CATNET, a permanent GPS network with real-time capabilities

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BIOGRAPHY

J. Talaya obtained his MSc in Mathematics from the University of Barcelona in 1991. From 1991 to 1998 he worked at the Institut Cartogràfic de Catalunya on several topics related to GPS, including high-precision GPS positioning and kinematic GPS for airborne sensor orientation. Since 1998, he has been the Head of Geodesy at the Institut Cartogràfic de Catalunya. He is currently doing his Ph.D. in algorithms and methods for robust geodetic kinematic positioning at the Universitat Politècnica de Catalunya.

E. Bosch was born in Barcelona in 1972. He obtained a B.Sc. in Telecommunications from the Universitat Politècnica de Catalunya, Barcelona in 1995, specializing in Electronic Equipment, and subsequently an M.Sc. in Telecommunications from the same university. Since 1998, he has been working in the Geodetic Department at the Institut Cartogràfic de Catalunya. His work includes the development and integration of communications systems, such as DAB (Digital Audio Broadcasting) and VSAT (Very Small Aperture Terminals) for GPS applications.

ABSTRACT

Since permanent GPS stations were identified as a key resource for the geodetic community, the number of permanent GPS networks has grown considerably. During the past few years there has been increasing demand for real-time GPS applications: RTK, GPS meteorology, volcano monitoring, TEC estimation, etc. Therefore, real-time capabilities of the permanent GPS networks will play an important role in the near future.

Since 1992, the Institut Cartogràfic de Catalunya (ICC) has deployed a permanent GPS network that covers the area of Catalonia. The network consists of 8 stations, with an average distance of 100 km. between them. The ICC is deploying a satellite communication system to provide the GPS network with real-time capabilities. The system will be based on VSAT (Very Small Aperture Terminal) technology, and will be divided into three segments: VSAT terminals to be installed at the GPS sites, a spatial segment with a capacity of 112 Kbps and a central Hub site located at the ICC's headquarters.

The GPS receivers will send data at 1 Hz to the VSAT terminal, which will transfer it to the central Hub at the ICC. Once the data has been received, it will be processed by the GPS data server, which will store the observations and set the appropriate UDP/IP channels, in order to feed data to the different real-time services to be provided by CATNET. In addition to this, GPS files will be available in order to perform real-time GPS water vapor estimation for meteorology.

The various real-time services provided by CATNET will be broadcast via DAB (Digital Audio Broadcasting), the new digital radio standard. DAB has a capacity of 1.7 Mbps, allocating up to 6 high-quality audio programs, and a significant amount of space (at least 150 Kbps) will also be available for data transmission. The real-time data will be transmitted using TDC (Transparent Data Channels), which can be configured from 9.6 up to 115 Kbps. The first test on DAB data transmission was carried out in March, and in July 1999 a test was completed on the broadcasting of RTK information using DAB Transparent Data Channels (TDC).

INTRODUCTION

Since 1991, the Institut Cartogràfic de Catalunya (ICC) has been working on the SPGIC project (Integrated Geodetic Positioning System of Catalonia) [2], based on sparse geodetic networks, knowledge of the geoid and GPS. Thus SPGIC may be defined as a set of geodetic permanent stations, networks, procedures, regulation data, communications, software, hardware and technical advice for the purpose of high-precision local positioning in Catalonia.

One of the fundamental elements of the SPGIC project is CATNET (CATalan NETwork), a network of permanent GPS stations. The network consists of 8 permanent stations, which cover an area of 30,000 square kilometers with 6 million inhabitants (figure 1). The network has been designed to provide uniform coverage, ensuring that any point within Catalonia will lie within the triangle defined by the outermost stations, while it gives some redundancy in Barcelona and the surrounding area (the most populated part of Catalonia).

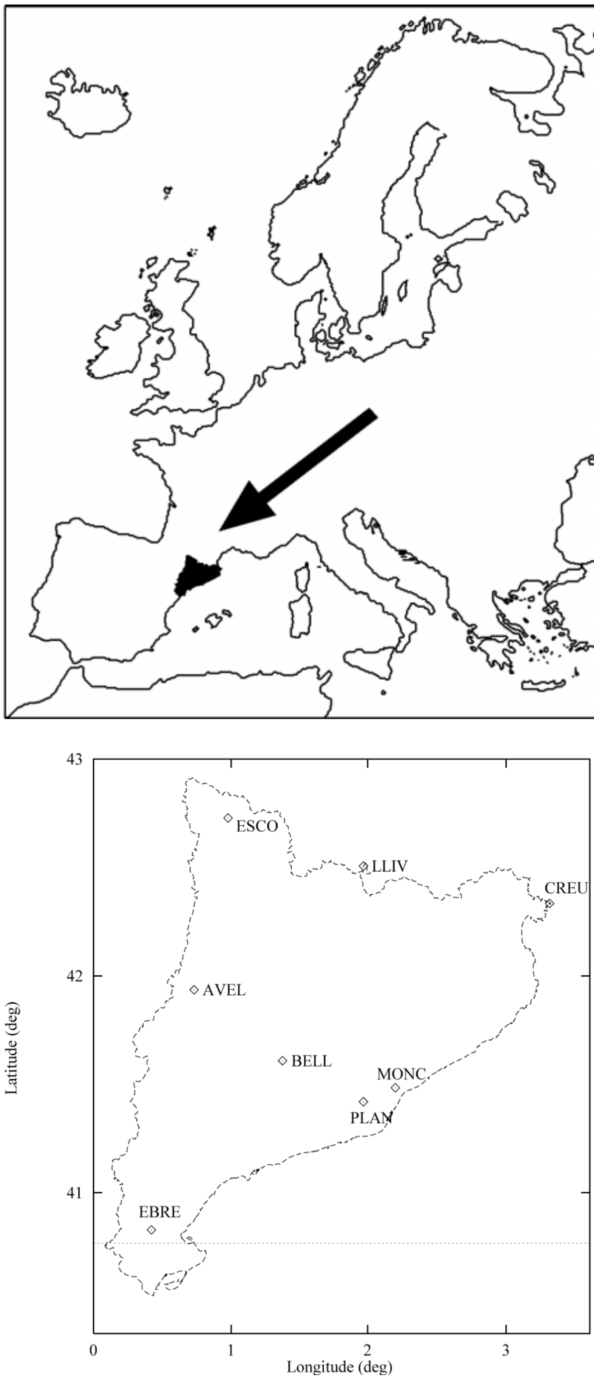


Figure 1: CATNET

All the stations have geodetic GPS receivers and choke ring antennas. The importance of kinematic positioning was recognized as soon as the network was first deployed, so the receivers record data at 1 Hz. However, when they are not needed, part of the files are filtered to 15 second record interval prior to downloading them to the ICC's headquarters. The data is downloaded by means of cellular telephone lines and is distributed via ftp (ftp.icc.es).

REAL-TIME GPS NETWORK

The CATNET provides an excellent frame of reference for geodetic positioning in Catalonia, and several applications can be carried out in postprocessing. However, the possibility of having real-time access to the data observed by the GPS network would dramatically increase the synergy of CATNET. For instance, GPS could be used to improve meteorological models, broadcast of single station RTK messages and even to perform centimeter positioning over the entire territory of Catalonia, Regional Area RTK Positioning (RARTK).

In order to provide a real-time service, the data has to be sent from the GPS stations to the ICC's headquarters, processed and then distributed to the users for their applications. After careful analysis, the ICC decided to use satellite communications for data transfer to the ICC and Digital Audio Broadcasting (DAB) for data dissemination when real time is required.

VSAT TECHNOLOGY

The aim is to transfer the data collected by the permanent GPS stations to the ICC. Therefore, a reliable, low-cost communications system is necessary to connect several stations distributed across Catalonia to the ICC's headquarters. The VSAT [4] meets all the requirements, since it is a system that supports total freedom of station location at a reasonable cost.

VSAT stations, now the accepted acronym for Very Small Aperture Terminal, represent one further step in the evolution of satellite systems, whose dimensions have been progressively reduced, from the INTELSAT stations with 30 m. dishes, the TV broadcasting systems with 60 cm. dishes and the GPS receivers to the latest personal satellite communications services that use LEO (Low Earth Orbits) satellites.

VSAT technology supports a broad range of communications services with antennas no bigger than 2.4 m. These stations do not support high traffic capacities, but they are cheap and easy to install in relation to the high-capacity public networks. With these VSAT terminals the user equipment is plugged directly into the communications platform, avoiding the use of public switched networks.

The user is proprietary and the manager of the communication network, and therefore has complete freedom of network configuration and a fast response to communications requirements.

The current VSAT networks use geostationary satellites. The fact that the satellite position appears to be stationary from the earth station simplifies the earth station structure, since it does not have to track the satellite. Conceptually there is a relay at a long distance, with wide territorial coverage and an overall delay of about 0.25 s.

The small antenna size of the VSAT stations reduces the sensitivity of the VSAT receiver. In order to overcome this restriction, a central station known as the Hub, with improved characteristics, has to be deployed at the central site to which all the data is to be transferred. The Hub has a bigger antenna than the VSAT stations, of four to eleven meters. As a result of its improved gain, the Hub is capable of accurately receiving data from the low-power VSAT stations and vice versa. This configuration is called a star network, and is shown in figure 2.

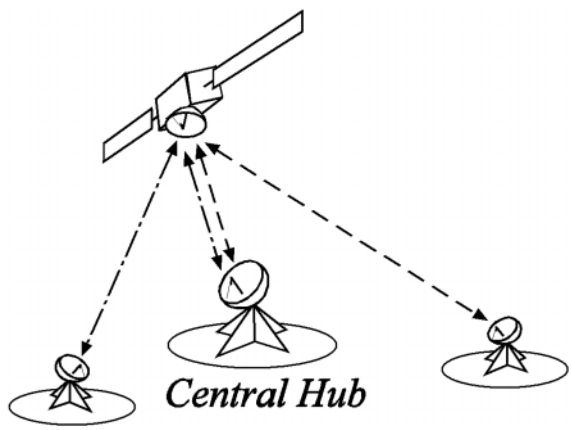


Figure 2: VSAT Star network configuration.

In 1998, a decision was taken at the ICC to set up a VSAT network for the new Catalan seismic network and to provide the GPS network with real-time capabilities. The network core is a seismic oriented network, which had to be slightly modified in order to make GPS data transmission possible [5]. The first stage in the new seismic system was deployed in May 1999, and it consisted of three stations, two of them coincident with permanent GPS stations (LLIV and AVEL). The remote VSAT stations have RS-232 ports, which enable transmission of the GPS data to the central Hub at the ICC. The VSAT network and the satellite link have been tested with the seismic sensors, and in September 1999 the first two GPS stations will start real-time data transmission. This combined GPS/seismic solution offers a better performance in terms of communications resources and operational costs than a separate network installation.

The VSAT earth stations establish radio links with the satellite by means of modulated carriers. Each carrier is assigned a portion of the total resources offered by the satellite in terms of bandwidth and/or transmission time. All the VSAT stations have to share the same satellite transponder, in order that a protocol may exist to avoid collisions between stations. In order to regulate multiple access to the same resource, several techniques can be applied. In the case of the VSAT network adopted by the ICC, the TDMA (Time Division Multiple Access) technique is employed. TDMA allocates a different time interval, known as a slot, to each of the stations, including the Hub, and this is reserved for their exclusive use. The time employed to scan all the stations is called the Frame Repeat Interval (FRI), and it is a critical parameter for obtaining the proper system performance. The FRI also plays a critical role in the latency of the transmission, since the FRI has to be lowered to decrease the total latency, which implies a worse efficiency of the bandwidth assigned.

DAB TECHNOLOGY

As stated earlier, once the data is available in real time, having been processed to provide real-time services, it has to be broadcast to the end user. The broadcasting media have to meet certain requirements: they must be low-cost, of good quality, cover a large area and have sufficient data capacity. The ICC has adopted DAB (Digital Audio Broadcasting) [3] as the main data broadcasting system for its real-time services, although other systems will also be used (RDS, GSM,…). DAB is a standard for commercial digital radio transmission; it has a capacity of 1.7 Mbps, allocating up to 6 high-quality audio programs, and a significant capacity (at least 150Kbps) will also be available for data transmission.

A TDC (Transparent Data Channel) has been developed, in order to provide a transparent RS-232 connection from the DAB data inserter to the DAB radio receiver. Therefore, it is possible to connect a GPS receiver generating RTK information to the DAB data inserter RS-232 connector, and after being broadcast, the same information will be available on the DAB receiver RS-232 connector in readiness for insertion into a rover GPS receiver. This feature is shown in figure 3.

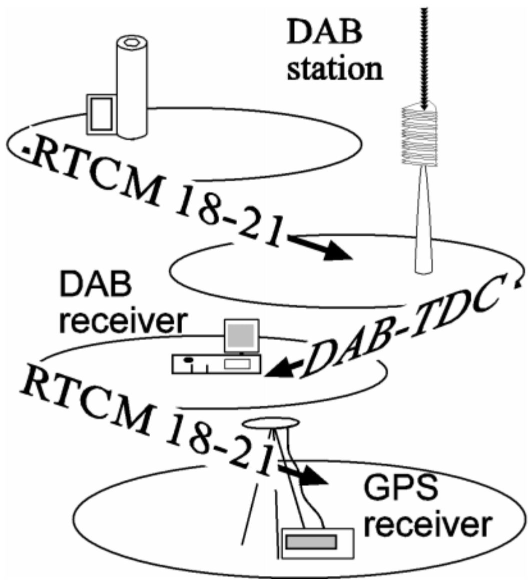


Figure 3: RTK corrections via DAB

The TDC enables the establishment of connections from 8,000 bps up to the full DAB stream capacity. Such bandwidth is sufficient to transmit RTK corrections at an interval of 1 second. It is possible to transmit more than one TDC channel on the same DAB frequency, so different services can be broadcast using the same DAB infrastructure.

The first test on DAB data transmission was completed in March 1999. The first transmissions of code and phase corrections using TDC were carried out in July 1999, with the collaboration of the Centre de Telecomunicacions de la Generalitat de Catalunya (Telecommunications Center of the Autonomous Government of Catalonia - CTGC), the DAB operator in Catalonia. The number of users of DAB radios is growing rapidly, so the price of the DAB receiver will show a significant decrease in the near future.

APPLICATIONS

In order to take full advantage of the real-time capabilities of the network, the ICC is working on the deployment of five public services that will bring CATNET closer to the users.

RASANT

Since 1995, the ICC has been broadcasting code corrections from one permanent station located in the center of Catalonia (BELL), and the compressed RTCM corrections are broadcast via RDS (subcarrier of commercial FM programs). The name of the service is RASANT [6], it covers 99% of the population, and a precision of 1 meter (1 sigma) can be obtained.

Regional area code positioning

The idea of using a network of permanent GPS stations to improve positioning accuracy over the area covered by the network has existed since the development of the WAAS concept (Wide Area Augmentation System). The observations from a network of permanent GPS stations are combined to determine the parameters present on the models used for code GPS positioning, so the user obtains a set of corrections (satellite orbit correction, satellite clock correction, ionospheric model parameters...) that lead to good differential code positioning over a large area. The distances between GPS stations on WAAS range from 500 to 2000 km.

High-quality GPS receivers have a code noise of 20-30 cm., so the potential of code DGPS positioning is much better than the 1 meter provided by RASANT. When a user is working at more than 100 km. from the RASANT reference station, ionospheric residuals can significantly reduce their positioning accuracy. In a regional network like CATNET the WAAS concept can be applied, and regional models can be computed in order to attain the nominal accuracy of code positioning over the entire region.

Single station RTK

One single permanent GPS station can generate RTK corrections to enable centimeter positioning within a range of 15-20 km. As 50% of the population of Catalonia live in or very near the Barcelona area, broadcasting of single station RTK from two GPS sites (PLAN, MONC) will provide more than 3 million people with a centimeter level service.

On 12 July 1999, the ICC began the experimental phase of single station RTK broadcasting via DAB. RTCM messages (type 18-21) were transmitted using a Transparent Data Channel (TDC) with a capacity of 8,000 bps. The first results were highly satisfactory and RTK/OTF solutions were obtained by the rover receiver. As expected, the DAB transmission showed a very good signal quality, due to the 1/2 convolutional encoding applied to the transmission. Further tests will be made by the end of 1999, particularly with relation to the DAB broadcasting performance under different conditions (kinematic tests, DAB multipath environment, etc.).

Regional area RTK

Although single station RTK can provide an excellent service in limited areas, it is difficult to set up a network of GPS permanent stations that cover the entire territory with a distance between stations of 30-40 km. The geodetic community has begun to study the idea of using regional area RTK to overcome the 20 km. limitation of single station RTK. Processing of the data from all the reference stations would produce a vector of high-precision regional area corrections (orbit corrections, satellite clock corrections, ionospheric corrections, tropospheric corrections) that should lead to OTF ambiguity resolution within the entire region.

Much work has yet to be completed, but two experiments using CATNET data [1] have validated the concept. The experiments consisted in generating a ionospheric model that uses data from the three stations located in outlying areas of Catalonia and then interpolating the model at a receiver located in the center of Catalonia (BELL). Using data from the model, the ambiguities could be solved On-The-Fly in a real-time simulation.

By the end of the planned deployment, CATNET will consist of 8 stations that will transmit the GPS observations to the ICC's headquarters in real time. Therefore, there will be some redundancy in the regional area RTK process, which will make the service very robust, because it will be possible to implement integrity monitoring based on the network processing. Furthermore, in the event of a receiver failure at one of the sites, the process will be able to compute the regional model with the data from the remaining stations, and the service will be continued, with some local weakness.

Once the vector of corrections has been computed, it will be broadcast to the users via DAB. As this will be a public service, the idea is that the user will end up with a set of RTK corrections in the RTCM standard format, which can be input to any GPS/RTK receiver for performing centimeter positioning. Thus the user will have to generate a synthetic RTCM/RTK message using the information provided via DAB and its position. This synthetic message could be reconstructed by the DAB receiver (or an external processor) in the same way that the FM receiver rebuilds the RTCM code messages in the RASANT system. Another possibility for providing the service could be GSM, in the event that some parts of the country were not covered by DAB and were covered by cellular GSM telephony.

Near real-time data publication

The availability of real-time data means that it can be used on less restrictive real-time applications where the data can be transmitted through the web. For example, the use of GPS data for improving meteorological models entails a maximum delay of 0.5 - 2 hours in the provision of tropospheric delay estimations. The ICC will make 0.5 - 1 hour rinex files available on its ftp server within the framework of the MAGIC project (a collaborative project with other European institutions for the use of GPS in meteorology). It should be noted that that some of the stations are equipped with high-precision meteorological sensors.

Finally, surveyors that download the data from the web to perform postprocessing computations appreciate the fact that they can download the data while they are in the survey area and check the quality of the computations, before moving to a different area.

DEPLOYMENT STAGES

The implementation of this system requires a systematic approach, in order to validate all the different components and establish the appropriate configuration for each subsystem. The three main subsystems are: data transfer to the ICC using VSAT, data management/processing and data broadcasting/dissemination to the end user.

The first stage will be the experimental phase in VSAT communications. The ICC VSAT communications system has been in operation since May 1999, with three seismic stations sending the data in real time to the ICC, and the communications link has shown that it performs well. In September 1999, two permanent GPS stations (AVEL, LLIV) will be connected to the VSAT stations and will start sending data in real time to the Central Site equipped with two separate data managers, one for each network (seismic, GPS), as shown in figure 4. Each station will be transmitting at 1 Hz, with a total delay of up to 5 seconds. During this phase it will be possible to design the interfaces to the data management/processing subsystems.

The next stage will be the Pre-operational phase. During this phase three more stations will be transmitting GPS observations at 1 Hz and the data latency will be lowered to 1-2 seconds. With more than three stations providing real-time data, it will be possible to commence the experimental phase with the services: RACP (Regional Area Code Positioning) and RARTK (Regional Area RTK). CATNET will begin to make near real-time data files available through the web. Single station RTK service through DAB will become operational in the area of Barcelona.

The Operational Phase will commence after the installation of the remaining two stations, which will produce a network of 8 stations with an average distance between them of approximately 100 km. At this stage, it should be possible for RACP and RARTK to begin the pre-operational phase.

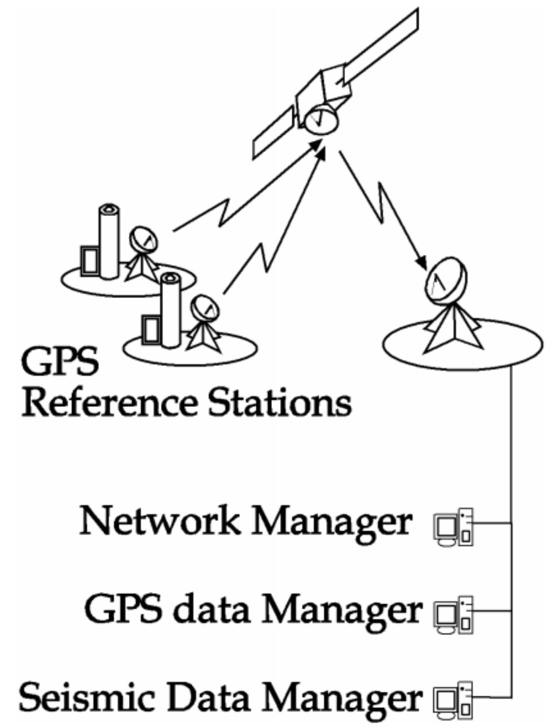
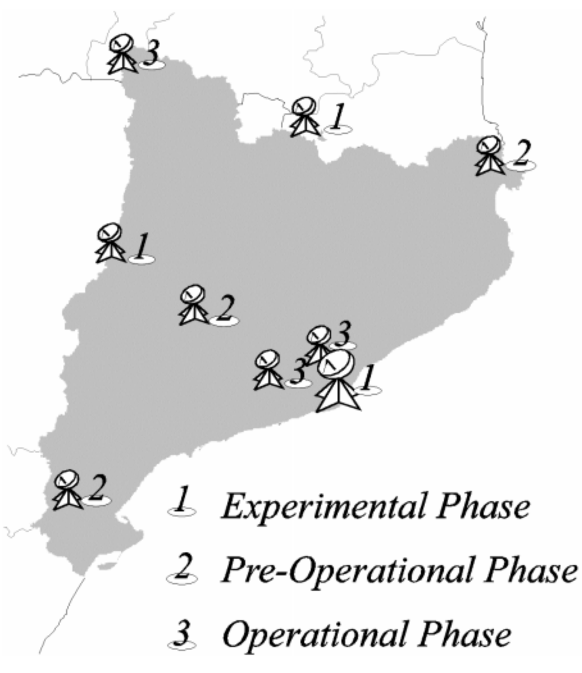


Figure 4: Real-time GPS network configuration

Following completion of these stages, Catalonia will be covered by a real-time permanent GPS network, and various services will be built on this infrastructure, to the substantial benefit of the surveying and navigation community.



CONCLUSIONS

In recent years, there has been a general deployment of regional area GPS networks, most of these for scientific purposes. The future of the permanent GPS networks will lie, on the one hand, in their real-time capabilities, and on the other hand, in their extension to civil use.

The ICC has taken the first steps towards the conversion of its network of permanent GPS stations (CATNET) into a real-time GPS network and the provision of a set of different services, in order that full advantage should be taken of the real-time capabilities of the network.

VSAT technology has been identified as a low-cost, effective communication system for real-time transmission of data from the permanent GPS stations, and the VSAT network can share part of the infrastructure with other networks, such as a seismic network, in order to reduce installation and operational costs.

Deployment of the new DAB standard will provide a very useful broadcasting medium for the diffusion of the various real-time services available to the user community.

ACKNOWLEDGEMENTS

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