Proposal of an Internet-Based EGNOS Receiver Architecture and Demonstration of the SISNeT Concept

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BIOGRAPHY

Emilio González is a Telecommunication Engineer from the Polytechnic University of Madrid (Spain). His work in GMV has been devoted to the design and development of EGNOS user segment applications. He is project manager of the ShPIDER receiver project.

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Antonio Salonico is a system engineer at Telespazio SpA (Italy). Coming from a satellite communication and TT&C background he is now the program manager of the EGNOS TRAN project. He holds a M.S. in electronic engineering from University of Rome Tor Vergata.

INTRODUCTION

EGNOS will broadcast their wide area / integrity messages through GEO satellites. Satellite broadcasting through GEO means is proved to be an efficient strategy for aeronautical 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 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 RDS or GSM/GPRS broadcasting). In this context, ESA awarded Telespazio with the EGNOS TRAN project, which focused on the terrestrial and aviation applications.

ESA 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). For in-depth information on the ESA SISNeT technology, the reading of [SISNeT references] is recommended.

The overall architecture of the SISNeT system is depicted in Figure 1. The Base Station (BS) gets the EGNOS messages from an EGNOS receiver, and transmits them to the Data Server via a specific TCP/IP-based protocol, called SIS2DS. The Data Server (DS) transmits the EGNOS messages to users over the Internet, in real time, using a specific protocol called DS2DC.

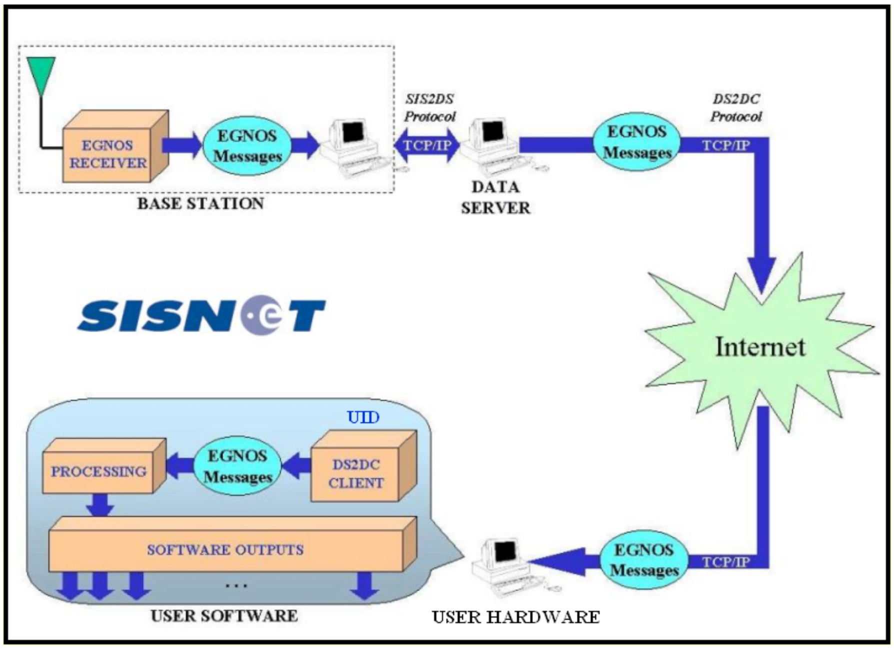

Figure 1: Overall architecture of the SISNeT system.

User Software can take advantage of the EGNOS information provided by SISNeT, in addition to other extra services (e.g. provision of GPS ephemeris parameters or access to already broadcast SBAS messages). This results in better performances, and it is especially useful in urban environments, where the availability of the EGNOS signal is not guaranteed, due to the presence of obstacles (e.g. trees, buildings, etc.) A user equipped with a GPS receiver and a wireless modem (e.g. GPRS) can access the SISNeT services, thus being able to benefit from the EGNOS augmentation signals, irrespectively of the GEO visibility conditions.

On the other hand, the Scientific and Engineering community may find major advantages in using SISNeT: the EGNOS signal can be obtained and processed without having to invest in an EGNOS receiver. Just a connection to the Internet is needed. These same benefits are also applicable to educational environments. Indeed, the ESA SISNeT technology is presently being employed at several European universities and training centers, allowing entire groups of students experimenting with the ESTB signal, without acquiring any SBAS receiver.

ESA and European Industry have developed a variety of applications that demonstrate the interest of using this new technology. For example, a SISNeT handheld receiver based on a mobile phone [Handheld references], or SISNeT applied to urban buses [Bus references].

As a specific contract inside the EGNOS TRAN activities, Grupo GMV launched the development of a SISNeT Receiver. This system was called ShPIDER (SISNeT high-Performance Internet-Dependent EGNOS Receiver). In addition, the existing Internet infrastructure was secured, and indications on how to improve the system, aiming at a professional deployment, were provided.

SHPIDER PHYSICAL ARCHITECTURE

As a prototype, ShPIDER physical architecture is based on a complete CPU board, of type ETX.

The GPS receiver inside the system is a Falcom JP3 receiver, a single-board 12 parallel-channel receiver using the highly integrated SiRFStar II chipset. The GPS receiver continuously tracks all satellites in view, thus providing accurate satellite measurements and navigation data. This receiver has outstanding accuracy, power consumption and sensitivity figures.

Figure 2: ShPIDER receiver appearance.

An MC35 GPRS modem from SIEMENS has been used. This dual-band modem is certified in accordance with GSM phase 2/2+. It is very suitable for its integration in the platform, as its weight, power consumption and size are quite low.

The hard disk is an IBM-MICRODRIVE, which provides high-capacity, high-performance removable storage (1 GB) in a one-inch hard disk drive. It uses the industry standard CF+** Type II format and is compatible (with an adapter) with the PCMCIA Type II technology.

The baseboard uses surface-mount manufacturing and traditional technology. It provides external interface connectors with both the GPS and GPRS antennas, on the one hand, and to the power supply and user serial port, on the other. The baseboard supports the interfaces for the CPU board, GPRS modem and GPS receiver. Internal connectors for VGA, keyboard and mouse are also provided; this way, maintenance of the system is made simpler.

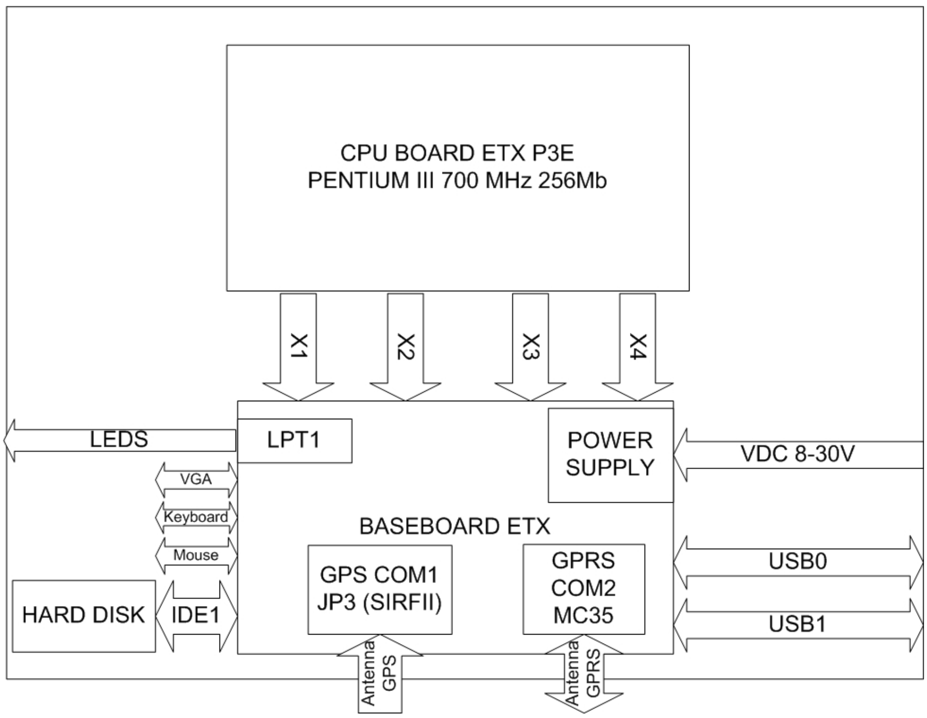

Figure 3: ShPIDER Physical architecture.

The specially adapted case contains status LEDs (red/yellow/green), an on/off switch and a small LCD. It is a robust, waterproof case with standard LEMO connectors for user and power interfaces, and SMA/SMC for antenna inputs.

SHPIDER INTERFACES

Figure 4 shows the external interfaces of the ShPIDER receiver, which are described below:

- The SISNeT Data Server (DS) provides EGNOS corrections to the Receiver through the Internet (via GPRS).
- The GPS receiver inside ShPIDER is locked to GPS satellites, and uses their pseudo-range measurements to provide navigation solutions.
- In addition, ShPIDER may send the computed outputs via TCP/IP over GPRS to a monitor station (MS). This function is commanded from the operator computer and uses directly the ShPIDER GPRS modem.

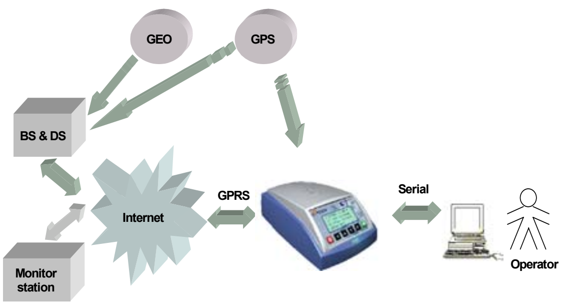

Figure 4: ShPIDER external interfaces.

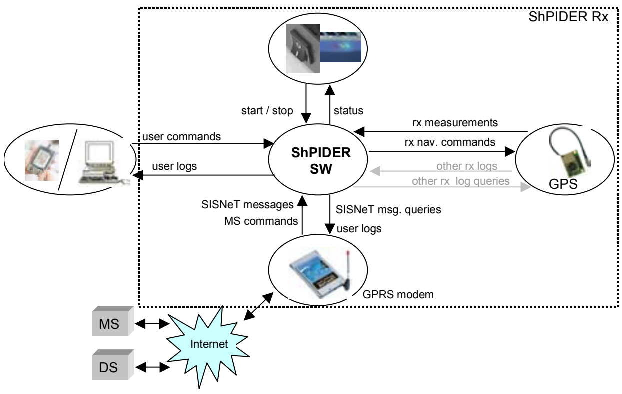

Figure 5: Internal interfaces

SHPIDER SOFTWARE ARCHITECTURE

Figure 5 shows the internal interfaces, from the point of view of the ShPIDER software.

ShPIDER is operated quite similar to a standard GNSS receiver. Once switched on, the receiver enters a transient stage, in which the last recorded configuration is applied, and then a stationary phase. Power, SISNeT monitoring and navigation status is visually output through flashing LEDs and through the LCD indicator. In normal operation, the GPS receiver is providing pseudo-range measurements and, if the SISNeT link is established, the corrections are being applied.

The operator can configure the receiver by introducing commands through a serial port, and, conversely, a number of dedicated output "logs" are returned, showing the navigation results, current configuration or overall receiver status. Besides, NMEA messages can also be output. Several kinds of commands have been designed, for SISNeT navigation, GPRS link management, EGNOS navigation configuration and log scheduling. A degree of flexibility is gained by enabling the traffic of commands and logs in both serial port and GPRS channels.

Internally, the event-driven software architecture allows reacting to the arrival of measurement messages from the GPS receiver, SISNeT messages from the DS via a "GPRS communication module", or commands from the user or monitoring station. The logging of measurement messages is pre-configured in the GPS receiver, and a "serial module" requests the ephemeris data at the beginning of the process, upon command of the "navigation engine".

The navigation engine performs the navigation with the SISNeT messages, together with a RAIM algorithm and an error estimation function.

Finally, a "manager module" performs the synchronization control. This control is not straightforward, as it must have into account the status of each data source: on the one hand, the possible loss of the GPRS links and, on the other, the possible lack of messages from any input port. Furthermore, to prevent from crashes of the GPRS modem or the application itself, a standalone software watchdog has been developed. A small protocol is established between the application and the watchdog; if the former fails to report, the watchdog restarts the application; if it reports a confirmed loss of TCP/IP socket connection, the watchdog initializes the Internet connection.

MECHANISMS TO INCREASE AVAILABILITY

As EGNOS messages go through a channel for which they were not designed, we face several drawbacks:

- Delays of messages are always bigger than the nominal. Even with an upgraded server, directly connected to the uplink facility (hence avoiding two GEO-ground leaps), the delay distribution of the messages over time is unpredictable (it depends on the Internet traffic and packet routing). In the worst case, some messages may arrive after their timeout intervals, specially for the fast corrections. Even if this is not the case, the corrections may suffer a significant degradation, according to the formulas laid down on the SBAS standards [1].

- It is possible that some messages are lost. The fact is that the effect of losing a message is different according to its type. For example, to miss a message type 1 (EGNOS mask) is worse than to miss the GEO ephemeris message (message type 9).

The logical impact of the effects described above is the degradation of the navigation solution. In a defective scenario, fast corrections could not be used. The effects would be even more evident in the calculus of the integrity protection levels. They could be so pessimistic that they could lie above the alert limits specified for the current operation.

Fully aware of these limitations, SISNeT is not intended to be a replacement for EGNOS, and it has not be designed to provide integrity, the target parameters for a trade-off study are accuracy and availability. In this context, several actions were proposed to increase availability, without disregarding accuracy performances. Namely:

- Fast EGNOS acquisition: One of the SISNeT services is the possibility to recover past EGNOS messages. ShPIDER takes advantage of this for getting a faster EGNOS acquisition. In a regular receiver, it is common not to have full EGNOS solution until about 100 seconds or more (depending on the current broadcast), because ionospheric corrections for the particular receiver location have not been retrieved. ShPIDER, after a receiver stop, or when the SISNeT server has granted access, requests a representative set of corrections; thus, it is more likely to have all the information needed to compute an EGNOS solution. This way, EGNOS acquisition is achieved in 10 to 20 seconds.
- Don't use fast corrections in the solution, beyond a given margin. Fast corrections can degrade so much that they may worsen the overall performance in case of late arrival. Slow corrections would always be used. (This feature has not been implemented).
- Use satellites not monitored by EGNOS. The effect of using satellites which are not monitored in EGNOS mask, but whose measurements are used in the GPS fix can enhance the accuracy of the results. This effect can be significant in the outskirts of the ECAC region, where fewer ESTB-monitored satellites are tracked.

- Reduce degradation factors for the fast corrections. If we assume that all delays are always bigger than in the real EGNOS, degradation slopes should be reduced.
- Lengthen timeouts. Specially for fast corrections, if timeout intervals are enlarged a bit, the risk of discarding the corrections is diminished and hence the accuracy improves. This action should be applied together with the previous one in order not incur in bigger sigma degradations.
- Use ionospheric corrections whenever possible. A stringent aspect of the EGNOS system is the way ionospheric corrections are applied. If three or four ionospheric grid points (IGP) surrounding the ionospheric pierce point (IPP) of a given line-of-sight are monitored, the estimated slant delay and model variance due to ionosphere can be computed. We studied the effect of blending in this calculus the values provided by EGNOS, in the monitored IGPs, with the values extrapolated from surrounding EGNOS IGPs, for the non-monitored points. Assuming a smooth ionosphere electron distribution, the committed error with respect to a nominal situation is compensated by far by the degree of availability gained.

These actions are performed only in a SISNeT-compatible “phase of flight”. Integrity is not assessed; only an error estimation is made. We have to note that the experiments above have been made through simulation. In practice, the mean delay is very small and those effects are almost unnoticeable.

ERROR ESTIMATION

To have a best idea of our system positioning error, a simple estimation of the position error is calculated, allowing some peculiarities. This estimation is not intended to be rigorous, but reveals as an added value to the navigation, as further developed applications can adjust the service to the estimated navigation error.

Pseudo-range residual variance calculation

After applying clock, orbit, ionosphere and troposphere corrections for a given satellite, error variance can be assumed to be the sum of all terms:

$$\sigma^2_{pseudorange} = \sigma^2_{flt} + \sigma^2_{uire} + \sigma^2_{air} + \sigma^2_{tropo}$$

- σ^2_{tropo}: troposphere correction variance. It can be always used, since it comes from a model.
- σ^2_{air}: airborne receiver correction variance. It does not depend on EGNOS messages. It will always be possible to calculate it.
- σ^2_{uire}: model variance for the slant range ionospheric error. It is needed to have EGNOS ionospheric corrections in order to calculate it. If these corrections are available, MOPS [1] model will be used. If some corrections are not available, the mentioned mixed model will be used.
- σ^2_{flt}: this is the model variance for the fast and long term residual error (satellite clock and orbit).

There are several cases depending on the availability corrections. In next point it will be described how this variance is calculated.

Variance of Fast and Long Term Correction Residuals

$$\sigma^2_{flt} = \begin{cases} (\sigma_{udre*} + \varepsilon_{fc} + \varepsilon_{rrc} + \varepsilon_{ltc} + \varepsilon_{er})^2 & \text{if } RSS_{UDRE} = 0 \\ & \text{or not available} \\ \sigma^2_{udre*} + \varepsilon^2_{fc} + \varepsilon^2_{rrc} + \varepsilon^2_{ltc} + \varepsilon^2_{er} & \text{if } RSS_{UDRE} = 1. \end{cases}$$

where:

σ_{udre*} : Broadcast UDRE standard deviation, already augmented by $\delta UDRE$.

ε_{fc} : degradation parameter for fast correction data.

ε_{rrc} : degradation parameter for range rate correction data.

ε_{ltc} : degradation parameter for long term correction or GEO navigation message data.

ε_{er} : degradation parameter for en route through non-precise approach applications.

Fast and slow corrections may not be available due to a lost message or a delay in arrival over message timeout. Depending on the available corrections in a specific epoch, this variance will be calculated in a different way. For simplicity in the explanation hereafter, it will be assumed $RSS_{UDRE} = 0$:

- **Fast + Slow + degradations**: use MOPS – Appendix A model [1].

$$\sigma_{flt} = \sigma_{udre*} + \varepsilon_{fc} + \varepsilon_{rrc} + \varepsilon_{ltc} + \varepsilon_{er}.$$

- **Slow + degradations + (timed out fast)**: fast corrections still have not been applied to navigation solution, therefore the residual error will not only include the broadcast UDRE residual, but also the fast correction residual.

$$\sigma_{flt} \approx \sigma_{udre*} + \sigma_{fast} + \varepsilon_{ltc} + \varepsilon_{er}$$

σ_{udre*} and σ_{fast} must be estimated using previous UDREs and fast corrections (see below).

- **Other cases**: use User Range Accuracy (URA) from navigation message. No correction has been applied to the measured pseudo-range. Hence standard deviation for orbit and satellite clock errors is in the order of the GPS URA for GPS satellites and the GEO URA (message 9) for EGNOS satellites.

$$\sigma_{flt} = URA$$

UDRE variance estimation

Some conclusions have been reached studying real ESTB data: broadcast UDRE residuals change very slowly in time, and its change is very small; usually from a UDREI to the next or previous.

As this estimation is not intended to provide integrity, but only to estimate the positioning error, the solution chosen is to use the last UDRE variance received even though it has timed out.

$$\sigma_{udre}(t) = \sigma_{udre}(t\text{-}delay)$$

Taking into account the slow variation of broadcast UDRE, to use such simple estimation seems a good compromise.

Fast correction variance estimation

Studying fast corrections variations, we can assume a division into low frequency variations of several meters, and high frequency variations of decimeters. Although we have delays in all messages arrivals, long-term variations will not be our concern. We can follow them easily because its characteristic time varies much slower than the delays. Short-term variations are difficult to model. There is no clear tendency. They change in two ways: steps and random noise.

The solution taken is a very simple one based on random noise: estimated next fast correction will be the mean of N last fast corrections available. Choosing a big N, we have a better long term mean. It improves the variance of the random noise, but makes the variance of the steps worse. Choosing a small one, we improve the steps variance, and worsen the noise variance. An N of 10 fast corrections has been chosen as a good compromise, selected after experimental tests.

Error estimation

Once the residual pseudo-range error estimations are computed, standard deviations for a model distribution of the navigation error is computed according the formulae described in MOPS, Appendix J [1]. A constant is applied to scale the standard deviations to the 95% percentile, assuming a Rayleigh distribution in the horizontal plane and Gaussian in the vertical dimension.

TESTS AT VALLADOLID

Currently, GMV Sistemas is performing several tests demonstrating the performance of ShPIDER in an operational environment.

The preliminary results showed very promising performances (Figure 6). ShPIDER Least Squares solution was compared to the hanheld SISNeT receiver referenced above [Handheld references], which applies the corrections from the already computed outputs of the GPS receiver inside. Carrier-phase smoothing was still not implemented in those experiments; the overall performances would have been better in that case.

Figure 7 shows the performance of ShPIDER with and without SISNeT corrections. It is evident the better performance of the receiver when the corrections are applied. The operation mode is also shown, showing the ability of computing full-EGNOS navigation, EGNOS navigation with the mixed ionospheric scheme, and ranging-only solution.

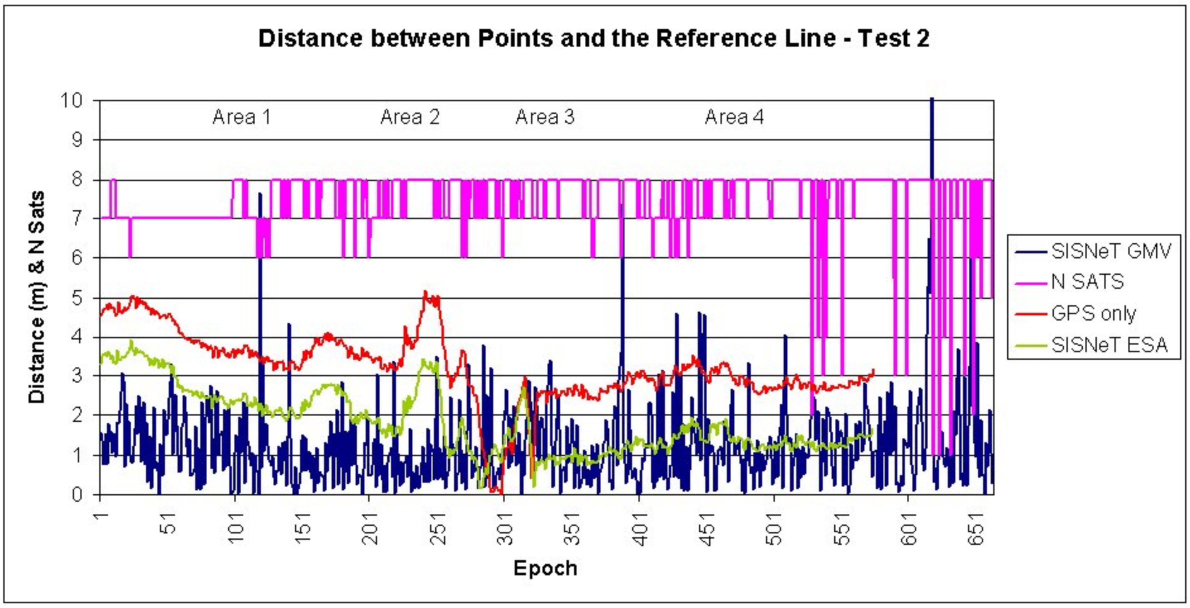

Figure 6: First results without carrier-phase smoothing of pseudoranges.

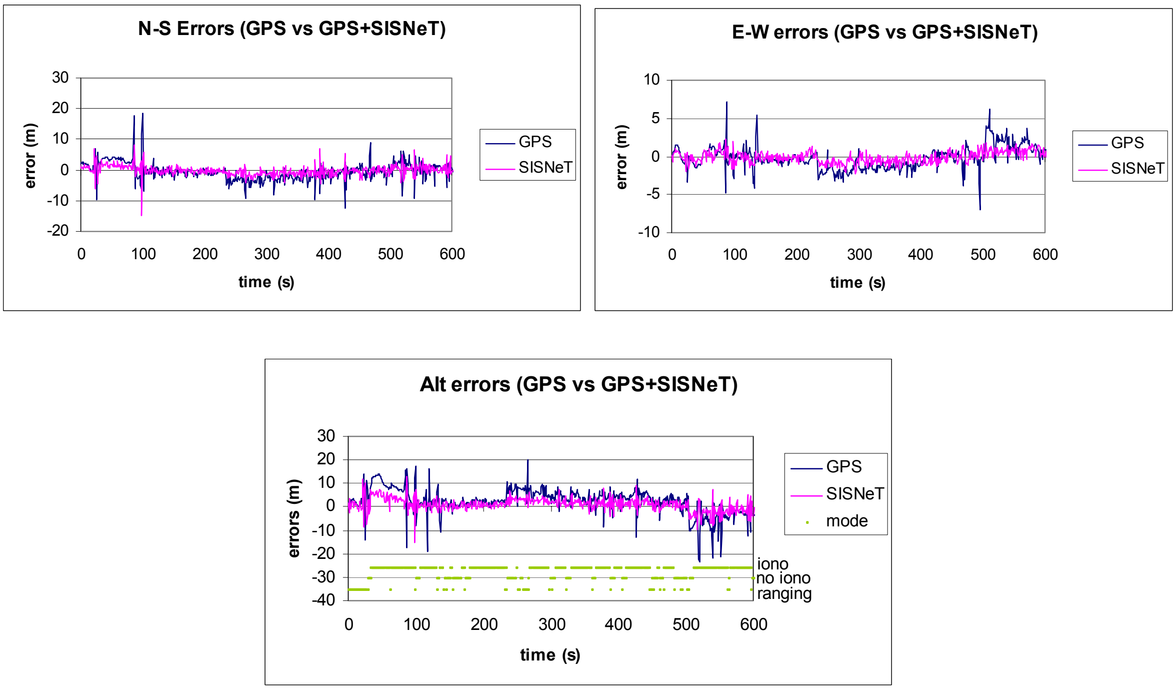

Figure 7: Dynamic test with ShPIDER. North, East and Up errors comparing GPS and GPS+SISNeT.

Another set of experiments were carried out using a rover equipped with ShPIDER as test receiver and a NovAtel OEM4 receiver for the reference, with RTK algorithms. Expected accuracy of the reference is 2 cm. Figure 8 shows some results from one of the tests. Horizontal error is maintained below 2 meters except when the receiver lost SISNET corrections. In this figure we must consider an offset of 0.4 m, which is the distance between the receiver antennas.

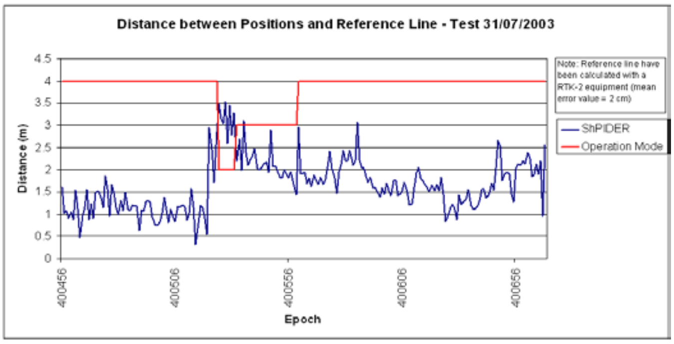

Figure 8: Distance between ShPIDER positions and reference line (Valladolid tests).

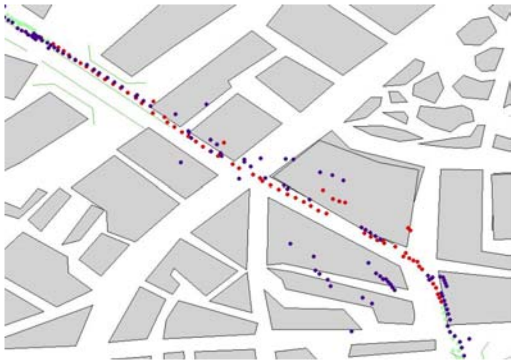

Figure 9: SISNeT (red) vs. GPS (blue) tracks in an urban environment. Results from urban bus tests in Valladolid.

Finally, ShPIDER was installed in one of the vehicles of the fleet of urban buses in Valladolid (Spain). This operational demonstration involved sending the computed navigation solution to the Control Centre from which the fleet is managed in the city. The results obtained so far indicate an interesting improvement in the availability of EGNOS solution in sub-urban and urban environments. Accuracy is also improved when compared to GPS (Figure 9).

ETRAN RESULTS

One of the motivations for the development of ShPIDER was its testing within the EGNOS TRAN activities in Rome (Italy). In those tests, the navigation outputs of ShPIDER were recorded and compared to an ETRAN receiver. This one is a GPS/GEO receiver connected with a terminal which requests SBAS messages from the Telespazio Service Center whenever GEO reception level is below a given threshold. The Service Center gets the SBAS messages and broadcast them via GPRS, quite the same way as the SISNeT DS.

Table 1 shows the availability of the positions for both the ETRAN- and SISNeT-based receivers. Table 2 shows some accuracy results.

Availability	Total position availability		Total augmented position availability	
	samples	%	samples	%
Ref. pos.	644	24.79%		
ETRAN Rx	2277	87.64%	1704	65.59%
ShPIDER	2598	100.00%	1727	66.47%

Total number of observed epochs: 2598

Table 1: Availability in the ETRAN experiments.

Accuracy	samples	East		North		Position	
		mean	σ	mean	σ	mean	σ
ETRAN	643	-0.520	1.913	1.450	2.596	2.783	2.240
ETRAN DGPS	397	-0.850	2.273	1.492	2.886	3.145	2.548
ShPIDER	643	-0.930	5.467	0.948	7.267	7.082	5.851
ShPIDER DGPS	522	-1.089	4.752	0.427	6.106	6.258	4.678
GPS	644	-1.84	3.216	-1.904	5.610	2.648	6.467

Total number of epochs with reference: 644

Table 2: Accuracy in the ETRAN experiments.

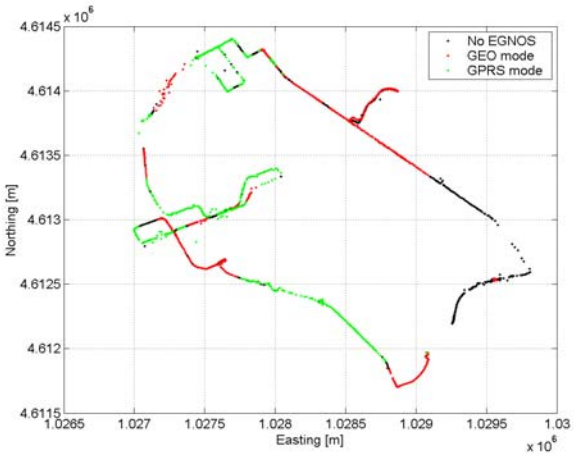

Figure 10: EGNOS TRAN trajectory (red and green lines indicating the availability of SBAS corrections)

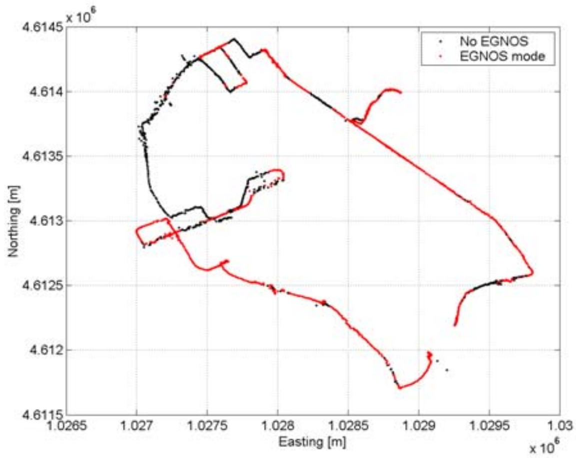

Figure 11: ShPIDER trajectory (red line indicating the availability of SBAS corrections)

The reference trajectory was obtained with measurements from the ETRAN receiver and a surveyed fixed receiver, using a kinematic software application from Astech. Possible causes of the low availability of the reference are that L1-only measurements were used, and also that inurban environment the phase ambiguity algorithms do not always work. It is also worth noting that the ShPIDER antenna was 50cm away from the ETRAN antenna on the car roof. ETRAN receiver and ShPIDER positions have been obtained from GGA logs. GPS positions have been obtained from post-processed ETRAN measurements.

In general the EGNOS TRAN solution shows a better accuracy while the ShPIDER a better position availability due to the availability-enhancing mechanisms described above. The experiments were conducted with no smoothing in ShPIDER measurements; besides, the latency of the corrections for ShPIDER was higher due to the longer distance to the Data Server. This could explain the lower accuracy of the receiver.

Another result was that, due to the highly masked urban environment of this trial, the wide area corrected position of both the ETRAN user terminal and ShPIDER do not show a significant improvement with respect to the GPS solution due to the low number of corrected satellites.

POCKET-SHPIDER

Currently, a PDA version of ShPIDER is being developed in GMV Sistemas. Pocket-ShPIDER, as it is called, integrates the ShPIDER navigation engine, plus an own geographical information system.

Pocket-ShPIDER is an application that runs on a PocketPC 2002 platform, and it has been tested in the Compaq iPAQ H3970 model. Given that this PDA does not include a GPRS modem, the system uses one from a mobile telephone. The communication between the mobile and the PocketPC is done through Bluetooth. Trials have been done with the Sony Ericsson T68i model. Of course, we also need a SiRF-based GPS receiver which can send data in SiRF binary protocol.

Figure 12: Complete System: Ericsson T68i, iPAQ H3970 with Pocket-ShPIDER application and EMTAC PCMCIA GPS receiver.

Pocket-ShPIDER as navigator allows to display the GPS position corrected with SISNeT inside a cartography, which the user can interact with. This way, the user can zoom-in and zoom-out, pan, open several maps, and so on. At the same time as the user moves, the map also moves and turns, so that the GPS position is always placed in the middle of the screen and the map is oriented according to the user's course.

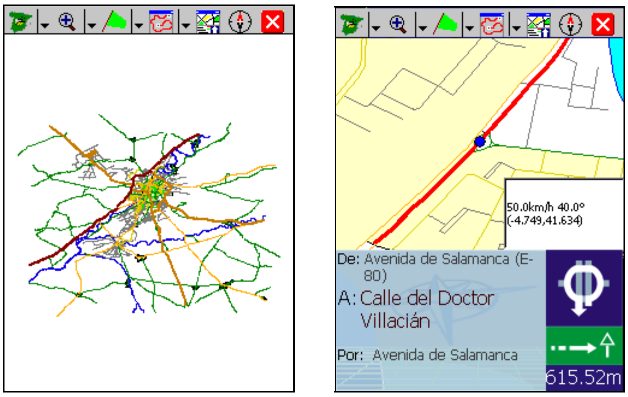

Figure 13: Pocket ShPIDER screen captures. Displaying the cartography of Valladolid (Spain) on the left, and guiding along a route on the right.

Pocket-ShPIDER also allows to choose origin and destination waypoints and calculate a route between both points. The route can be can be calculated as the shortest, the fastest or the most suitable one (for example avoiding a street). Finally, the user can be guided along the computed route.

Pocket-ShPIDER is now in the qualification phase. Its evolution will go in parallel with the ShPIDER prototype, but will also focus on location-based services taking advantage on its graphical interface and mapping capabilities.

SISNET TO HELP THE BLIND

TORMES is a Personal Navigator for the Blind developed jointly by the Spanish Organization for the Blind (ONCE) and GMV Sistemas. Location, Routing and Guidance are the main functions of this low cost system that involves the use of a speaking “Sonobraille” platform and a standard GPS receiver. The “Sonobraille” platform reports out loud the position relative to an internal cartography and indicates the direction to be followed to arrive a predefined destination.

Figure 14: Close-up of “Sonobraille” integrating TORMES.

Additionally TORMES is involved in the SISNeT project as a test platform for studying the benefits of such technology for navigation devices and personal location systems. A set of tests has been performed using a SISNeT receiver from ESA. The tests targetted to compare the performance of the system in different places, considering a variety of GPS visibility areas and different GSM/GPRS coverage zones. Further reading on this issue can be found in [Blind pedestrian references].

FUTURE WORK

Short term tasks in mind are to finish the processing of the operational tests and to compare the receiver with GPS, EGNOS and existing SISNeT receivers. The aim is to stress the advantages of SISNeT, and to indicate possible improvements.

In the long run, some ideas are clear:

- To study a better way to apply the EGNOS corrections, for instance, providing only the ionospheric corrections which a user needs based in his position.
- To exploit the ability of providing location-based services. For example, tourism information based on SISNeT, advertisement, remote control...

CONCLUSION

The authors believe that the SISNeT technology, as a solid synergy between SBAS systems and the Internet, will open the door to a large amount of innovative applications for Satellite Navigation. It is already showing its capabilities by means of prototypes such as ShPIDER or Pocket-ShPIDER, and will surely become a mature technology in the field of location-based services.

ACKNOWLEDGMENTS

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