THE ROLE OF TIME AND FREQUENCY IN EGNOS (EUROPEAN GEOSTATIONARY NAVIGATION OVERLAY SYSTEM)

A. Job*, J. Legenne*, M. Brunet**, J-M. Pieplu***, A. Batchelor****

* European Space Agency (ESA): 18, avenue E. Belin, 31401 Toulouse, France
** Centre National d'Études Spatiales (CNES): 18, avenue E.Belin, 31401 Toulouse, France
*** Alcatel: 105 avenue du général Eisenhower, 31037 Toulouse, France
**** Racal Research Limited, Reading, Berkshire RG2 0SB, England

Abstract

The European Geostationary Navigation Overlay System (EGNOS) is being developed in Europe to provide GPS and GLONASS regional augmentation services to aviation, maritime, and land users. EGNOS will provide the following services: i) GEO-based GPS-like Ranging signals to improve the availablity and continuity of GPS and GLONASS navigation services. ii) Ground Integrity Channel (GIC) to improve the integrity of GPS- and GLONASS-based navigation and position determination for safety-critical applications. And iii) Wide-Area Differential corrections (WAD) to improve the accuracy of GPS-SPS and GLONASS. Additionally, EGNOS will disseminate accurate time to users, synchronized to GPS, GLONASS, and UTC time scales. The paper provides an overview of EGNOS ground-segment architecture, gives requirements related to time aspects, and describes preliminary analysis and performances through test trials. It also covers initial results achieved in the frame of the EURIDIS program, conducted by CNES, after several months of measurements.

INTRODUCTION

The commission of the European Union (CEU), Eurocontrol, and the European Space Agency (ESA), which together form the European Tripartite Group (ETG), jointly defined the European Navigation per Satellite Program, whose first step is GNSS-1.

GNSS-1 is based on the enhancement of the existing GPS and GLONASS navigation per satellite systems, respectively operated by the US and Russian Departments of Defense. The basic principle of GNSS-1 relies on the addition of a ground-segment, which will process and deliver GPS and GLONASS differential corrections and integrity data to users, and on new geostationary satellites. The EGNOS program was defined by the ETG in 1994-1995. Its initial phase has just ended with the system Preliminary Design Review (PDR), while the implementation phase is about to start. EGNOS service is expected to be delivered in the year 2002 to Civil Aviation, Land Mobile, and Maritime users.

The role of time and frequency in EGNOS is of paramount importance, since any synchronization error would be derived into navigation error. This paper gives a brief overview of EGNOS architecture, including its main functions. It also provides time requirements as specified at system level, and describes the design and expected performances of time functions.

DESCRIPTION OF THE MAIN EGNOS FUNCTIONS AND ARCHITECTURE

The EGNOS system will provide the following functions:

- GEO Ranging: Transmission of GPS-like signals from GEO satellites (INMARSAT-III AOR-E and IOR, and the ESA ARTEMIS satellites). This will augment the number of navigation satellites available to the users and, in turn, the availability of satellite navigation.
- GNSS Integrity Channel (GIC): Broadcasting of integrity information. This will increase the availability of GPS / GLONASS / EGNOS safe navigation service up to the level required for civil aviation non-precision approaches.
- Wide Area Differential (WAD): Broadcasting of differential corrections. This will increase the GPS / GLONASS / EGNOS navigation service performance, mainly its accuracy, up to the level required for precision approaches down to CAT-I landing.

EGNOS Architecture

To ease the understanding of the role of time functions, this section provides a summary description of the EGNOS architecture. The EGNOS is composed of four segments: ground segment, space segment, user segment, and support facilities.

- The EGNOS Space Segment is composed of transponders embarked on board GEO satellites.
- The EGNOS User Segment consists of GNSS Standard receivers developed according to RTCA MOPS DO-229.
- The EGNOS Support Segment includes some facilities needed to support System Development, Operations, and Qualification.
- Finally, the EGNOS Ground Segment as described below.

EGNOS Ground Segment Overview

The EGNOS Ground Segment consists of *Ranging and Integrity monitoring Stations* (RIMS), which are connected to a set of redundant control and processing facilities called *Mission Control Center* (MCC). The MCC determines the integrity, ephemeris and clock differential corrections for each monitored satellite and ionospheric delays, and generates GEO satellite ephemeris. This information is sent in a message to the *Navigation Land Earth Station* (NLES), to be up-linked along with the GEO Ranging Signal to GEO satellites. These GEO satellites downlink these data on the GPS Link 1 (L1) frequency with a modulation and coding scheme similar to the GPS one. All ground Segment components are interconnected by the *EGNOS Wide Area Communications Network* (EWAN).

Please refer to [3], [4] and [5] for more detailed information concerning EGNOS overall architecture.

SYSTEM REQUIREMENTS ON TIME ASPECTS

The Navigation mission of EGNOS would basically not have required for the system any explicit reference to an external time scale. EGNOS being based on differential principles, all measurements and data are referred to an internal EGNOS Network Time (ENT) whose performance requirements shall be derived exclusively from navigation accuracy performance requirements. Therefore, system requirements do not address for instance any ENT stability performance.

System Specification requires EGNOS ENT to be steered within 50ns of GPS system time; this is a requirement derived from Signal In Space (SIS) specification of RTCA MOPS and ICAO SARPS. Even if the GPS reference is not well known because not directly accessible (with SA on SPS signals), this steering requirement is not very stringent and mostly specified to be compatible with the maximum capacity of the message (256m) used to correct the GPS satellite clock.

The above requirement will also allow the use of one particular mode of navigation, called Ranging, where differential corrections are not used and the user can mix in its navigation solution GPS and EGNOS GEO signals whose time references are closely related enough if maintained within the specified range. For this mode EGNOS has specified an UERE (User Equivalent Range Error) of 25m (95%) for the GEO Ranging signal; this error encompasses:

- ENT-GPS time offset error
- ENT-GEO time transfer error
- GEO-User range error.

The ENT-GEO time transfer error is specified to be less than 10ns (maximum), after offset and drift correction provided in EGNOS GEO message #9. This particular requirement is of special interest for a precise time broadcast function in real time.

Effectively, beside its principal navigation mission, EGNOS signals may be used as a means to broadcast ENT, which is a PTTI source closely related to GPS time and to UTC.

For the UTC connection, EGNOS will provide in message # 12, as required in SIS specification, the time difference and the drift between ENT and UTC. But, in discrepancy with the SIS requirement, the real-time offset will not be provided in relation with UTC, which is a "paper" time, but with a physical primary clock of a European laboratory participating in UTC.

EGNOS system presently requires that ENT shall be within 20ns of UTC; this shall be understood as the uncertainty on the time difference with UTC(k), because the UTC-UTC(k) time difference is not under EGNOS control and not available in real time. When this latest information is made available to EGNOS (real time or with prediction) EGNOS will revisit the performance requirement.

The following sections will provide in response to the requirements, a description of each time functions, and the expected performances, based on analysis and experiment.

EGNOS SYSTEM OVERVIEW RELATED TO TIME

Both GPS and GLONASS use Time Difference of Arrival (TDOA) as the basis for the formation of receiver-to-satellite range measurements. Therefore, accuracies of the receiver and satellite clocks involved have a direct impact on the range measurement accuracy achieved. Both GPS and GLONASS satellites provide information in their broadcast navigation messages that enable system users to correct for satellite clock errors; i.e. the offset of individual satellite clocks from the nominal satellite system time-scale. These corrections are accurate to within a few nanoseconds. However, in the case of GPS, they do not account for Selective Availability (SA) dither, and unless they are estimated and removed, they will degrade user-positioning performance. Furthermore, for high integrity applications it is desirable to produce independent estimates of the satellite clock errors, in order to monitor the broadcast corrections.

In order to determine highly accurate estimates of satellite clock errors and disseminate them to system users, the EGNOS system performs three basic clock functions located in the Central Processing Facility:

- RIMS clock synchronization and generation of the EGNOS Network Time (ENT);
- Steering of ENT to GPS time;
- Determination of the satellite clock offsets from ENT;
- Estimation of the difference between ENT and UTC.

Figure 1 below describes the links between EGNOS sub-systems related to time functions.

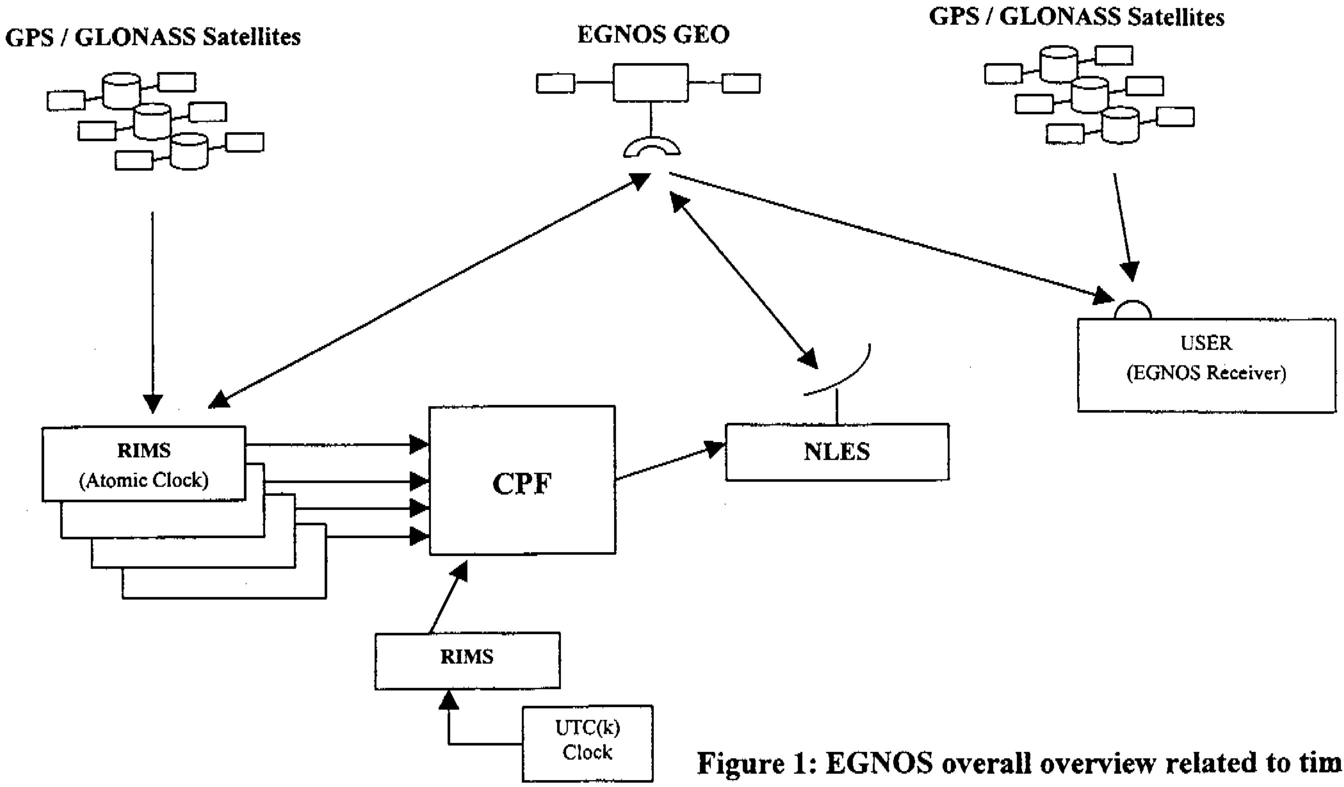

Figure 1: EGNOS overall overview related to time

RIMS Clock Synchronization and Generation of ENT

RIMS clock synchronization is performed using the *composite-clock* technique. In the composite-clock technique, ENT is defined as the implicit ensemble mean of all RIMS clocks and the synchronization process generates estimates of the offset and drift of each RIMS clock relative to it. These estimates can then be used to reference all RIMSs' pseudo-range measurements to ENT. This synchronization process is necessary in order to allow simultaneously observed pseudo-range measurements from multiple RIMS to be combined in the function that estimates satellite clock errors (see below).

A simpler, alternative synchronization technique is the *master-clock* technique, whereby one RIMS clock is nominated to provide the network time and all other RIMS clocks are synchronized to that clock. The composite-clock method has two significant advantages over this approach. Firstly, the master clock approach has a single point of failure; if the master clock is lost, ENT is lost. In contrast, the composite-clock ENT is maintained as long as there are two clocks in the ensemble. Secondly, the stability of ENT provided by the master-clock method is of course limited to the stability of the master clock itself. With the composite clock technique, the stability of ENT becomes the stability of the implicit ensemble mean of all of the RIMS clocks. Assuming an ensemble of n identical, independent, clocks, this gives a $\sqrt{n}$ improvement in stability. This last feature of the composite clock has the important side effect of increasing the ability of the system to detect and isolate clock failures.

The composite clock algorithm is executed by means of a Kalman filter. The filter measurement data comprises a linearly independent set of *common-view* observations with minimum a priori variance. A common-view observation for a pair of RIMS is formed by subtracting simultaneously observed pseudo-range measurements to a common satellite. Before subtraction, the pseudo-ranges are *pre-processed* to remove RIMS antenna-to-satellite antenna geometric ranges and reduce unwanted errors, such as multipath delays and thermal noise. The resulting common-view observations represent direct measurements of the RIMSs' clock offsets plus residual errors.

The filter states comprise the offsets and drifts of each RIMSs' clock relative to a hypothetical *ideal* time-scale. The consequence of this formulation is that the filter provides estimates the offsets and drifts relative to the *implicit*, weighted average of all of the RIMS clocks. This implicit ensemble mean essentially defines the EGNOS time-scale, ENT. The relative weighing of clocks used within the filter is dependent upon several factors, but is largely determined by the process noise models associated with each of the clocks. These models characterize RIMS clock stability.

Since only clock difference measurements are available to the filter, the filter model has unobservable components that cause secular growth trends in the state error covariance matrices. Special measures must be employed to remove these trends, otherwise they will eventually lead to numerical instability within the filter. It can be shown that, once the secular growth trends due to the unobservable components of the system model have been removed from the covariance matrix, the resulting covariance describes the errors in the filter state estimates relative to the implicit ensemble mean, *not* the ideal time-scale. Full details of the composite clock algorithm can be found in [1].

Steering of ENT to GPS Time

In order to limit the dynamic range of the satellite clock corrections, thereby reducing the size of the WAD clock messages and improving the efficiency of the message dissemination process, it is necessary to steer ENT to the GPS time-scale. Steering of ENT to the GPS time-scale is performed using a second-order, low-pass digital filter. The steering input signal is an instantaneous estimate of the ENT–GPS time-scale offset. This is computed from the estimated satellite clock offsets from ENT and the GPS broadcast satellite clock corrections, which are estimates of the satellite clock offsets from the GPS time-scale. The cut-off frequency of the filter is chosen to provide the best reduction of Selective Availability (SA), whilst avoiding significant lags due to the relative drift of ENT with respect to the GPS time-scale. The more stable ENT is, the lower the cut-off frequency can be set and the greater the reduction of SA.

The EGNOS system baseline will easily meet the ENT-GPS time-scale steering requirement of <50 nsec. The *all cesium* scenarios examined demonstrate that a steering accuracy of < 3 nsec can be achieved. These results must be treated with caution, since they are based upon synthetic data sets with idealized models of SA and RIMS clocks. However, the results are consistent with other findings, such as those quoted in [2].

Steering accuracy of < 3 nsec will allow ENT realizations from different CPFs to be synchronized autonomously, without need for a dedicated ENT-A to ENT-B synchronization function. However, if such a function is required, experimentation with real and synthetic data has shown that synchronization of different ENTs can easily be achieved with an accuracy of better than 3nsec (2σ). This is the system requirement imposed to make CPF switchovers transparent to EGNOS users.

Satellite Clock Corrections

Satellite clock corrections and correction rates are computed using all available pseudo-range and Doppler measurements from the pre-processing function. The measurements are referenced to ENT using the RIMS synchronization parameters and then collected into groups by satellite. For each satellite, weighted least-squares estimates of its clock's offset and rate-of-change with respect to ENT are computed. The offsets are later separated by low-pass filtering, similar to that used for the ENT steering function (described below), into the slow and fast components which comprise the satellite clock correction messages. The rate-of-change estimates are used to project the corrections forward in time by the expected system latency.

Broadcast ENT through Geostationary Earth Orbit (GEO) Satellites

The satellite fast and slow clock corrections are disseminated to EGNOS users in via the GEO satellite in separate messages. The EGNOS user receiver decodes these messages and reconstitutes the combined satellite clock offsets from ENT for each of satellite it tracks and applies them to its pseudo-ranges, together other WAD corrections provided by EGNOS. In this way, the ENT time-scale replaces the GPS-, or GLONASS-, time-scale in the receiver's navigation solution. Hence, not only does the receiver compute an improved estimate of position, because of the WAD corrections, it also computes an estimate of its internal receiver clock offset from ENT.

Once available on the ground, ENT has to be accurately transferred on board GEO satellites. Indeed, the GEO time is defined at the output of the GEO payload, precisely at the L1 antenna center of phase. This function is ensured by the so-called Long-Loop, a servo-control mechanism, based on the near symmetry between the up and down links from the NLES to the GEO satellite.

UERE on ENT

A fixed user equipped with an EGNOS receiver could obtain ENT in real time through one or several GPS-corrected signals or GEO channel. The accuracy of this information is directly the User Range accuracy as indicated in the table below:

Range accuracy in m (1σ)	GPS	GEO
UDRE (orbit + clock)	0.65	1.0
Ionospheric error	0.50	0.50
Tropospheric error	0.20	0.20
Receiver noise	0.50	1.0
Multipath (45° elev.)	0.25	0.25
GPS latency	0.42	-
UERE (5° elev.)	4.1	4.1
UERE (20° elev.)	1.8	2.1
UERE (90° elev.)	1.0	1.3

Table 1: EGNOS User Equivalent Range Error (UERE)

A user able to control properly its multipath environment (or mitigate the multipath through several channels) will obtain a total time transfer accuracy in the range of 4 to 6 ns (1σ).

Estimation of the Difference between ENT and UTC Time Scales

UTC means Coordinated Universal Time. It is a coordinated time scale, obtained from a combination of data from about 230 clocks kept by 65 laboratories spread worldwide. UTC is made available in the form of time differences with respect to local time UTC(k) of laboratory k. The computation is carried out in deferred-time for the standard dates, currently every five days, and the results are published monthly by the BIPM in *Circular T* in the form of time differences [UTC – UTC(k)]. UTC is therefore available in deferred time on a monthly basis. Only UTC(k) are maintained permanently in about 48 time centers.

UTC being a theoretical average of many clocks around the world, it is not possible to establish a direct link between ENT and UTC. Instead, it is necessary to use a physical clock participating to the elaboration of UTC.

Therefore, the time difference between ENT and UTC can be broken down into 2 terms:

$$\mathrm{ENT} - \mathrm{UTC} = [\, \mathrm{ENT} - \mathrm{UTC(k)} \,] + [\, \mathrm{UTC(k)} - \mathrm{UTC} \,]$$

(k standing for any European laboratory participating to the elaboration of UTC)

UTC (k) – UTC

The time differences [UTC – UTC(k)] are made available on a monthly basis by the BIPM through the Circular T, and are out of the scope of EGNOS.

Performances of the time difference [UTC – UTC(k)] is as follows:

- IUT and CCDS Recommendation is to keep [UTC – UTC(k)] within 100 ns (1σ),
- The estimated uncertainty for the time differences [UTC – UTC(k)] is currently at the level of 10ns (1σ), provided in deferred time by *Circular T.*
- The estimated uncertainty of a prediction of the time difference [UTC – UTC(k)] depends on the period of prediction, and could be in the range of 20 ns (1σ).

ENT – UTC (k)

To synchronize ENT and UTC(k), an EGNOS RIMS will be co-located with lab k to be physically connected to its atomic clock (with interfaces at 10 MHz and 1pps levels). EGNOS RIMS synchronization module will estimate directly the time difference between ENT and RIMS(k) with an uncertainty of less than 3ns (2 σ). The time difference will be broadcast with message type 12 with the above uncertainty.

PRELIMINARY PERFORMANCE OVERVIEW THROUGH TEST TRIALS

Early Test System

In order to investigate the performance of the CPF clock functions, a wide range of experiments were conducted. These experiments utilized both recorded GPS data sets, collected simultaneously from a network of receivers distributed throughout Europe, and synthetic data sets produced using Racal Research's in-house GPS data generator. The synthetic data sets were required in order to provide truth data for clock errors and SA. The synthetic data generator provides a comprehensive model of GPS pseudo-range error sources. Furthermore, to ensure realism, its error models were calibrated against recorded data sets.

RIMS Synchronization Experiments

The EGNOS system requirement for RIMS clock synchronization accuracy is 3nsec 2σ. Experiments using both real and synthetic GPS data sets have shown that the EGNOS system baseline will meet this requirement, provided that RIMS multipath is not excessive.

The above conclusion was drawn after evaluation of the clock synchronization filter with multiple test scenarios. These scenarios were designed to investigate the following factors:

(i) size and density of RIMS network;
(ii) use of both precise and GPS broadcast ephemerides for computation of the geometric ranges to satellites;
(iii) use of single- and dual-frequency data ionospheric delay error modelling;
(iv) variation in filter update rates; and
(v) variation in the satellite elevation cut-off angle below which pseudo-range measurements are ignored.

Figure 2 shows a typical example of synchronization errors for a synthetic, fifteen RIMS, scenario, with each RIMS equipped with a high-quality cesium clock. The synthetic data used were calibrated against data recorded with high-quality, dual-frequency, geodetic receivers and antennas. The figure shows the errors in the realizations of ENT computed from each RIMS clock using the filter synchronization parameters.

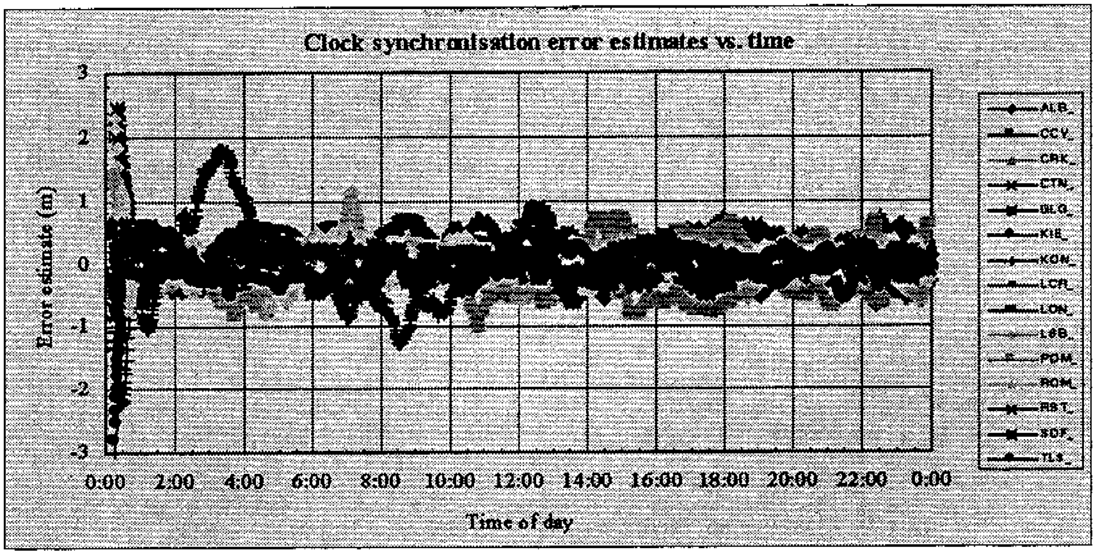

Figure 2: Typical RIMS synchronization performance

Satellite Clock Error Estimation

Independent experiments have been carried out in order to determine the accuracy of the satellite clock corrections. The experiments have demonstrated that RMS errors of about 0.5m are to be expected with the EGNOS system baseline design. As with the other results quoted, high-quality, dual-frequency, geodetic receivers and antennas are assumed. Similar test scenarios were used to those described for the RIMS clock synchronization function.

ENT to GPS Time Scale Steering

An example of the steering filter's performance is shown in below in Figure 3. Three, seven RIMS scenarios are shown: SYN-4(7), all high quality cesium; SYN-5(7), all high-quality rubidium; and SYN-6(7), a mixed scenario with one cesium and six rubidium clocks.

Figure 3 illustrates the high steering accuracy that can be achieved when high quality cesium clocks are used. The EGNOS system baseline, containing fifteen such clocks, will easily meet the ENT-GPS time-scale steering requirement of <50 nsec. Indeed, the *all Cesium* scenarios examined demonstrated that a steering accuracy of <3 nsec can be achieved, provided at least five high-quality Cesium clocks are present in the ensemble. These results must be treated with some caution, since they are based upon synthetic data sets with idealized models of SA and RIMS clocks. However, the results are consistent with other findings, such as those quoted in [2].

Another interesting feature of Figure 3 is that it illustrates the relationship between the stability of ENT and the choice of steering filter cut-off frequency. To reduce SA significantly, a very long time constant is required in the steering filter. This in turn requires that the relative drift between the ENT and GPS time-scales over periods commensurate with this time constant is very small. For the mixed and all-rubidium ensembles, SYN-5(7) and SYN-6(7) respectively, this is not the case, and leads to the biases seen in the steering errors for these ensembles. Reducing the time constant removes these biases, but at the expense of allowing SA to *leak* through.

Steering accuracy of <3 nsec will allow ENT realizations from different CPFs to be synchronized autonomously, without need for a dedicated ENT-A to ENT-B synchronization function. However, if such a function is required, experimentation with real and synthetic data has shown that synchronization of different ENTs can easily be achieved with an accuracy of better than 3nsec 2σ.

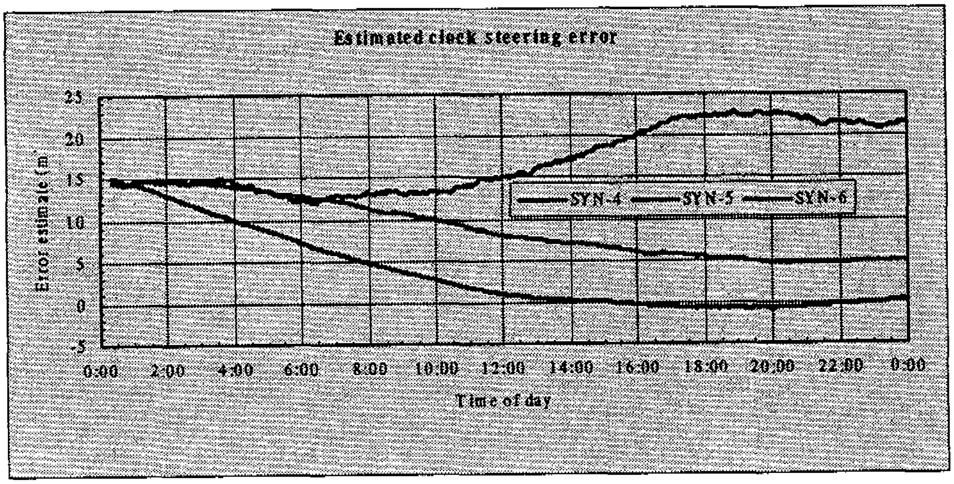

Figure 3: typical ENT steering results (cut-off frequency 2×10^{-5}Hz)

EURIDIS RANGING

Since July 1995, CNES has conducted the development of EURIDIS, a test-bed representative of the EGNOS Ranging using INMARSAT 3 AOR-E navigation payload.

EURIDIS Ground Segment

EURIDIS Ground Segment is based on the following Figure 4:

- Three Geostationary Ranging Stations (RIMS) forming a large-based triangle: Aussaguel near Toulouse, Kourou in French Guyana and Hartebeeshoek in South Africa.
- a Mission Control and processing Center (MCC) located at the CNES site in Toulouse (France) for processing and ground segment monitoring,
- a Navigation Land Earth Station (NLES) in charge of generating the GEO ranging signal,
- a communication network dedicated to EURIDIS.

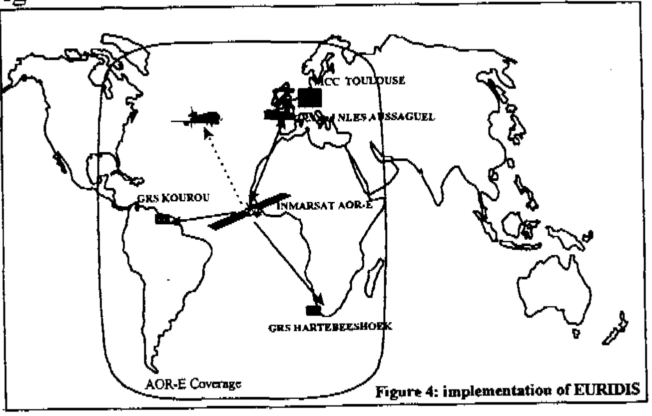

Figure 4: implementation of EURIDIS

EURIDIS Performance (Ref. [8])

Even with the limited infrastructure, the objective has been given to EURIDIS to demonstrate the Ranging performance of EGNOS: 25m (95%). To meet this required accuracy on the GEO UERE, the following requirements have been derived:

- the GPS time must be known within 20 ns (1σ)
- the time transfer to the GEO must be achieved with an error less than 20 ns (1σ)
- in order to determine the GEO satellite position with an accuracy less than 7.5 m(1σ), each RIMS must be synchronized within 10 ns (1σ).

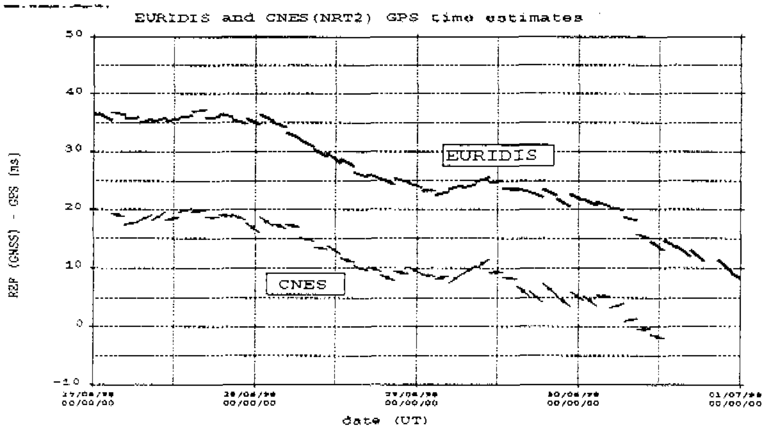

Figure 5: EURIDIS GPS Time restitution

GPS Time Restitution

With many limitations with regards of EGNOS (use of only one reference station, without correction of GPS broadcast orbits, etc.), the uncertainties are expected to be less than 10ns (1s) (cf. Table 2). These results were compared with a CNES independent chain using a GPS time-oriented receiver (NRT2, four channels). Figure 5 plots EURIDIS and CNES results from June 27 to July 1 1998. We can observe a systematic difference of 16 ns with a standard deviation of 1ns. The bias is not consistent with Table 2 error budget, and further experiments are planned to determine the origin of this bias. The variation of GPS time is also under study and could be correlated with the ionospheric corrections.

Error source	Euridis (1 σ)	NRT 2 (1 σ)
SA dither	1 ns	1 ns
GPS position	9 ns	9 ns
Troposphere	1 ns	1 ns
Ionosphere	3 ns	3 ns
Antenna position	1 ns	1 ns
Receiver noise	< 1 ns	< 1 ns
Filtered GPS multipath	1 ns	1 ns
Antenna, cables	2 ns	1 ns
Total	**9,9 ns**	**9,7 ns**

Table 2: expected uncertainty budgets of GPS Time restitution for EURIDIS and CNES (NRT2)

GPS Time Transfer to the GEO

The GEO time is defined at the output of the GEO payload, precisely at the L1 antenna center of phase. This precise time must be synchronized to the GPS time with an accuracy of 10ns(1σ). That function is ensured by a servo-control technique, based on the near symmetry between the up and down links NLES-GEO. One original feature of EURIDIS Long Loop was rather to apply a time bias corresponding to the drift between GEO time and GPS time as observed from Aussaguel RIMS. In order to ensure the independence between GEO time and the orbit restitution process, the Long Loop reference time, fully mastered by the MCC, is used as GEO transmission time estimate in the orbit restitution filter. A navigation payload simulator was specifically developed by SEXTANT in order to test the behavior of the EURIDIS Long Loop on the ground test bench. It simulates the RF interfaces with the Long Loop equipment including satellite movement, ionospheric delays on C1, C2 and L1 links, and satellite clock drift. Excellent results were obtained, showing performances of ± 5 ns peak to peak over 24 hours of simulation.

With real INMARSAT 3 AOR-E satellite, it is not possible to measure directly the quality of the GEO time transfer and to verify the error budget, which was evaluated to be 10.8 ns (1σ) in a previous paper [7]. A global performance is available with UERE evaluation.

GEO UERE Performance

From a user point of view, UERE is the only parameter that matters, as it translates into a positioning error, when the geometry of the satellites is known. UERE usually include all the terms having an impact on the user positioning error. In EURIDIS, down link propagation and user receiver errors are not considered. UERE thus only characterizes time synchronization and orbit errors coming from EURIDIS ground segment. It represents errors coming either from the GEO orbit or from the time synchronization onboard the GEO satellite.

UERE is computed every second in the ground segment in Aussaguel as part of the integrity checks. Long-term UERE in Aussaguel (over approximately one day) was found to be 4m RMS (13.3 ns).

Another estimation of UERE, has been done using Kourou measurements. UERE was found to be 6 m RMS (see Figure 6). Discontinuities that can be observed don't come from the signal itself, but are due either to orbit updates (every 12 hours) or to time correction models sent to the user (also every 2 hours).

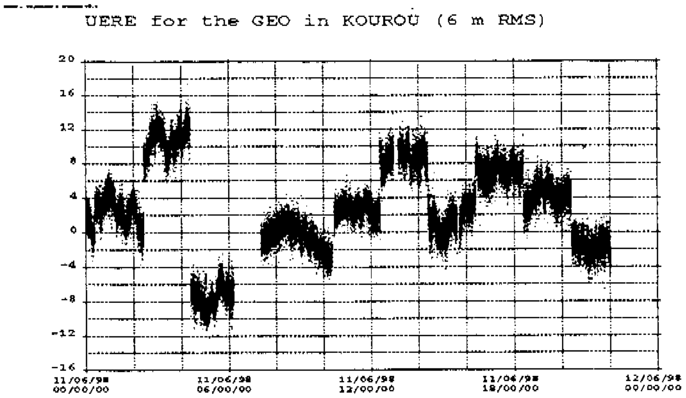

Figure 6

The EURIDIS UERE signals is under evaluation at Sèvres near Paris with BIPM time as reference, and then will be performed at Washington with USNO-MC clock reference.

CONCLUSION

As described in this paper, the role of time and frequency is of paramount importance in EGNOS. Any synchronization error would be derived into navigation error. To answer to these stringent constraints:

- A very stable ENT will be generated and steered to GPS Time with an accuracy estimated to better than 3 ns.
- EGNOS RIMS clocks will be synchronized to ENT with an accuracy of 3ns (2σ).
- ENT will be transferred very accurately to GEO satellites with the long-loop process.

Additionally, EGNOS will provide in real time the difference between ENT and UTC(k). Based on EGNOS GEO signals, users with GNSS multi-channel receivers will have the capability to synchronize very accurately their clocks.

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