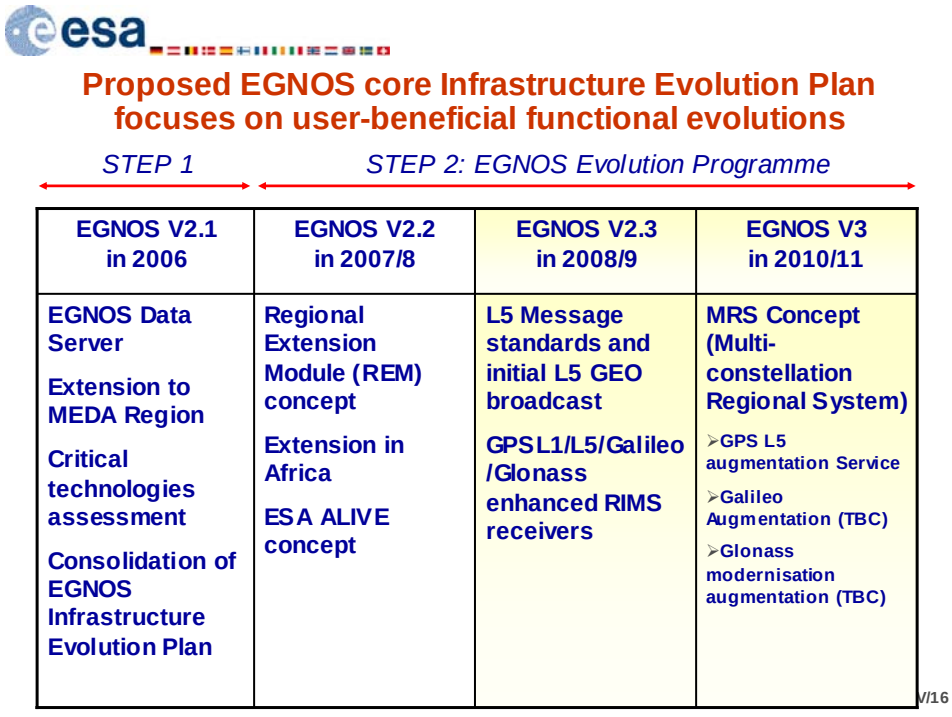

Figure 6: Proposed EGNOS Infrastructure Evolution Plan

Main additional mission functionalities of this EGNOS evolutionary framework include:

- The EGNOS Data Access System or EDAS (EGNOS V2.1).
- The Regional Extension Module (REM) concept (EGNOS V2.2).
- The ESA Alert Interface via EGNOS (ALIVE) concept (EGNOS V2.2).
- And the Multi-constellation regional System (MRS) concept (EGNOS V3).

Those are described in some detailed in the next sections.

6. EGNOS V2 main features

6.1 EGNOS Data Server

6.1.1 The ESA EDAS Concept

The EGNOS Data Access System (EDAS), will constitute the main interface point, for multimodal Service Providers, to supply the EGNOS products in real-time, within guaranteed delay, security, and safety performance boundaries. Application Service providers will then exploit these EGNOS products and, as a result, offer services to end users.

The EDAS performs the following primary functions over the data obtained from INSPIRE:

- Applying the necessary security mechanisms to protect INSPIRE and the EGNOS system;
- Transform the EGNOS raw products to internationally accepted open standards, more easy to be post-processed;
- Protect EGNOS proprietary data formats and protocols;
- To allow the connection of an almost unlimited number of users;
- To allow the definition of different levels of data provision (from raw data to more elaborated products).

The mosaic of services that could derive from the EDAS is really large, including:

- Provision of SISNeT services;
- Development of EGNOS pseudolites;
- Provision of EGNOS services through Radio Data System (RDS);
- Provision of EGNOS services through Digital Audio Broadcast (DAB);
- Provision of Wide Area Real-Time Kinematics (WARTK) services, allowing obtaining decimetre-level accuracies at continental scale;
- Accurate ionospheric monitoring;
- Provision of EGNOS performance information in real-time.
- Archiving of EGNOS messages and RIMS data.
- Provision of EGNOS corrections in the standard RTCM SC104 format, ready to be used by DGPS receivers.

The EDAS will be developed via the GNSS Support Program Step 1 (Task 3), with a view to have an operational system in 2006, thus opening the path to its commercial exploitation by the EGNOS Economic Operator.

The ultimate objectives of the activity are:

- Developing an operational EGNOS Data Access System (EDAS), including an EGNOS Data Server and an EDAS/Service Provider Interface Software component.
- Perform some demonstrations of Service Providers exploiting the EGNOS Data Access System, and demonstrating the potential behind this concept.
- Having the EGNOS Data Access System ready to be integrated into the EGNOS V2 operational context.

6.1.2 EDAS Architecture

The architecture of the EDAS is illustrated in Figure 7. The EDAS obtains the EGNOS raw data from one of the EGNOS Mission Control Centres (MCC) in real-time, and within guaranteed delay, security, and safety performance boundaries

The main component inside the EDAS is called EGNOS Data Server. This component performs two main operations on the EGNOS raw data obtained from the MCC:

- On the one hand, it converts the EGNOS raw data into EGNOS products, provided following internationally accepted open standards.
- On the other hand, it provides a robust Security Layer, protecting EGNOS from external attacks.

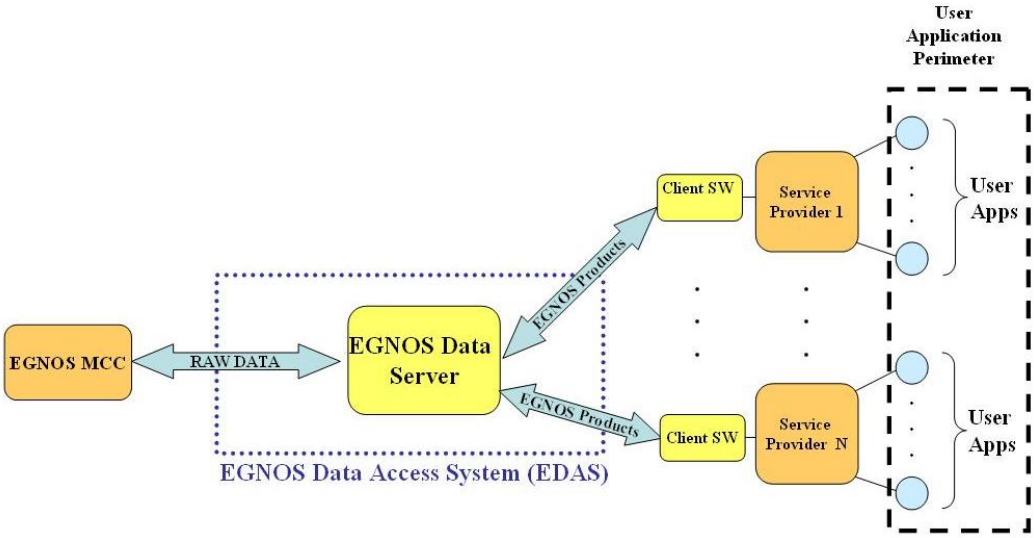

Figure 7: EGNOS Data Access System (EDAS) Architecture

The EGNOS products are available to the Service Providers through the use of a specific Client Software (to be provided by ESA).

Finally The Service Providers exploit the EGNOS products, supplying services to end users through non-GEO means.

6..1.3 EDAS Interfaces

As shown in Figure 1, the EDAS has two principal interfaces:

- **On one side, it interfaces with one of the four EGNOS Mission Control Centres (MCC)**, to obtain the EGNOS raw data. Specifically, the EDAS will be physically installed near one of the EGNOS MCCs, establishing the EDAS-MCC connection by means of a dedicated line or via Frame Relay.

- **On the other side, the EDAS interfaces with the Service Providers**. This is done by means of a Client Software running on the Service Provider platform, which will be provided by ESA as a CFI. The Client Software will be characterised by a multi-platform nature. The physical connection between the EDAS and each Service Provider will be implemented by means of a dedicated line or via Frame Relay.

Taking the above into account, the following requirements for a Service Provider (SP) to be connected to the EDAS do apply:

- The SP shall install the Client Software in the Service Provider platform. The Client Software will be provided by ESA as a Customer Furnished Item (CFI).
- The SP shall interface its service provider application to the Client Software. The necessary Client Software / SP Interface Specification will be provided by ESA.
- The SP shall physically connect to the EDAS by means of a dedicated line or Frame Relay.
- The SP should provide all the necessary security elements to protect its platform from external attacks that, as a side effect, could affect the EDAS. This is to be done through the installation of firewalls and any necessary software / hardware elements.

It is important to notice that the interface between the Service Providers and the end-users is to be defined by the Service Provider itself.

EDAS is planned to be developed as part of EGNOS V2.1, in the context of the Step1 GNSS Support Program. For further details on the EDAS concept, the reader is addressed to [1].

6.2 EGNOS Regional Extension Module Concept

One of the clear EGNOS evolution paths is the extension of the EGNOS service area beyond the original ECAC area. Several are the possible extension target scenarios, including for instance, North of Africa (MEDA region), Middle East region, East of Europe or even the whole African continent. Given the large number of possible extensions, and to avoid costly “a la carte” dedicated solutions, ESA and EGNOS Industry have conceived a generic extension concept’s which has been named the EGNOS Regional Extension Module (REM).

The REM concept is illustrated in Figure 8. It consists of a number of dedicated reference stations, a local monitoring centre, a network concentrator and a clean and unique interface with EGNOS core system.

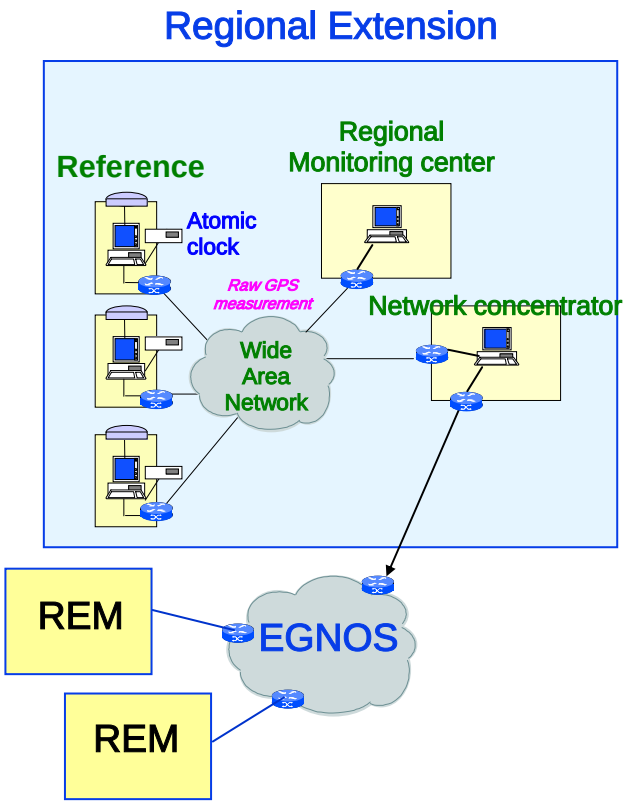

Figure 8: EGNOS Regional Extension Module (REM) Concept

The benefits expected for this generic concept, include:

- EGNOS extensions will be based largely on recurrent extension design concept;
- Extension is performed in multiple steps, through connection of several REM units. This allows a controlled system scalability;
- Provides operational autonomy to the extended region;
- Clean & simple interfaces with EGNOS Core system for extended region;
- No degradation in EGNOS ECAC in case REM remote problem.

The EGNOS REM concept is currently under detailed assessment as part of an EGNOS Definition Phase. In this study, the application of REM to EGNOS will be illustrated through an instantiation for the case of an EGNOS extension in Africa (named as ISA System). A total of 3 to 4 REM modules are currently envisaged for the whole African continent service coverage.

6.3 The ESA ALIVE Concept for disaster prevention/mitigation

6.3.2 Motivation: Why SBAS may help in disaster prevention?

Disaster prevention and mitigation is a subject to which currently intensive attention is devoted. One of the main goals is to identifying ways to inform people at risk, for instance, through natural events such as earthquakes, tsunamis, hurricanes, storm surges, extreme precipitation and flooding, or volcanic eruptions, so that specification actions can be taken to mitigate the impact of the disaster and ultimately, to save lives. Moreover, the same information channels would be valuable tools to support rescue and aid operations in the aftermath of disasters thus reducing the total loss of human lives. This discussion is motivated by the obvious principle that ***disaster prevention, mitigation and preparedness are better than mere disaster response.***

Those most affected by disasters are often the poor and the socially disadvantaged in developing countries as they are the least equipped to cope with the situation. In large regions of the Earth, loss of life and capital caused by disasters is increased by the lack of sufficient communication infrastructure for warning, preparation and rescue. For instance, in countries like Africa and the Indian Ocean, where the lack of communication is a severe limitation for efficient warning systems, additional communication paired with a positioning service could be of great help.

In this context, the possibility to use Satellite Based Augmentation Systems (SBAS) message broadcast capability is of considerable interest.

Indeed, SBAS systems (EGNOS, for the case of Europe) are associated with a number of inherent characteristics, which make the SBAS solution very attractive:

- The three existing SBAS together provide a global coverage (see Figure 9);
- SBAS receivers are based on GPS receivers and share the same worldwide accepted standards;
- SBAS GPS combine the possibility of warning with the ability to determine the location of the receiver in the same equipment (key feature);
- The SBAS systems, having been conceived as safety of life systems with integrity, include the necessary built-in features to guarantee adequate message broadcast, integrity of messages, confirmation of transmission; acknowledge messages to sending organizations, etc;
- It is estimated that there is enough transmission Bandwidth (BW) available to accommodate the proposed function;
- SBAS are institutionally controlled, do include security features and are operated for safety of life (i.e. all days all hours of the year with Safety of Life operational standards).

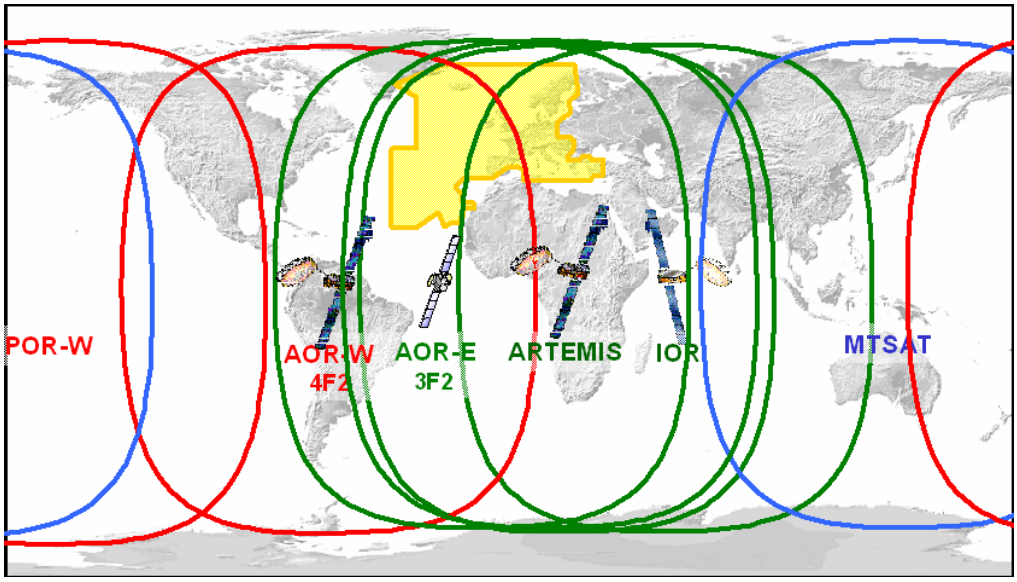

Figure 9: GEO Broadcasting areas of the three existing operational

6.3.3 Architectural Concept and Preliminary Identification of Operational Interfaces

The implementation of the ALIVE concept is based on the more general concept of using the available EGNOS BW to broadcast spatially related information from an originator to EGNOS users through dedicated SBAS messages.

Figure 10 illustrates a possible architectural implementation of such communication function embedded within the EGNOS system.

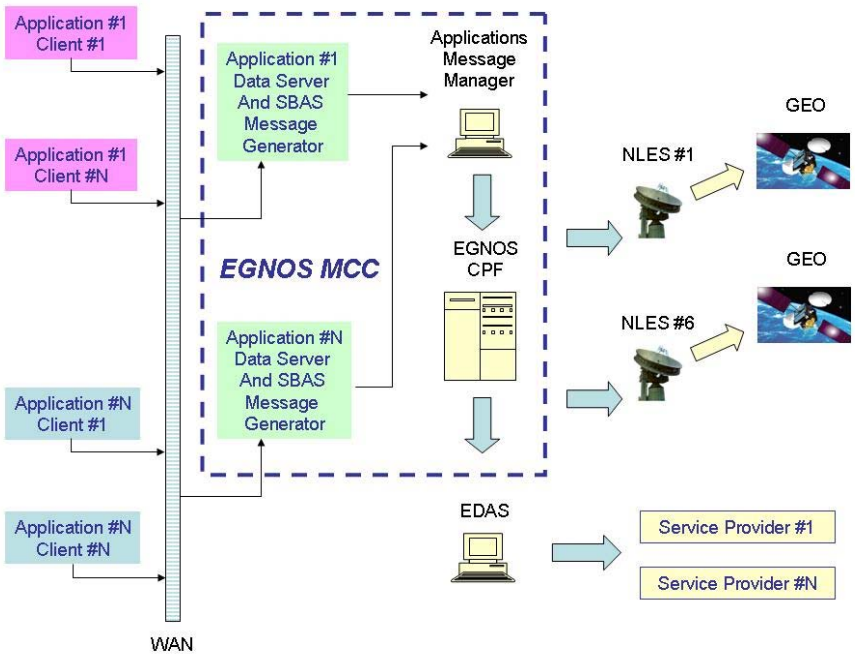

Figure 10 - Broadcast of information though EGNOS

Independently from the application considered, the information to transfer to EGNOS users is made available to the EGNOS computing platform (CPF) through links and pre-processing stages. This information is then broadcast as an SBAS message. Users having the possibility to process these specific messages can then extract the enclosed information and use it in the way they need.

The added value of this process it the opportunity to provide reliable information to users equipped with an EGNOS terminal within the entire EGNOS geostationary coverage as indicated in Figure 12.

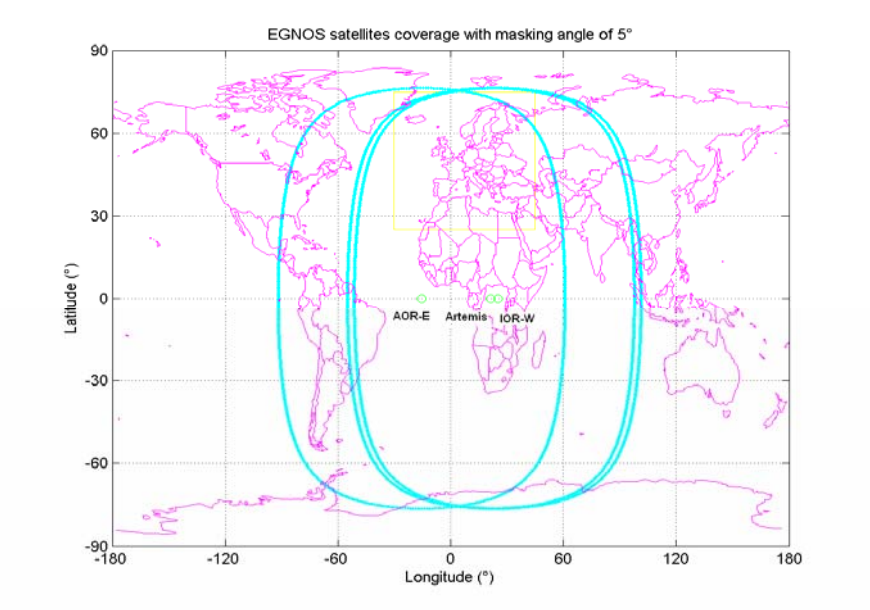

Figure 12 – EGNOS Geostationary Satellites Cover

Safety critical information (event, recommended action) is typically associated to spatial information (location). This will be of particular importance for the functions of ALIVE.

Organizations at national and international level in charge of disasters management or for the provision of civil protection services make use of infrastructures for monitoring, communication and control. Here we denote such infrastructures as Disaster Management Centres.

The architectural implementation of the ALIVE concept on the basis of the EGNOS system is illustrated in Figure 13.

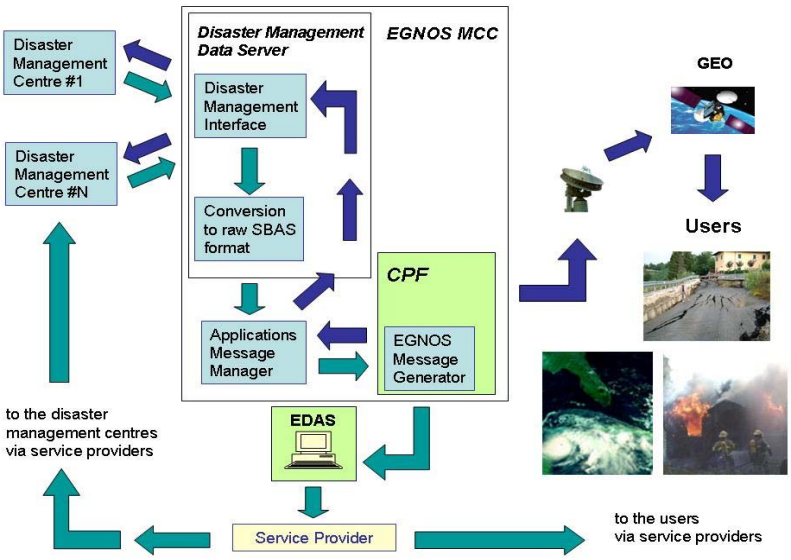

Figure 13 – Architectural implementation of ALIVE function

Disaster Management Centres have the task to collect and generate relevant information (e.g.: event, location, status, action) required to fulfil all the missions for which they have been designed. The information generated by Disaster Management Centres is sent to a dedicated Disaster Management Data Server (Specific Application Data Server) within the EGNOS MCC. Disaster Management Centres receive through the Disaster Management Data Server the acknowledgement that the information has been sent with the typical EGNOS guarantee of service. The information is converted in a row SBAS format and is sent to an Applications Message Manager.

The Applications Message Manager has the following tasks:

1. to receive the row SBAS messages from all Applications Data Servers;
2. to put the row SBAS messages in a preliminary sequence according the mission requirements of each application;
3. to send the SBAS messages to the CPF;
4. to receive the acknowledge from the CPF that the message has been sent;
5. to return the acknowledgement to the Disaster Management Data Server that the message has been sent.

The EGNOS computing platform (CPF) rearranges the broadcast sequence of the SBAS messages according to the input provided by the Applications Message Manager.

The analysis of the preliminary mission requirements of ALIVE revealed that there is no problem to allocate additional SBAS messages among the broadcast of EGNOS current messages.

Once the broadcast sequence is ready, the message (or messages) containing the information generated by the Disaster Management Centres, is included in the EGNOS up-link and down-link loop in the same way as other messages. Any user (within the EGNOS satellites footprint) equipped with an EGNOS receiver capable of processing these additional messages is made aware of the problem, location, status and action. Again, the EGNOS link loop guarantees the delivery of the information to enabled users.

7 EGNOS V3 Main features: the Multi-constellation Regional (MRS) Concept

SBAS International Standards are currently under development at ICAO Navigation Panel to include GPS L5 modernisation and Galileo Navigation System. This work is supported with the technical work of the EUROCAE WG 62, in the case of Europe, and RTCA WG-2, in the case of the United States. ESA, in close coordination with the Galileo joint Undertaking and with the involvement of key European Industries and Civil aviations, is strongly supporting this SBAS L5 technical standardization work.

At its last Navigation System Panel (held in May 2005), ICAO confirmed the operational interest of GPS L1/L5 SBAS augmentation service, which should allow reaching CAT-1 performances and maintain APV services in case of L1 or L5 frequency loss (e.g. due to local interference). This robustness and enhanced performance interest is further apparent if Galileo satellites are also considered. Indeed, in this case, the system could even maintain CAT-1 services in the extreme case of a full constellation loss. This, in turn, leads us to a CAT-1/APV-2 *"sole means"* service in nominal conditions, with 51 (current SARPS message limitation) monitored satellites.

These considerations have lead to the definition of the SBAS ***Multi-constellation Regional System (MRS)*** concept, which is currently under detailed assessment by ESA and the Galileo Joint Undertaking. Specifically, MRS is currently been assessed in the context of the GEM and GARMIS activities of the GJU 6th Framework programme. In support to the GJU, ESA is technically managing those MRS activities, and complementing those with a specific analysis instantiated in EGNOS-MRS, on what has been named **EGNOS V3** system. EGNOS V3 is currently a study concept.

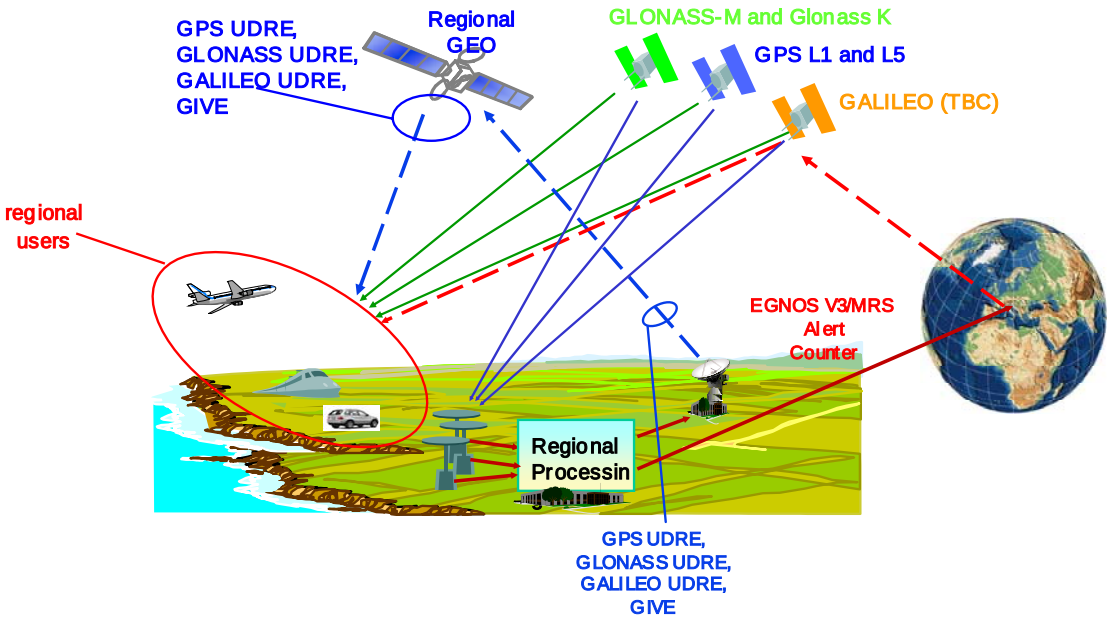

Figure 14: EGNOS V3 concept

8 Summary

EGNOS is the European SBAS and a first step towards GALILEO, the European SATNAV constellation. EGNOS has reached major key milestones through the formal technical qualification process (known as ORR--Operational Readiness Review) in May/June 2005, and the formal start of initial operations, in July 2005, of EGNOS V1. This two events mark a success completion of more than 8 years of intensive work by ESA and European industry.

EGNOS measured and qualified performances have shown to be excellent, well exceeding several of the formal EGNOS AOC requirements (e.g. values 1 to 3 meters of HNSE (95%) are routinely measured versus 7.7m specified; availabilities above 99% APV-1, excellent integrity and ionosphere margins against worst iono conditions of last solar cycle, etc).

In parallel to the start of EGNOS V1 operations, and similarly to the WAAS US Systems, EGNOS will be subjected to modernised versions EGNOS V2 and EGNOS V3, aiming at enlarging the service area; provide additional services; further improve performances and to follow SBAS standard evolutions which may result as a consequence of GPS modernisation and the introduction of the European Galileo system. Current views on the EGNOS Infrastructure evolution plan for the period 2006-2010 have been presented here with emphasis on the EGNOS Data Server (EDAS) service; Regional Extension Module (REM) concept; provision through SBAS system on disaster alert information (ESA ALIVE system) and the concept of Multi-constellation Regional Augmentation, which could provide full robustness to Safety of life application.

Step 1 of this modernisation (2005-2006) plan has been approved and is already kicked-off. In parallel, EGNOS Evolution Definition studies on-going to produce a concrete EGNOS infrastructure Evolution Plan for 2006-2010 and for ESA and EU members' endorsement.

Acknowledgements

The European Space Agency (ESA) EGNOS P.O. would like to acknowledge here the tremendous effort and excellence provided by all European Industries involved in the EGNOS development during the last 8 years (see Figure 15.)

Fig 15: Main European industries involved in the EGNOS V1 development.

References

[1] F. Toran and J. Ventura-Traveset, *"The EGNOS Data Access System (EDAS), The Access Point to the EGNOS Products in Real-Time for Multi-Modal Service Provision,"* Proceedings of the GNSS 2005 Conference, Munich Germany, July 19-22, 2005.

[2] C. Montefusco et al., *"Assessment of EGNOS performance in worst ionosphere conditions (October and November 2003 storm),"* Proceedings of the GNSS 2005 Conference, Munich Germany, July 19-22, 2005.