The ESA SISNeT Technology: Real-Time Access to the EGNOS Services through Wireless Networks and the Internet

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BIOGRAPHY

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Dr. Ruizhi Chen holds a MS in computer science from Helsinki University of Technology, and a Ph. D in Geodesy from Helsinki University. He worked in the Finnish Geodetic Institute (FGI) as a research scientist during 1989-1997, and in Nokia as an engineering manager during 1998-2001. He is now working in FGI as a professor and head of the department of navigation and positioning. He is responsible for developing the PDA-based SISNeT receiver under ESA contract.

ABSTRACT

Similarly to other Satellite Based Augmentation Systems (SBAS), EGNOS– the European SBAS – will broadcast augmentation signals for GPS through Geostationary Earth Orbit (GEO) satellites. GEO broadcasting is proved to be an efficient strategy for avionic applications and other modes of transport. For some applications, though, it may be of interest to complement GEO broadcasting through other transmission means. For instance, building obstacles in cities or rural canyons may difficult the GEO reception. In those situations, complementary real-time Internet-based broadcasting of the EGNOS signal is of major interest as a way to continue taking the most of the EGNOS potential, irrespectively of the user environment. In this context, the European Space Agency (ESA) has launched an internal project to provide access to the EGNOS test bed messages through the Internet. The product of this project is a new technology, called SISNeT (Signal in Space through the Internet), which is the main purpose of this paper. Thanks to SISNeT, any user with access to the Internet (e.g. through wireless networks – GSM or GPRS –) may access the EGNOS product, irrespectively of the GEO visibility conditions. As it will be shown throughout this paper, an EGNOS-SISNeT powered receiver provides much better availability of accuracy than a GPS-only receiver for typical urban environments. Indeed, while EGNOS achieved availability performances are quite resistant to user masking effects, the geometrical degradation linked to poor masking angles has a major degradation effect on GPS-only achievable availability.

INTRODUCTION

EGNOS, the European Geostationary Navigation Overlay Service [1], is the first step on the European contribution to the Global Navigation Satellite System, and a fundamental stepping-stone towards GALILEO, Europe's own Global Navigation Satellite System. EGNOS is an augmentation system to the GPS and GLONASS Satellite Navigation systems, which provides and guarantees navigation signals for aeronautical, maritime and land mobile Trans-European network applications. In addition to EGNOS, there are two other Satellite-Based Augmentation Systems (SBAS) contributing to GNSS-1: the US Wide Area Augmentation System (WAAS) and the Japanese MTSAT Augmentation

System (MSAS). Since January 2000, a pre-operational signal of EGNOS is available through the so-called ***EGNOS System Test Bed (ESTB)*** [2-4]. The ESTB has proven to be an excellent vehicle to demonstrate the system operation to final users. During 2000 / 2001, demonstrations were performed involving a large variety of user communities and, therefore, of user requirements. In particular, successful demonstrations were performed for land mobile, civil aviation, helicopters, trains, maritime and precision farming [2-4].

Similarly to other Satellite Based Augmentation Systems (SBAS), EGNOS– the European SBAS – will broadcast augmentation signals to GPS through Geostationary (GEO) satellites. GEO broadcasting is proved to be an efficient strategy for avionic applications and other modes of transport. For some applications, though, it may be of interest to complement GEO broadcasting through other transmission means. For instance, building obstacles in cities or rural canyons may difficult the GEO reception. In those situations, complementary means of broadcasting (e.g. FM, Digital Audio Broadcasting –DAB—and the Internet) have a remarkable interest. In this context, the European Space Agency (ESA) has launched, an internal project to provide access to the EGNOS test bed messages in real time through the Internet. The product of this project is a new technology, called SISNeT (Signal in Space through the Internet) [5 - 12], which is the main purpose of this paper. The SISNeT technology and the ESA SISNeT set-up architecture are described here in some detail.

The benefits of SISNeT will also become apparent throughout this paper. Through a detailed simulation exercise, we will show that an EGNOS-SISNeT powered receiver provides much better availability of accuracy than a GPS-only receiver for typical urban environments. Indeed, in all-in-view situations, typical EGNOS accuracy (95%) performances will be of the order of 1-2 meters (vs. 10 - 20 m of GPS-only). The impact of EGNOS-SISNeT becomes more apparent when typical urban environment situations are assumed revealing that, while EGNOS achieved availability performances are quite resistant to user masking effects, the geometrical degradation linked to poor masking angles provokes a major performance degradation on GPS-only based solutions.

1. THE EGNOS SYSTEM

The European Tripartite Group (ETG) – formed by the European Space Agency (ESA), the European Commission and EUROCONTROL – is implementing, via the EGNOS project [1], the European contribution to the Global Navigation Satellite System (GNSS-1). The EGNOS system will provide and guarantee navigation signals for aeronautical, maritime and land mobile Trans-European network applications.

On behalf of this tripartite group, ESA is responsible for the system design, development and technical validation of an Advanced Operational Capability (AOC) of the EGNOS system. Technical validation will be completed in early 2004, making possible the operational use of the EGNOS Signal in 2004.

EGNOS will significantly improve the GPS services, in terms of accuracy, (from a typical performance of 20 meters to 1 - 2 meters), service guarantee and safety (via integrity signal) and availability (via additional ranging signals). It will operate on the GPS L1 frequency, and will subsequently be receivable by standard GPS front-ends.

In addition to EGNOS, there are two other Satellite-Based Augmentation Systems (SBAS) contributing to GNSS-1: the US Wide Area Augmentation System (WAAS) and the Japanese MTSAT Augmentation System (MSAS). Although all SBAS are currently defined as regional systems, it is commonly recognized the need to establish adequate co-operation / co-ordination among the different systems, so that their implementation becomes more effective and part of a seamless world-wide navigation system. The EGNOS system includes specific requirements, so that interoperability may be achieved.

In addition to interoperability, EGNOS has built-in expansion capability to enable extension of the services over regions within the broadcast area of the Geostationary (GEO) satellites used. The EGNOS coverage will first be the ECAC (European Civil Aviation Conference) area, and could be later extended to include other regions such as Africa, Eastern countries, and Russia. EGNOS will meet many of the current positioning, velocity and timing requirements of the land, maritime and aeronautical modes of transport in the European Region.

EGNOS is the first step of the European Satellite Navigation strategy and a major stepping-stone towards GALILEO, the future European satellite navigation constellation, planned to be fully deployed and operational in 2008.

2. THE EGNOS SYSTEM TEST BED

The EGNOS System Test Bed (ESTB) [2 - 4] 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 objectives include:

- Support to EGNOS design. In particular, algorithm design benefits from the ESTB experience in design and usage.
- Demonstration of the system capabilities to users. The ESTB constitutes a strategic tool for the ETG, which plans to promote the use of EGNOS

and analyze 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, aiming at fostering the use of ESTB and analyzing the needs of potential users, was successfully organized on July 2000. A second ESTB Workshop took place in November 2001 at Nice (France).

- Analysis of future EGNOS upgrades.
- Acting as a backbone for continuous EGNOS experimentation and design improvement process.

The architecture of the ESTB is shown in Fig. 1. The system includes:

- A network of 10 reference stations (RS), which are permanently collecting GPS / GEO / GLONASS data.
- A Central Processing Facility (CPF) generating the Wide Area Differential (WAD) user messages. This CPF is located in Honefoss (Norway).
- A second processing center located in Toulouse (France), devoted to the generation of the GEO ranging data, which also acts as a node for the transmission of the user message.
- Two Navigation Land Earth Stations (NLES). One is located in Aussaguel (France), and transmits through the INMARSAT III AOR-E satellite; the other NLES is placed in Fucino (Italy) providing access to the INMARSAT IOR satellite.
- A real-time communications network based on frame-relay links.

3. THE SISNET TECHNOLOGY

EGNOS will broadcast their wide area / integrity messages through GEO satellites. The ESTB is already broadcasting the EGNOS message through the INMARSAT III AOR-E satellite (broadcast through INMARSAT III IOR satellite is also planned in 2002).

Satellite broadcasting through GEO means is proved to be an efficient strategy for avionic applications and other modes of transport. For some applications, though, GEO broadcasting may provide some limitations. For instance, building obstacles in cities or rural canyons may difficult the GEO reception. Since the EGNOS message will still be very useful for those applications, a complementary transmission link may be considered to take the utmost advantage of the EGNOS potential. For this reason, ESA has recently launched specific contract activities (through the Advanced System Telecommunication Equipment program –ASTE–) to assess and demonstrate architectures where the ESTB signal is broadcast through non-GEO means (e.g. FM or GSM broadcasting).

In this context, ESA has also launched an internal project to provide access to the EGNOS test bed messages through the Internet. The product of this project is a new technology, called SISNeT (Signal in Space through the Internet) [5 - 12], which is the main purpose of this paper.

A first prototype of the SISNeT concept has been set-up by the ESA GNSS-1 Project Office, in August 2001.

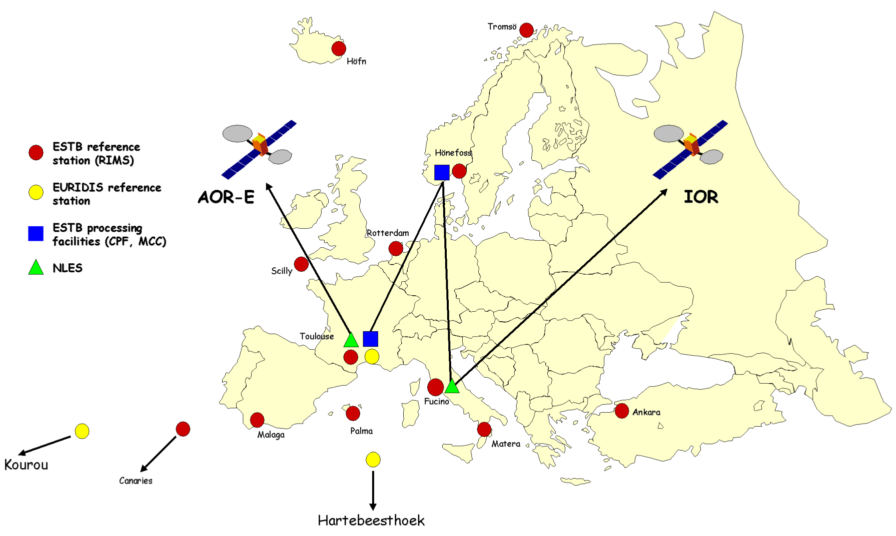


Figure1 - ESTB ground elements location

This prototype uses a PC computer to implement the user equipment software, and the connection to the service is achieved using the ESA private WAN network. The user software implements several SISNeT-based applications, which are described in this paper.

Since February 2002, the SISNeT service is accessible through the open Internet, via an authentication procedure. This strategy allows ESA to track the SISNeT-based applications under development, as well as those already implemented. Several contracts for the development of SISNeT-based products are currently ongoing. This paper introduces two of those developments: a SISNeT receiver based on a Personal Digital Assistant (PDA) and SISNeT demonstrations in urban buses.

The SISNeT project can grant important advantages to the GPS land-user community. A user equipped with a GPS receiver and a GSM (or GPRS) modem can access the SISNeT services, thus being able to benefit from the EGNOS augmentation signals, even under situations of GEO blocking.

On the other hand, the Scientific and Engineering community may find major advantages in using SISNeT: the EGNOS signal can be received and processed without having to invest in an EGNOS receiver. Just a connection to the Internet is needed. These benefits are also applicable to Educational environments.

Another advantage is centered in the low bandwidth requirements of SISNeT: the transfer rate ranges from 300 bps to 700 bps, being 470 bps the average value. These characteristics make SISNeT very adequate to be used with GSM / GPRS wireless networks.

4. SISNET SYSTEM ARCHITECTURE

Fig. 2 illustrates the SISNeT platform architecture. The three main components of the system are the following:

Base Station (BS). A PC computer connected to an EGNOS receiver through a serial port. Several software components are installed on the computer, allowing acquiring the EGNOS messages and sending it to a remote computer (called Data Server) in real-time.

Data Server (DS). A high performance computer, optimized for running server applications with a large amount of connected users. The DS functionality is implemented through a software application called SISNeT Data Server (SDS). This software receives the EGNOS messages from the BS and transfers them to remote SISNeT users in real time. In addition, the SDS implements other extra services provided by the SISNeT system (e.g. broadcast of text messages, GPS ephemeris information, etc.).

User Application Software (UAS). A Software application that strictly accomplishes the requirements stated in the SISNeT User Interface Document (UID) [13], thus being able to obtain the EGNOS messages in real time (1 message/s or 250 bit/s) from the DS. Each concrete SISNeT-based application is characterized by specific processing and output interface stages, which provide the desired functionality and user interface to the UAS. The software can be embedded in different kinds of computers and electronic devices (e.g. Personal Digital Assistants). ESA released the first implementation of the UAS in August 2001.

Presently, the BS and the DS are installed on the ESA ESTEC center (Noordwijk, The Netherlands). As introduced before, the DS is accessible to the open Internet through an authentication protocol. A SISNeT account may be requested by sending a mail message to SISNET@esa.int. Each account consists on a username, a password and the IP address of the SISNeT Data Server. The first implementation of the UAS is installed at the ESA EGNOS Project Office (Toulouse, France), where the system is continuously tested and improved.

5. SIMULATION RESULTS USING SISNET

After the internal validation of the SISNeT concept, ESA has developed advanced simulation algorithms, able to estimate the performance that SISNeT can offer to European users located in urban areas [14]. Specifically, the objective is to compare the accuracy obtained by GPS-only receivers with the accuracy achieved using SISNeT receivers, always in urban environments.

The available EGNOS simulation tools assumed a constant mask angle for all the users in the target service volume. The new algorithms allow defining different azimuth intervals, and assign a certain mask angle to each of them. This allows modeling the existence of buildings and other obstacles commonly found in urban environments.

Dubbed "Advanced Mask Angle modeling" (AMA), those algorithms have been integrated – as a major feature – into existing EGNOS simulation software: the ESA ESPADA tool [15,16]. A specific Graphical User Interface (GUI) allows the user configuring a masking scenario (see Fig. 3). This is done by simply filling a table, which relates azimuths and mask angles. The process is aided through 3D graphics, which show a conical intuitive representation of the resulting masking conditions. In the example shown in Fig. 3, a street with buildings at each side is modeled. The user is located at the origin of the co-ordinate system. The plotted surface can be understood as an opaque material: if that material avoids the user to see a particular satellite, then that satellite is considered not visible.

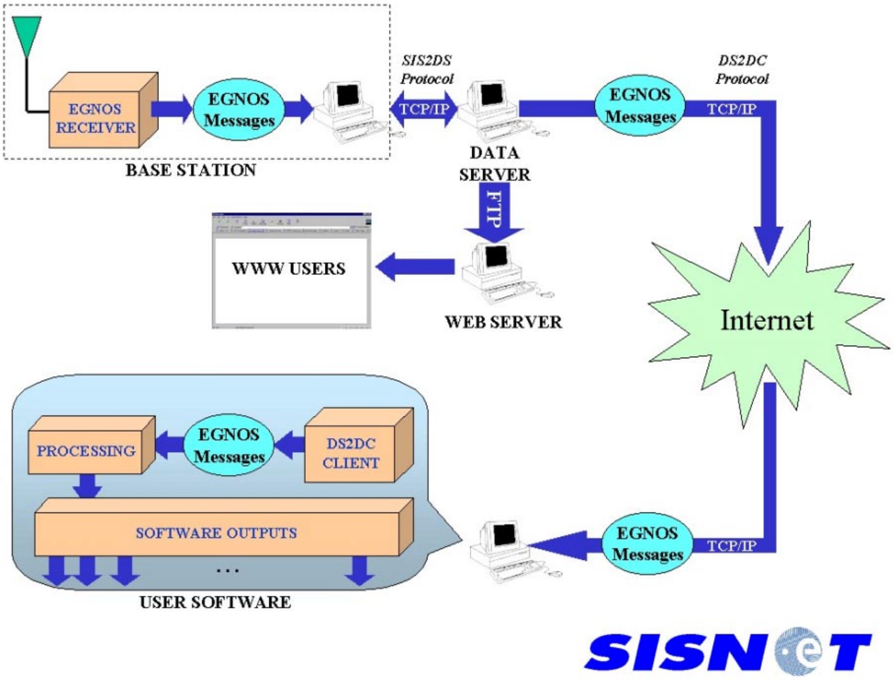


Figure 2 – SISNeT system architecture

More than 15 different simulations have been performed, all of them corresponding to urban scenarios, which are common in most cities. Three of them are presented here through Table 1, including the following information:

- **Scenario ID**. A numeric identifier assigned to each scenario, for further reference.
- **3D representation**. An intuitive representation of the masking scenario, shown to the user through a GUI (see Fig. 3). Note the streets are characterized by a 5 degrees mask angle, modeling the existence of far buildings.
- **Potential Scenario**. A picture showing a possible urban scenario corresponding to the 3D intuitive representation.

Note the presence of a N-E reference in both graphical representations, making possible a proper spatial correspondence between them.

Simulation results for the proposed scenarios are shown in Table 2. Each graphical output contains several accuracy (95%) requirements in the horizontal axis. The vertical axis shows the availabilities corresponding to each accuracy requirement, over a period of 24 hours. The unfilled bars correspond to a GPS-only scenario, while the filled ones refer to the application of the EGNOS differential corrections through SISNeT. Note the assumptions are conservative, based on both GPS User Range Error (URE) specified value as per recently released GPS SPS document [17] and EGNOS specified residual error statistics after corrections (which based on experimental results obtained with the ESTB and the EGNOS algorithms prototypes are shown to be very conservative.)

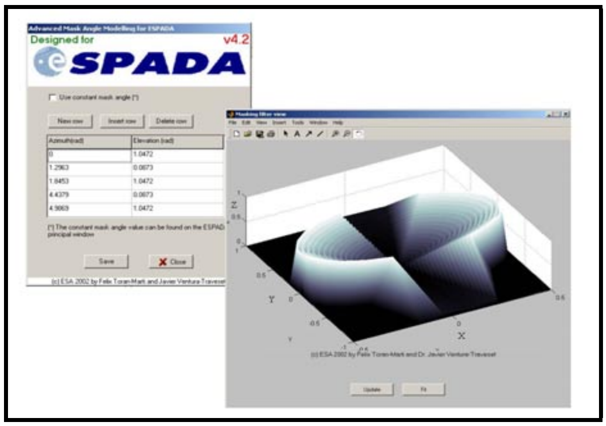


Figure 3 – Graphical User Interface for Masking Scenario Definition

Simulation results reveal that, under situations where the visibility of GPS satellites is constrained (say to 4 - 5 satellites), the availability of EGNOS corrections plays a major role. In fact, results for SISNeT scenarios show a significant performance improvement in terms of availability of accuracy, with respect to GPS-only scenarios (an absolute availability improvement around

Table 1 - Definition of Simulation Scenarios

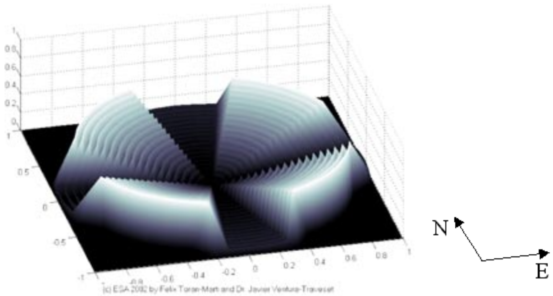
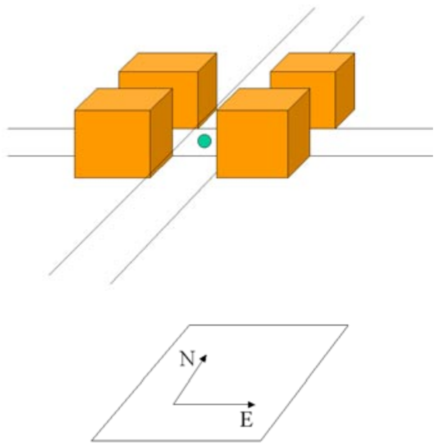
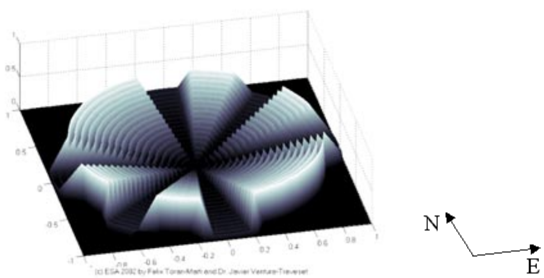
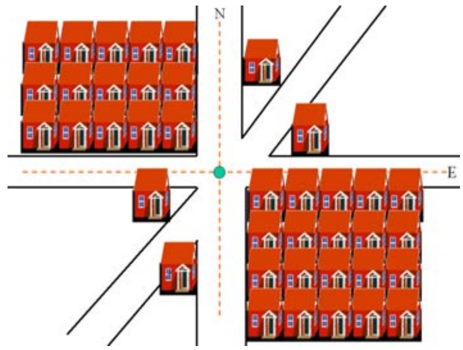
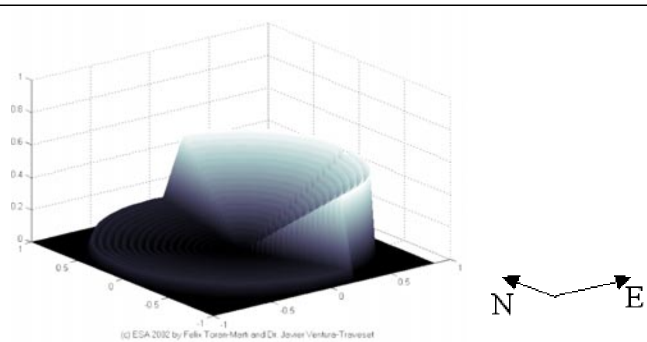
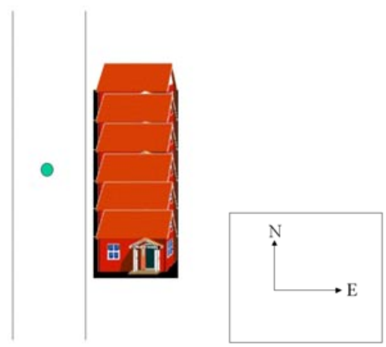
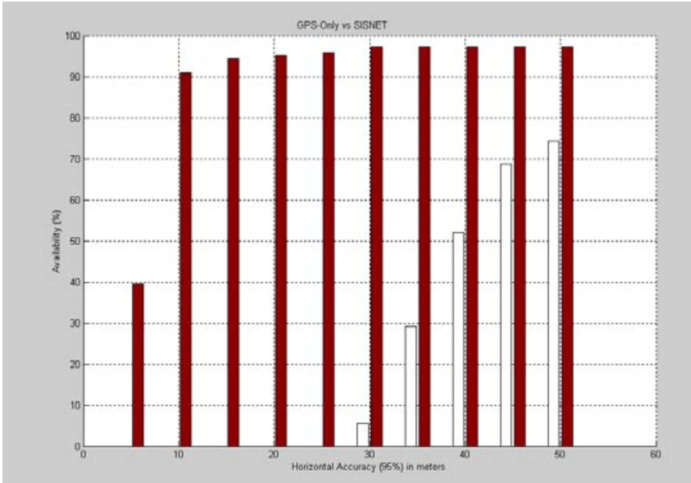
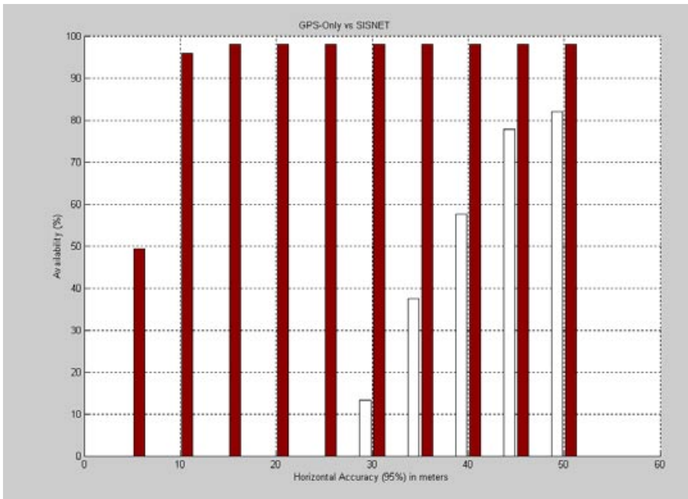
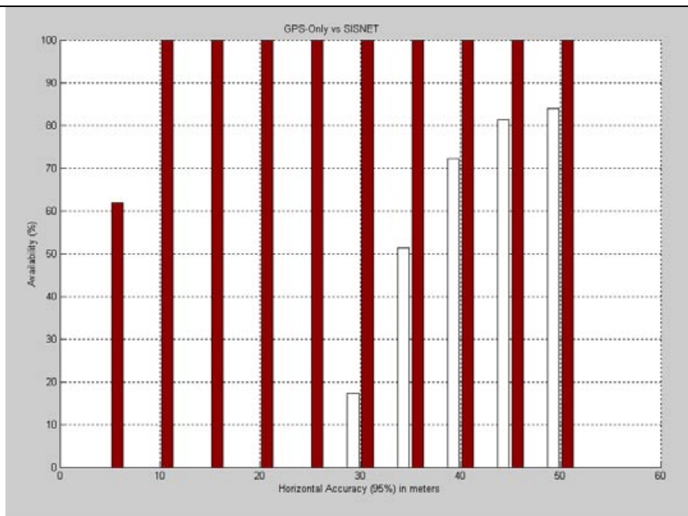
Scenario ID	3D Representation	A Potential Scenario
1		
2		
3		

Table 2 - Simulation Results

Scenario ID	Resulting Comparative Bar Plot
1	
2	
3	

85% is obtained for 30 meters of accuracy and, in the extreme, a 100% to 0% difference is achieved in several cases). These facts justify the convenience of having complementary ways to get the EGNOS product when GEO satellites may be obfuscated, hence, demonstrating the interest of using the SISNeT technology. Therefore, the combined use of GPS and EGNOS-SISNeT technology may allow maintaining few meters of accuracy, irrespectively of the urban environment conditions (degraded DOP). This may prove to have a major interest in Location-Based Services (LBS) applications.

6. SISNET-BASED REAL-TIME APPLICATIONS

Since the release of the first SISNeT prototype (in August 2001), ESA has internally developed three SISNeT-based real-time applications, aiming at demonstrating the SISNeT potential. These applications have been integrated into the ESA UAS, extending its capabilities. The next Sections give more details on the developed applications.

6.1. Real-time performance monitoring of the ESTB

In this development, the ESA UAS processing block has been substituted by an interface stage, able to adapt the information provided by SISNeT to the format employed by the ESPADA software (the ESA internal EGNOS simulation tool) [15,16].

ESPADA allows analyzing the EGNOS system performances using the real data broadcast by the ESTB (previously recorded into a file, using an EGNOS receiver and the appropriate logging software). The SISNeT / ESPADA integration avoids the need of logging sessions, since SISNeT provides a live virtual receiver wherever a connection to the Internet is available. Indeed, the present version of ESPADA is able to show performance availability maps in real-time, totally based on the EGNOS messages obtained through SISNeT. The only requirement is a connection to the Internet.

6.2. Real-time monitoring of the ESTB messages

Since SISNeT broadcasts the ESTB messages in real-time, an immediate application consists on implementing real-time algorithms for the analysis of each message contents. ESA has integrated this kind of algorithms into the SISNeT UAS, and linked it to several graphical monitoring panels (some of them are shown in Fig. 4). Consequently, UAS users can quickly and visually navigate the information transmitted by the ESTB in real-time.

6.3. Real-time monitoring of the ESTB signal through the World Wide Web

As explained above, the ESA SISNeT UAS is able to interact with the ESA ESPADA simulation software, obtaining real-time performance maps of the ESTB. In addition, the UAS is able to calculate the message type corresponding to each received ESTB message. By monitoring the received message types, is possible to determine the ESTB broadcast mode (as defined in [18]). Both results are expressed in the form of image files and periodically sent to an ESA Web server, enabling their visualization through a Web browser.

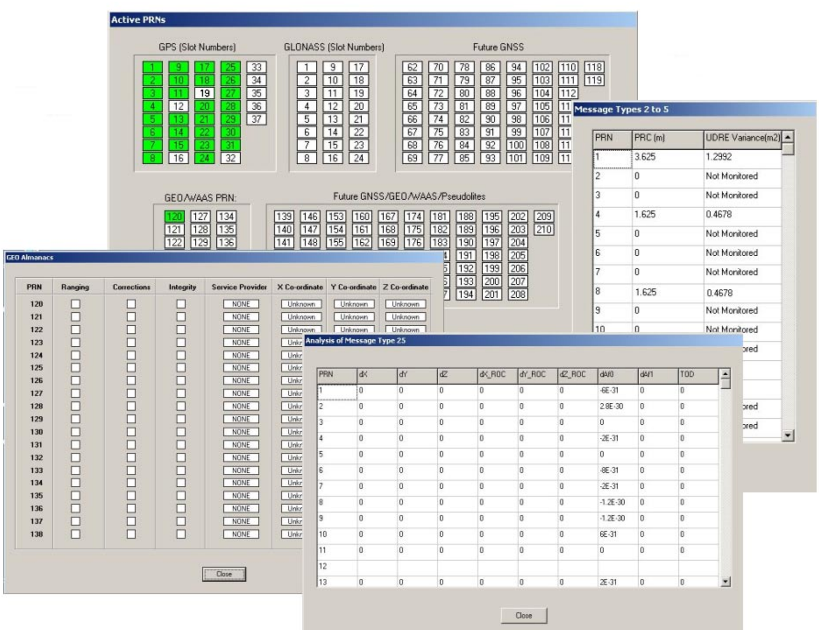


Figure 4 – Integrated panels for real-time monitoring of the ESTB messages

This service is available through the ESA ESTB website (http://www.esa.int/estb). The ESTB broadcast mode icon is updated each five minutes, while the performance map is updated each ten minutes. The web page is automatically refreshed each five minutes, acting as a real-time monitoring tool. A portion of that web page is shown in Fig. 5.

Figure 5 –Real-time monitoring of the ESTB signal status through the World Wide Web.

7. SISNET – BASED COMPLEMENTARY DEVELOPMENTS

7.1. SISNeT industrial context

After the internal validation of the SISNeT concept (in August 2001) and the announcement of the service accessibility through the open Internet (in February 2002), the next logical step consists on complementing this work with industrial initiatives. A considerable number of worldwide companies and institutions have shown a high interest on SISNeT development. The following are some of the potential projects that will be carried out during 2002 under ESA contracts:

Development of an integrated SISNeT receiver, including a GPS receiver and a GSM / GPRS link to the Internet;
Development of real-time software environments for the analysis of the ESTB messages;
Improvement of the SISNeT network in terms of performance, security and confidenciality;
Demonstrations of SISNeT receivers embedded into cars and buses;
Demonstration of the benefits of the SISNeT technology for blind pedestrians;
Develop software for existing GPS+GSM handsets, enabling them to access SISNeT;
Tests of the accuracy obtained via SISNeT in urban areas.

Next Section focuses on the last two items, describing an ongoing industrial activity performed by the Finish Geodetic Institute (FGI) under ESA contract.

7.2. A SISNeT-powered receiver based on a PDA device

The purpose of this project (started on March 2002) is to develop a SISNeT receiver based on a PDA, specifically an iPAQ Pocket PC device. The product of this project integrates a GPS receiver and a GSM / GPRS modem, both in the form of PC cards, plugged on the PDA through an expansion jacket (Fig. 6 shows the hardware configuration during development of the project).

Figure 6 – SISNeT handheld receiver based on an iPAQ PDA: Hardware configuration during development

Specific software is being developed, implementing a SISNeT UAS in full compliance with the SISNeT UID [13]. The UAS obtains the EGNOS corrections in real-time through the GSM / GPRS connection to the SISNeT Data Server.

The handset is equipped with a low-end GPS card and, hence, pseudorange information is not available. Instead, the receiver provides the position of the user and the satellites used in the calculation of the navigation solution. Since EGNOS provides corrections in the pseudorange domain, a transformation of the EGNOS corrections to the position domain is necessary. The UAS performs this operation and, finally, calculates the corrected position.

The position of the satellites is calculated by using the ephemeris information broadcast by the GPS system. Again, low-end receivers do not use to provide this information. Fortunately, SISNeT offers a solution to this problem, by making GPS ephemeris data available to users in a RINEX-like format, showing further the potential of this technology.

Furthermore, the employed receiver applies corrections based on the GPS ionospheric model before providing position. Therefore, it is necessary to remove those corrections before applying the EGNOS ionospheric corrections. To do that, it is necessary to know the value of the eight parameters of the Klobuchar model, which are not provided by the employed GPS receiver. Fortunately again, SISNeT provides those parameters, mitigating the problem.

Among other data, the UAS GUI (Fig. 7) shows the position calculated by the GPS receiver, as well as the EGNOS-corrected position. In addition, mapping capabilities have been added. Data is recorded into files, allowing post-processing the information.

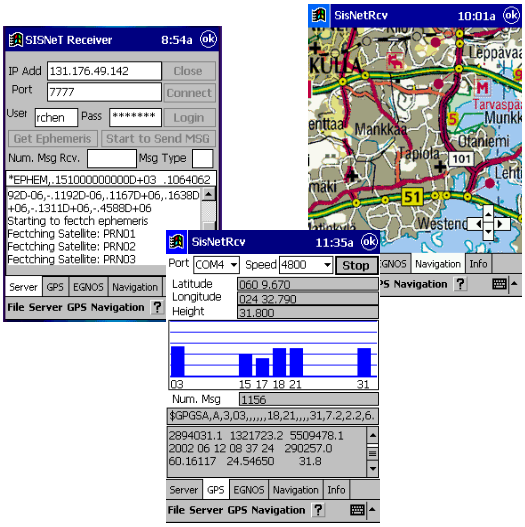


Figure 7 – Sample screens of the SISNeT handheld receiver user interface

Static and dynamic tests will be performed in Finland (see Fig. 8) at the end of the project, allowing having a first validation of Satellite Navigation through the ESA SISNeT technology. Those activities are especially interesting, since they allow testing the SISNeT potential in a worst-case scenario: urban environments (with the consequent potential GEO blocking problems) located at high latitudes (Finland.)

Figure 8 –SISNeT handheld receiver installed inside a car during preliminary tests

7.3. Other applications

ESA has recently launched a second contract based on the SISNeT technology with the Navocap society (Toulouse, France). This time, the objective points to the validation of the SISNeT technology onboard urban buses.

The first step of the project aims at developing the necessary software algorithms. In this case, the selected platform is a GSM / GPRS data terminal, equipped with the Microsoft Pocket PC operating system and a GPS receiver. This platform also includes driver software able to interface with commercial mapping packages (e.g. Route Planner).

Firstly, this configuration will be used to validate the developed algorithms. In a second step, those algorithms will be ported to navigation systems onboard urban buses, which are prepared to receive DGPS corrections through a TDMA UHF radio link.

Other SISNeT related applications are currently under assessment at the European Space Agency. One promising application aims at providing guidance information to blind pedestrians. While the performance of GPS-only in urban environments may not provide adequate accuracy for this application, the combination with SISNeT may be an excellent solution.

8. SUMMARY

In this paper we have introduced the SISNeT concept: a new technology that allows the access in real time to the EGNOS (the European SBAS) Signal-In-Space (SIS) through the Internet. SISNeT allows combining the powerful capabilities of Satellite Navigation and the Internet. The SISNeT architecture has been described in some detail here.

Through a detailed simulation exercise, we have shown that an EGNOS-SISNeT powered receiver provides much better availability of accuracy than a GPS-only receiver for typical urban environments. While in all in view situations, typical EGNOS accuracy (95%) performances will be of the order of 1-2 meters (vs. 10-20 m of GPS-only), the impact of EGNOS-SISNeT becomes more apparent when typical urban environment situations are assumed. Indeed, while EGNOS achieved availability performances are quite resistant to user masking effects, the geometrical degradation linked to poor masking angles has a major performance degradation effect on GPS-only based solutions.

Since the release of the first SISNeT prototype (in August 2002), the European Space Agency (ESA) has produced three internal SISNeT-based real-time applications, aiming at demonstrating the SISNeT potential. In addition, several SISNeT-powered receivers (e.g. based on PDA units) are currently under development through ESA Contracts.

It is firmly believed by the authors that the powerful combination of EGNOS / SBAS and the Internet can open a large amount of applications for Satellite Navigation, in the context of LBS services.

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