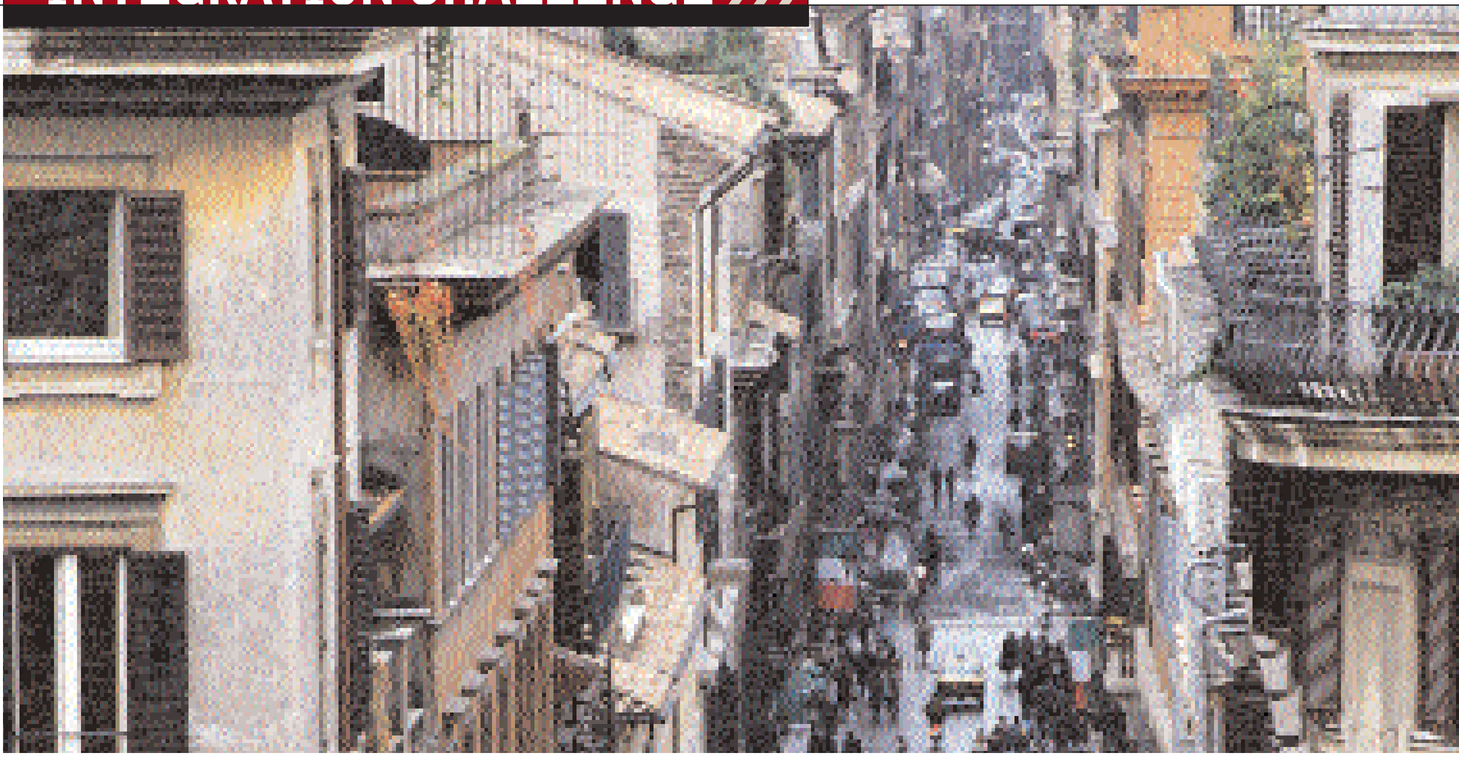

Positioning via the Internet

SISNet Technology Catches GPS in Urban Canyons

Satellite-based augmentation systems (SBAS), like GPS, also suffer from visibility limitations in urban settings. A prototype receiver combines EGNOS correction messages received through a wireless Internet connection with pseudorange measurements from its internal GPS receiver, delivering a significant improvement in positioning accuracy and availability.

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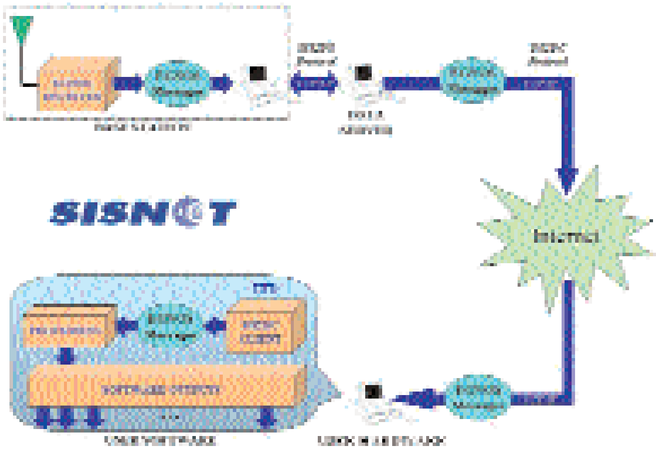
Broadcasting GPS wide area corrections and integrity messages through geostationary earth orbit (GEO) satellites — as planned by the European Geostationary Navigation Overlay Service (EGNOS) — can provide important positioning assistance for aviation and other transport modes. However, just like GPS, GEO broadcasting encounters limitations in urban and rural canyons, accentuated at high latitudes where the EGNOS GEO satellites are seen with low elevation angles. Since the EGNOS message holds significant potential for land-mobile applications, using a complementary transmission link can take advantage of this capability.

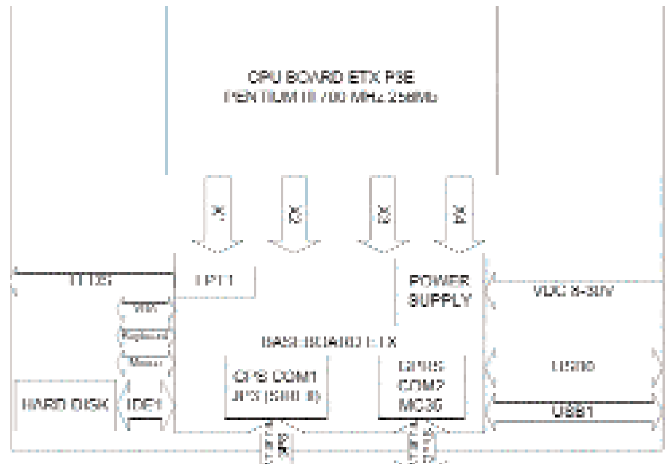
The European Apace Agency (ESA) launched specific contract activities to assess and demonstrate architectures broadcasting the current EGNOS System Test Bed (ESTB) signal through non-GEO means, among them the Internet. This project has produced a new technology called Signal in Space through the Internet (SISNeT). This could yield major benefits, in particular to users with poor GEO visibility, as well as expanding EGNOS use for scientific, technical, and educational purposes.

In this context, and under ESA contract, the Spanish firm GMV initiated work on a challenging project centered on SISNeT. It intends to provide a step forward in SISNeT implementation while integrating its results in a more general ESA-Telespazio project called EGNOS Terrestrial Regional Augmentation Network (TRAN).

Figure 1 depicts the overall SISNeT architecture, whereby the base station gets the



▲ **FIGURE 1** SISNeT system architecture



▲ **FIGURE 2** ShPIDER physical architecture

EGNOS messages from an EGNOS receiver, and transmits them to the data server via a specific TCP/IP-based protocol, called SIS2DS.

Recently, ESA upgraded the SISNeT platform, extracting the EGNOS messages from the ESTB Central Processing Facility where those messages are produced. This allows using the ESTB, even when no GEO transmission is taking place (due, for instance, to a possible failure in the uplink station). The ShPIDER receiver tested this in mid-2003 during a scheduled period without ESTB transmission through GEO.

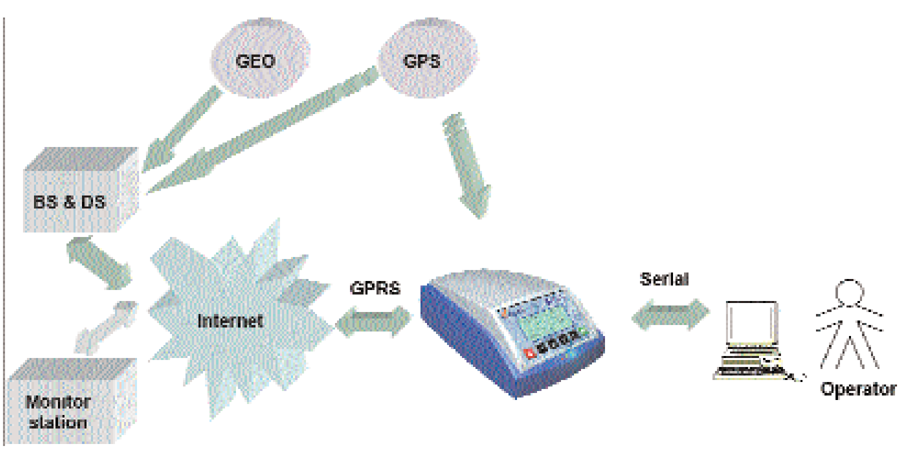
The SISNeT data server transmits the EGNOS messages to users over the Internet, in real time, using the DS2DC protocol.

User software can take advantage of the EGNOS information provided by SISNeT, in addition to other services such as provision of GPS ephemeris parameters or access to already-broadcast satellite-based augmentation system (SBAS) messages. This results in better performance, and is especially useful in urban environments where the availability of the EGNOS signal is not guaranteed, due to the presence of obstacles such as trees, buildings, bridges, and so on. A user equipped with a GPS receiver and a wireless modem can access the SISNeT services and benefit from the EGNOS augmentation signals, irrespective of GEO visibility conditions.

Scientific, engineering, and educational communities may also find major advantages in SISNeT, by obtaining and processing the EGNOS signal without having to invest in an EGNOS receiver. Only an Internet connection is needed. Several European universities and training centers now use SISNeT technology, enabling students to experiment with the ESTB signal without an SBAS receiver.

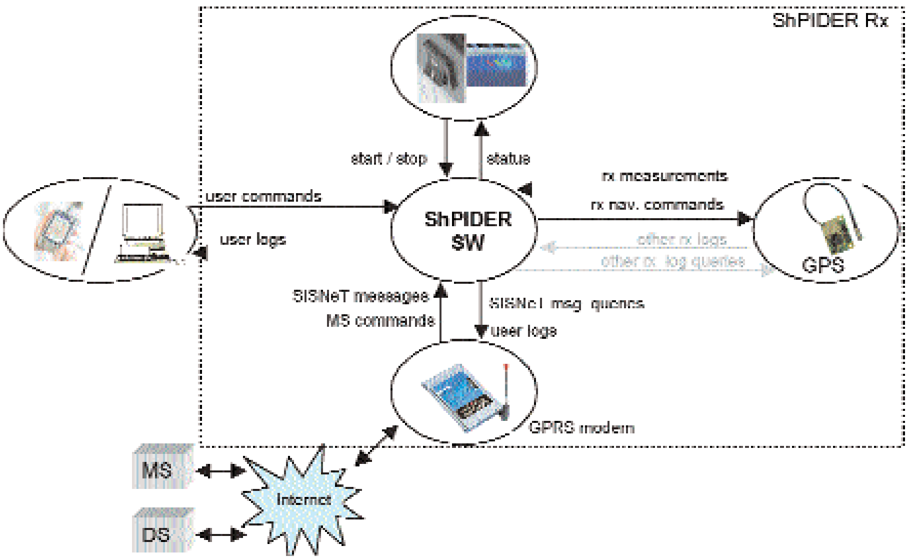
ESA and European industry have developed new applications using SISNeT, such as a handheld receiver based on a mobile phone, and systems for urban buses, fleet management, and navigation assistance for blind pedestrians.

In this regard, GMV has developed under ESA contract the SISNeT high-Performance Internet-Dependent EGNOS Receiver (ShPIDER), along with an Internet infrastructure and guidelines for improving the system for professional deployment. These recommendations include enhancing the SISNeT network to cope with up to 10 million users.



▶ **FIGURE 3** ShPIDER interfaces

▶ ShPIDER receiver



▶ **FIGURE 4** ShPIDER internal interfaces

ShPIDER Architecture

The prototype ShPIDER architecture is based on a complete central processing unit board integrating a 12 parallel-channel GPS receiver, a GPRS/GSM dual-band modem, and a 1-gigabyte hard drive (**Figure 2**).

The baseboard uses surface-mount manufacturing and traditional technology. It provides external interface connectors with GPS and GPRS antennas and to the power supply and user serial port.

The robust, waterproof case contains status light-emitting diodes (LEDs), an on/off switch, a small liquid crystal display (LCD), connectors for user and power interfaces, and antenna inputs. **Figure 3** shows the external interfaces of the ShPIDER receiver:

■ The SISNeT data server (DS) provides EGNOS corrections to the receiver through the Internet (via GPRS). The base station (BS) takes these corrections from the ESTB Central Procesing Facility in Honefoss, Norway.

■ The GPS receiver inside ShPIDER is locked to GPS satellites, and uses their pseudorange measurements to provide navigation solutions. The navigation results are sent to the user by means of a LCD, flashing LED's, and serial outputs. An application attached to ShPIDER may command it and take the receiver outputs.

■ 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. This feature, together with the ability to remotely command the receiver from the monitoring station, is very powerful, especially for the execution of tests and demonstrations.

Software

Figure 6 shows the receiver's internal interfaces, from the point of view of the ShPIDER software.

ShPIDER operates similarly 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 the LCD indicator. In normal operation, the GPS receiver provides pseudorange measurements and, if the SISNeT link is established, the corrections are 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. NMEA messages can also be output. Different commands manage SISNeT navigation, GPRS link management, EGNOS navigation configuration, and log scheduling. Enabling the traffic of commands and logs in both serial port and GPRS channels adds flexibility.

Increasing Availability

As EGNOS messages go through a channel — the Internet — for which they were not designed, we encounter several drawbacks:

■ **Message delays** are always bigger than the nominal. Even considering that the SISNeT data server now gets data directly from the ESTB Central Processing Facility (hence receiving messages in advance of GEO users), the Internet delay is unpredictable, as it depends on traffic and packet routing. In the worst case, some messages may arrive after their timeout intervals. Even if this is not so, the corrections may suffer a significant degradation, according to the formulas defined in SBAS standards.

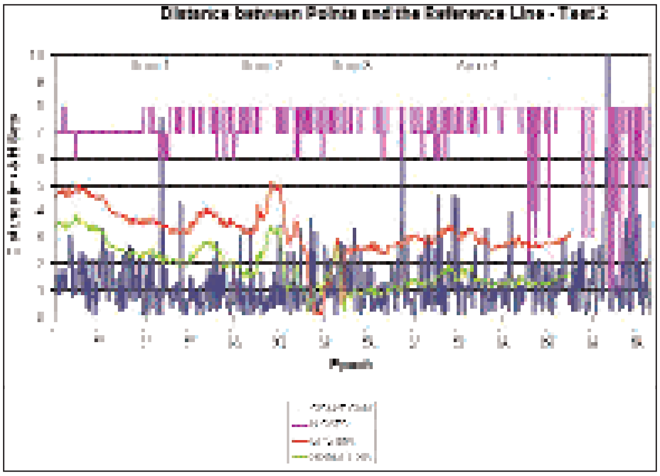
■ **Some messages may get lost.** The effect of message loss differs according to its type. For example, missing a message type 1 (EGNOS mask) is worse than missing the GEO ephemeris message (message type 9).

The logical impact of these effects is degradation of the navigation solution. In a defective scenario, fast corrections (see next paragraph) could not be used. The effects would be even more evident in the calculation of the integrity protection levels, which could be so pessimistic that they would lie above the alert limits specified for the current operation.

Fast and slow corrections model the temporal decorrelation of the different error sources. The fast corrections (message types 2 to 5) model rapidly changing error sources, including satellite clock errors. The slow corrections (message type 25) model more slowly changing error sources including long-term satellite clock drift and ephemeris errors.

SISNeT is not intended as a replacement for EGNOS and was not 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:

■ **Fast EGNOS acquisition.** SISNeT services offers the possibility of recovering 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



▲ **FIGURE 5** First results without carrier-phase smoothing of pseudoranges

▶ Rover with ShPIDER and reference receiver in Valladolid tests

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 should always be used.

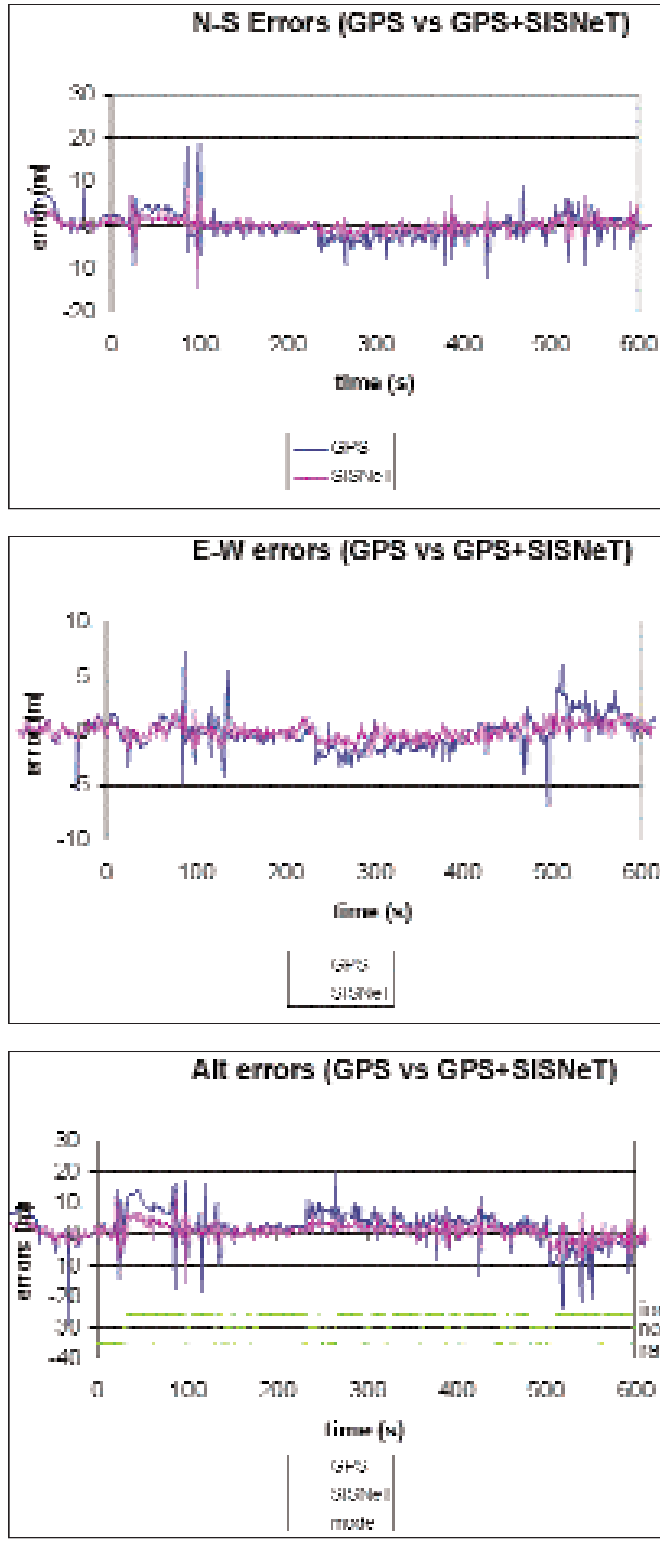
While we have not explored this possibility, we believe that it would work. Experience with other SISNeT receivers reveals that the loss of fast corrections does not overly affect accuracy. Moreover, an experiment showed that a loss of 30 percent of the EGNOS messages has an impact of just 0.5 meters on accuracy.

■ **Use satellites not monitored** by EGNOS. Using satellites which are not monitored in EGNOS mask, but whose measurements are used in the GPS fix, can enhance accuracy. This effect can be significant in the outskirts of the European Civil Aviation Conference (ECAC) region, where fewer ESTB-monitored satellites are tracked.

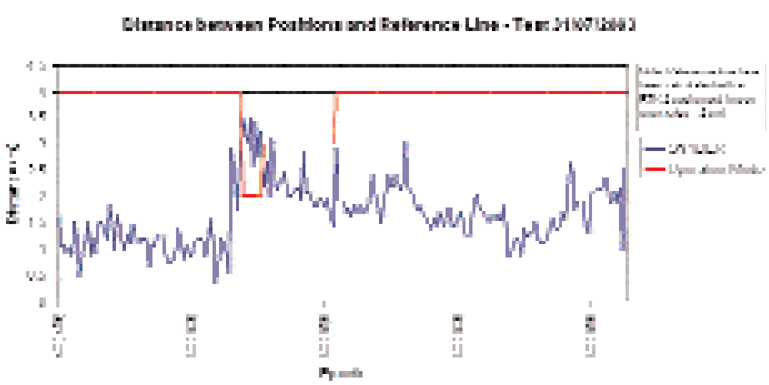
■ **Reduce degradation factors** for the fast corrections. If we assume that all delays are always greater than in the real EGNOS, degradation slopes should be reduced.

■ **Lengthen timeouts.** Especially for fast corrections, enlarging timeout intervals reduces the risk of discarding the corrections, and hence improves accuracy. This action should be applied together with the previous one in order not to incur larger sigma degradations.

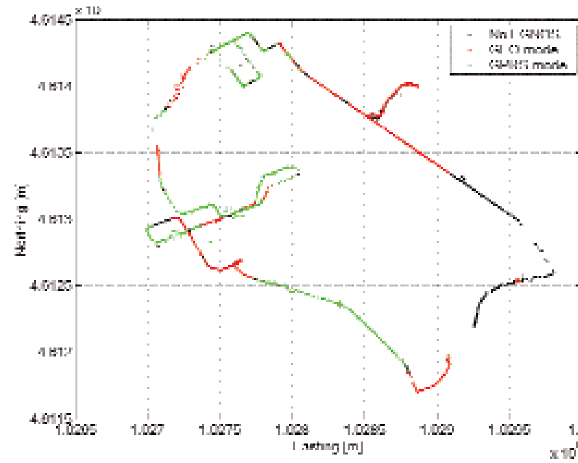
■ **Use ionospheric corrections** whenever possible. A stringent aspect of the EGNOS system is the way ionospheric corrections are applied. If three or four ionospheric grid points (IGP) surrounding the ionospheric pierce point (IPP) of a given line-of-sight are monitored, the estimated slant delay and model variance due to ionosphere can be computed. We studied the effect of blending 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 suffciently



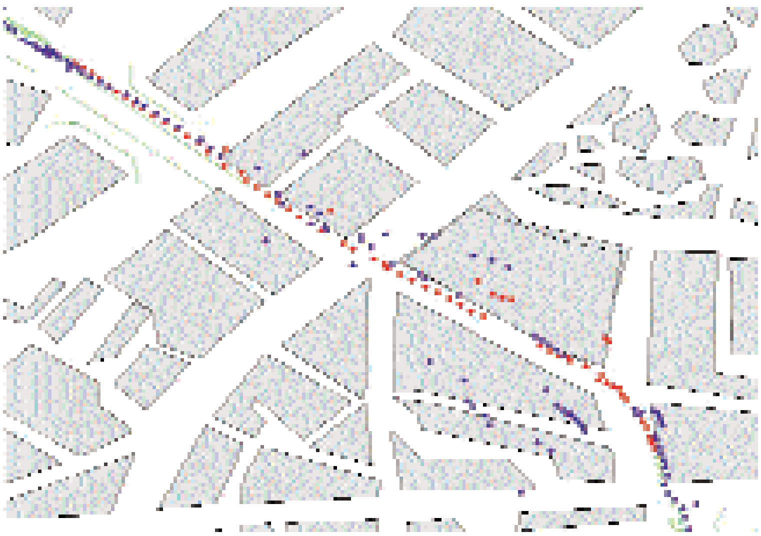
▲ **FIGURE 6** Dynamic test with ShPIDER. North, East and Up errors comparing GPS and GPS+SISNeT



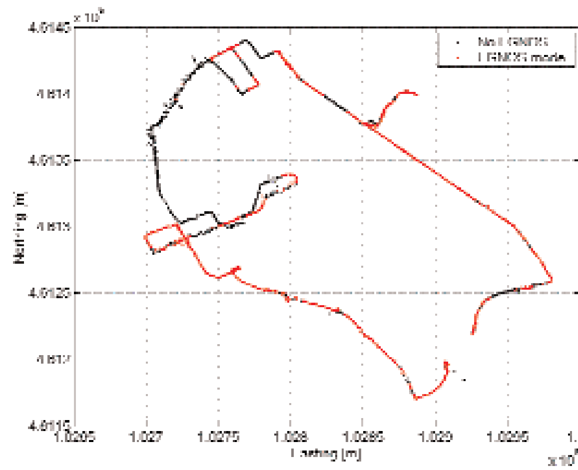
▲**FIGURE 7** Distance between ShPIDER positions and reference line from a test in Valladolid tests



▲**FIGURE 9** EGNOS TRAN trajectory (red and green lines indicating the availability of SBAS corrections)



▲**FIGURE 11** SISNeT(red versus GPS (blue) tracks in an urban environment; results from urban bus tests in Valladolid, Spain



▲**FIGURE 10** ShPIDER trajectory (red line indicating the availability of SBAS corrections)

compensated 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 made these experiments through simulation. In practice, the mean delay is very small and those effects are almost unnoticeable.

Valladolid Tests

GMV Sistemas is testing ShPIDER performance in an operational environment.

Preliminary results showed very promising performances (**Figure 5**). ShPIDER was compared to the hanheld SISNeT receiver, 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 6 shows ShPIDER performance with and without SISNeT corrections, making evident the receiver's better performance when the corrections are applied. The operation mode shows the capability of computing full-EGNOS navigation, EGNOS navigation with the mixed ionospheric scheme, and ranging-only solution.

Another set of experiments used a rover equipped with ShPIDER as a test receiver and an OEM receiver for the reference, with RTK algorithms (see photo on previous page). Expected reference accuracy is 2 centimeters. **Figure 7** shows that 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 meters, the distance between the receiver antennas.

Finally, ShPIDER was installed in an urban bus in Valladolid, Spain. This demonstration sent the computed navigation solution to the Control Center that manages the city bus fleet. Results to date indicate an interesting improvement in the availability of EGNOS solution in urban and suburban environments. Accuracy is also improved when compared to GPS, as expected (**Figure 11**).

ETRAN Results

One motivation for ShPIDER development was testing it within the EGNOS TRAN activities in Rome, Italy. We recorded the ShPIDER navigation outputs and compared them to an ETRAN receiver, a GPS/GEO receiver connected with a terminal that requests SBAS messages from the Telespazio Service Center whenever GEO reception level falls below a given threshold. The Service Center gets the SBAS messages and broadcasts them via GPRS, quite the same way as the SISNeT DS.

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

Both EGNOS TRAN and ShPIDER solutions (**Figures 9 and 10**) showed very promising accuracies. The position availability shown by ShPIDER was remarkable, thanks to the availability-enhancing mechanisms described earlier. The experiments were conducted with no smoothing in ShPIDER measurements. This could explain the lower accuracy of the receiver.

A public demonstration in May 2003, attended by ESA and industry representatives, used ShPIDER and the ETRAN receiver on different vehicles moving along the same track at the same time. The ShPIDER navigation outputs were displayed successfully in the Telespazio Service Center, demonstrating again the operational feasibility of the SISNeT concept.

Pocket-SHPIDER

GMV Sistemas is currently developing a personal digital assistant (PDA) version of ShPIDER, integrating the ShPIDER navigation engine and a geographical information system (GIS). As this PDA does not include a GPRS modem, the system uses one from a mobile telephone, and communicates between the mobile and the PocketPC via Bluetooth

Pocket-ShPIDER as navigator displays the GPS position corrected with SISNeT inside an interactive map. The user can zoom in and out, pan, open several maps, and so on. As the user moves, the map moves and turns, always placing the GPS position in the middle of the screen and orienting the map to user trajectory.

Pocket-ShPIDER also allows choice of origin and destination waypoints and calculate a route between both points — the shortest, the fastest, or the most suitable one. Finally, it can guide the user along the computed route.

Now in the qualification phase, Pocket-ShPIDER will evolve in parallel with the ShPIDER prototype, but will also focus on location-based services using its graphical interface and mapping capabilities.

▲ **POCKET SHPIDER**

SISNeT for the Blind

TORMES, a personal navigator for the blind developed jointly by the Spanish Organization for the Blind (ONCE) and GMV Sistemas, uses a speaking "Sonobraille" platform and a standard GPS receiver for location, routing, and guidance. The "Sonobraille" platform reports aloud the position relative to an internal map and indicates the direction to a predefined destination.

TORMES also serves as a test platform for studying the benefits of SISNeT technology for navigation devices and personal location systems. Tests using a SISNeT receiver from ESA compared the performance of the system in different places, considering a variety of GPS visibility areas and different GSM/GPRS coverage zones

TORMES system for blind navigation

Future Work

We plan on further processing of the operational tests and comparing the receiver with GPS, EGNOS, and existing SISNeT receivers, highlighting SISNeT advantages and indicating 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 that a user needs based in his position.
- To exploit the ability of providing location-based services, for example, tourism information based on SISNeT; also advertisement and remote control.

Conclusion

SISNeT technology, a synergy between SBAS systems and the Internet, will open doors for innovative applications of satellite navigation. It already shows its capabilities by means of prototypes such as ShPIDER or Pocket-ShPIDER, and will surely become a mature LBS technology .

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Manufacturers

ShPIDER uses a **Falcom** *JP3* receiver integrating the *SiRFStar II* chipset; a **Siemens** *MC35* GPRS modem; and an **IBM** *Microdrive*. Valladolid tests used a **NovAtel** *OEM4* receiver for the reference. ETRAN tests used a kinematic software application from **Thales**, with Thales *Sagitta* GPS/EGNOS receiver, geodetic L1 GPS antenna, and Siemens *SX45* PDA/GSM/GPRS unit. The ShPIDER unit used a **Trimble** L1 GPS antenna. Pocket ShPIDER has been tested in the **Compaq** *iPAQ H3970* with **Ericsson** *T68i* phone and **EMTAC** GPS receiver using a **SiRF** chipset.