EGNOS NETWORK TIME AND ITS RELATIONSHIPS TO UTC AND GPS TIME

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Abstract

EGNOS, the European Satellite Based Augmentation System, generates its own system time scale ENT (EGNOS Network Time). ENT is steered by the EGNOS Ground Control Segment to GPS time (GPST). The offset between ENT and UTC is broadcast in the EGNOS navigation message. To compute that offset, an EGNOS ground station was set up in the Observatoire de Paris and is connected to UTC (OP). Applying EGNOS corrections on GPS measurements provides a precise time and navigation solution referenced to ENT. Therefore, the assessment of the time difference between ENT and UTC is a key issue for time users. The aim of this paper is to assess the closeness of ENT to UTC and GPST.

First, the paper recalls the timing aspects of EGNOS and describes the connection of ENT to UTC (OP). Then the broadcast time difference ENT – UTC (OP) is analyzed and compared to an independent method of computing that offset. This independent method makes use of the calibrated OPMT IGS station that is indirectly connected to UTC (OP). The agreement between the broadcast information and the independent method is discussed with respect to EGNOS requirements. Using the BIPM Circular T that provides UTC – UTC (OP), we can then easily derive the offset between ENT and UTC. This independent method can also be carried out using the IENG IGS station connected to UTC (IT), providing therefore ENT – UTC (IT).

Moreover, an assessment of the time offset ENT – GPST is also carried out by two methods. The first method combines the broadcast offset ENT – UTC (OP) to the time differences UTC – UTC (OP) and UTC – GPST both extracted from BIPM Circular T. The second method combines the broadcast offset ENT – UTC (OP) to the REF – GPS obtained in the CGGTTS files coming from measurements made by the OPMT IGS receiver at the Observatoire de Paris referred to UTC (OP). Both results are compared and discussed.

INTRODUCTION

The European Satellite Based Augmentation System, called EGNOS (European Geostationary Navigation Overlay Service), provides to users in Europe an augmentation of three pseudo-GPS

signals plus corrections/integrity information about the available GPS constellation **[1-3]** enabling the computation of a safe and precise position that can be dated in a legal time scale (UTC).
The Figure below recalls the main SBAS missions:

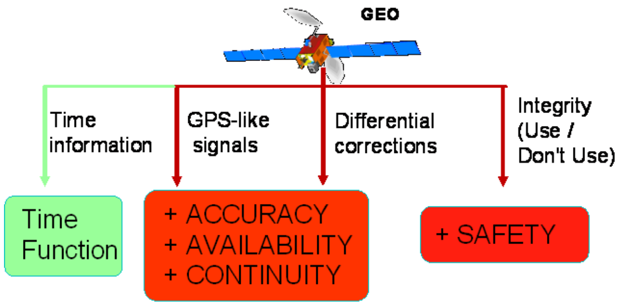

Figure 1. SBAS missions.

These missions lead to some timing requirements, described briefly in hereafter and more precisely in **[4]**. EGNOS also broadcasts in its navigation message the time difference between EGNOS Network Time (ENT) and UTC. This requires connecting ENT to at least one UTC (k) in Europe. To this aim, an EGNOS Earth station of the Ground Segment, the so-called Ranging and Integrity Monitoring Station (RIMS), was installed in the Observatoire de Paris (OP) – Paris Observatory – in July 2003. This connection has already been described in detail in **[5]**; the major points are recalled hereafter.

The first aim of this paper is to evaluate the time difference between ENT and UTC (or its realization UTC (OP) at the Observatoire de Paris) by two completely independent methods. The first one simply uses the EGNOS message #12 that contains an evaluation of the time offset between ENT – UTC (OP) as seen by EGNOS system combined with the time offset UTC – UTC (OP) computed by the BIPM, while the second one uses IGS receivers connected directly or indirectly to a UTC (k).

A second aim of this paper is to evaluate the time difference between ENT and GPST using two different methods.

TIME IN EGNOS

EGNOS provides with GPS regional augmentation services to aviation, maritime, and land users by using a transponder onboard geostationary (GEO) satellites **[1-3]**. The EGNOS Ground Segment consists of Ranging and Integrity monitoring Stations (RIMS), which are connected to a set of redundant control and processing facilities (CPF), in order to determine the integrity, ephemeris, and clock differential corrections for each monitored satellite, to compute the ionosphere delays, and to generate the GEO satellite ephemeris. The GEO satellite downlinks these data on the GPS L1 frequency with a modulation and a coding scheme similar to GPS.

EGNOS TIME REQUIREMENTS

All measurements and data are referred to an internal EGNOS Network Time (ENT), whose performance requirements were derived exclusively from navigation accuracy performance requirements. The European Space Agency (ESA) requires ENT to be steered within 50 ns (5σ) of GPS Time (GPST). This requirement is mostly specified to keep compatibility with the maximum capacity of the message used to correct the GPS satellite clocks. It will allow the user to combine in its navigation solution GPS and EGNOS signals. For the GEO "Ranging" mode, ESA has specified a User Equivalent Range Error (UERE) of 25 m (2σ).

This UERE is comprised of:

- the [ENT - GPS Time] time offset error
- the [ENT - GEO Time] transfer error (GEO Time, being the equivalent time scale onboard the GEO, precisely at the L1 antenna center of phase)
- the [GEO – User] range error.

The [ENT - GEO Time] transfer error is specified to be less than 10 ns (3σ), after offset and frequency corrections provided in EGNOS GEO message #9. This particular requirement is of special interest to a precise time broadcast function in real time.

Table 1 below summarizes the EGNOS time requirements:

Table 1. EGNOS time requirements **[6]**.

1	[ENT - GPS Time] offset ≤ 50 ns (5 σ)
2	[GEO Time - GPS Time] offset ≤ 50 ns (5 σ)
3	[GEO Time – ENT] accuracy ≤ 10 ns (3 σ)
4	[ENT – UTC (OP)] accuracy ≤ 10 ns (3 σ)

One of the objectives of this paper is to check the requirements #1 and #4. As required in SIS (Signal in Space) specification, EGNOS provides in message #12 the time difference between ENT and UTC. Since UTC is a deferred-time paper time scale, the time difference [ENT – UTC] will be computed using a physical clock signal of a European National Metrology Institute, taking into account or not the prediction of the difference between this UTC (k) and UTC.

RIMS CLOCK SYNCHRONIZATION, ENT GENERATION

RIMS clock synchronization is performed using a composite clock technique **[5]** in which ENT is defined as the implicit ensemble mean of a set of RIMS clocks and the synchronization process generates estimates of the time and frequency offsets of each RIMS clock relative to it. ENT is then steered to GPST using a second-order, low-pass digital filter. The steering input signal is an instantaneous estimate of the [ENT – GPS Time] offset. The latter is computed from the estimated satellite clock offsets with respect to ENT and the GPS broadcast satellite clock corrections.

RELATIONSHIP BETWEEN ENT AND UTC

To synchronize ENT and UTC, it was decided to put at the Observatoire de Paris a special RIMS called "RIMS-UTC" or PARA in the system. A block diagram of this equipment from **[6]** is given in Figure 2 below.

The time difference [ENT – UTC] is computed by the Central Processing Facility (CPF) within EGNOS system using the following formula:

$$\text{ENT} - \text{UTC} = [\text{ENT} - \text{UTC (OP)}] + [\text{UTC (OP)} - \text{UTC}]$$

where:

- [ENT – UTC (OP)] is determined by the CPF as an output of its ENT composite clock algorithm.
- [UTC (OP) – UTC] is computed by the CPF using a prediction algorithm. Currently, this prediction is not implemented and, therefore, EGNOS broadcasts in its message #12 the time offset [ENT – UTC (OP)] for the real time synchronization to UTC, in compliance with **[7]**.

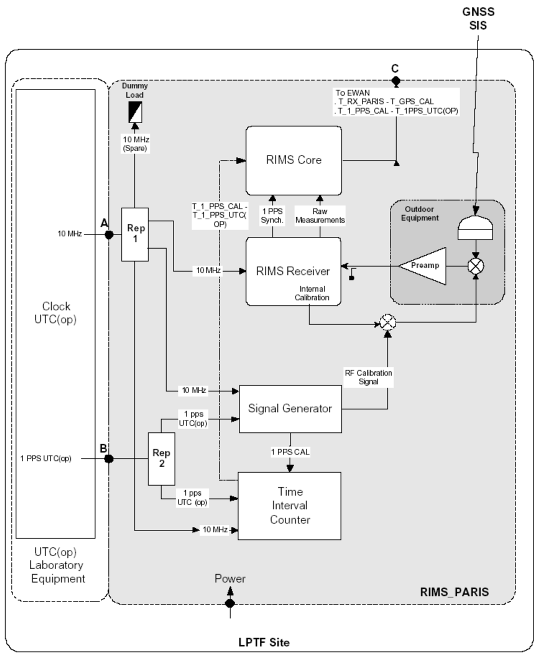

Figure 2. Block diagram of the RIMS-UTC – PARA.

The message type #12 referred to as MT12 contains an estimation of ENT – UTC (OP) expressed in the form of a linear model (an offset A0, a drift A1, and a reference time t_{ot}), assumed to be valid for 1 day, that can be extrapolated at any current time from its reception until the reception of a new set of such parameters or until its validity time. The maximum broadcast interval of MT12 is 300 s **[7]**. There are different possible time references for MT12; they are listed in the Table below:

Table 2. Possible references for UTC synchronization in MT12 **[7]**.

UTC Identifier	UTC Standard
0	UTC as operated by the Communications Research Laboratory (CRL), Tokyo, Japan
1	UTC as operated by the National Institute of Standards and Technology (NIST)
2	UTC as operated by the U. S. Naval Observatory (USNO)
3	UTC as operated by the International Bureau of Weights and Measures (BIPM)
4	UTC as operated by European Laboratory TBD
5 to 6	Reserved for future definition
7	UTC not provided

EGNOS RELEASES & GEO STATUS

Some improvements have been implemented in a new EGNOS release called ESR2.2 in order to provide, among other objectives, a more accurate content in its message #12. This ESR2.2 release has been on air for test purposes through the PRN124 (Artemis) GEO frame from the beginning of February 2008 and was deployed and used in the EGNOS operational chain since the 6 October 2008 for the PRN120 (INMARSAT AOR-E) and PRN126 (INMARSAT IOR-W) GEO frame elaboration.

Moreover, the EGNOS operational system is composed of two navigation chains and evolved on 17 February 2009: the navigation chain using PRN124 moved from the TEST part to the operational one and PRN126 moved in the other way (from operational part to the TEST one). So, in the hereafter sections, PRNOP2 information refers to a combination of PRN126 data until 17 February and of PRN124 data after this date. To know the current status of each EGNOS GEO frame, a Web server is available **[8]**.

ENT - UTC EVALUATION USING MT#12 & BIPM CIRCULAR T

COMPARISON OF BOTH OPERATIONAL GEO/PRN

A first comparison based on the daily mean value of the "broadcast model" within Message Type 12 (MT12) for each PRN has been carried out for October 2008 to September 2009 when the two operational navigation chains were broadcasting the ESR2.2. The results for both PRNs (Figure 3 below) are very close, as depicted hereafter, the interruption from 12 January to 18 February 2009 being due to the impossibility of configuring PARA. All figures below are expressed in nanoseconds (unless otherwise stated) and reported modulo 1 second. Information on the way to compute values from the "broadcast model" is given in **[4]** and **[9]**.

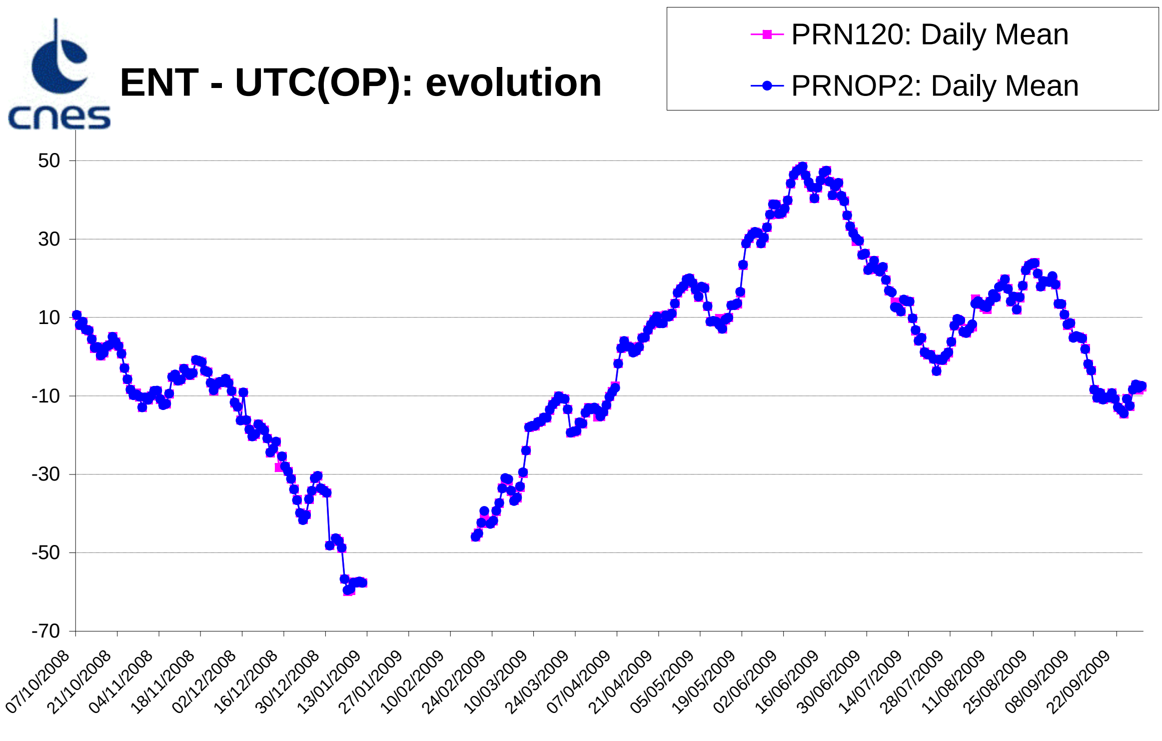

Figure 3. ENT – UTC (OP) broadcast daily means.

A second comparison based on the daily value computed at noon using also the "broadcast model" for each PRN is performed. Figure 4 shows the difference between two estimations of ENT – UTC (OP) coming from the two PRNs (noon value and daily mean):

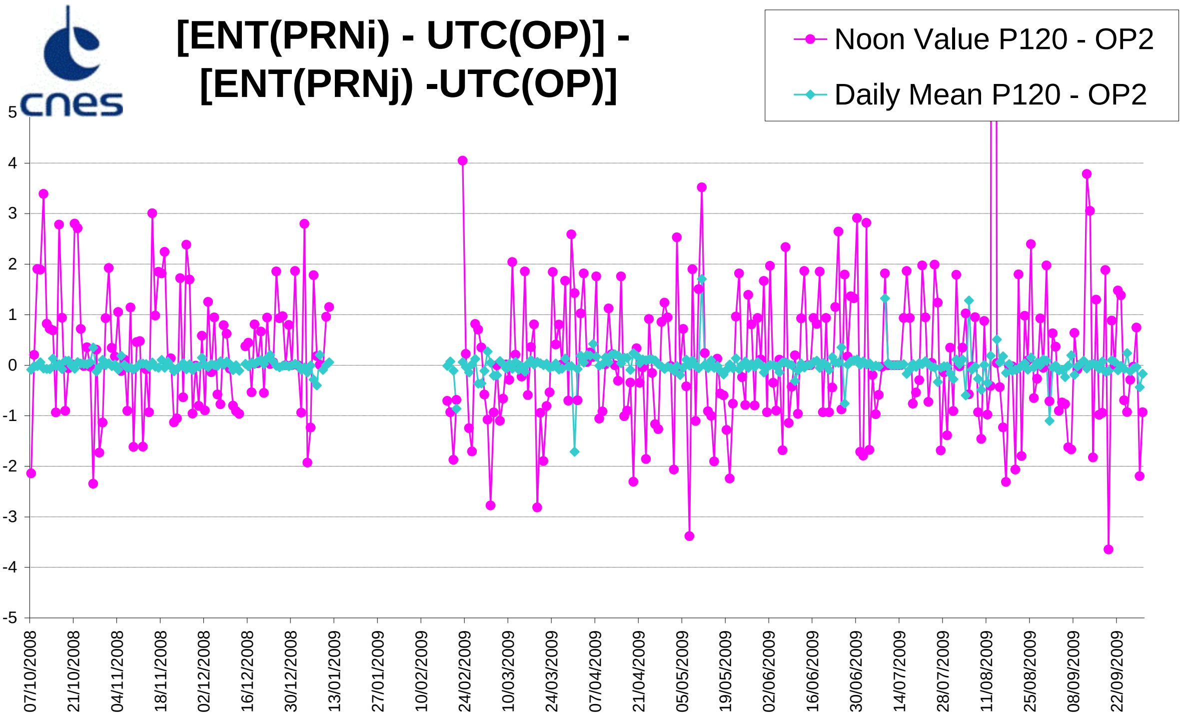

Figure 4. $[ENT – UTC (OP)]_{PRN120}$ - $[ENT – UTC (OP)]_{PRNOP2}$.

If the differences between the ENT – UTC (OP) information broadcast by each operational navigation chain are negligible for the daily mean, this is not the case for the noon value, where differences of several nanoseconds are observed. This is currently explained by the slope that is included in each model of MT12 that is not representative of the expected one. This observation is under investigation at EGNOS system level.

Comparison with BIPM Circular T Information

The previously computed daily mean has been compared to the time offset UTC – UTC (OP) obtained from BIPM Circular T **[10]**. As in BIPM Circular T, the sampling is only one point every 5 days, in order to have a maximum number of points for this comparison; the information coming from the ESR2.2 test phase has also been taken into account here. This is possible because we have demonstrated previously that the difference between the different EGNOS GEO is negligible for the daily mean of [ENT – UTC (OP)].

From the above figure, we can conclude that EGNOS broadcasts in real time have an offset $[ENT – UTC (OP)]_{MT12}$ close to UTC – UTC (OP).

UTC and ENT Compared in Differed Time

As shown in the previous sections, the current UTC – ENT broadcast time offset in MT12 is not based on any prediction of UTC – UTC (OP) and so in real time events dated in the ENT time scale can be then time tagged in UTC with an accuracy depending on how close UTC (OP) is to UTC.

Nevertheless, in differenced time UTC – UTC (OP) behavior is known **[10]** and it is, therefore, possible to compare UTC and ENT using:

$$[UTC - ENT](t) = [UTC - UTC(OP)]_{BIPM}(t) - [ENT - UTC(OP)]_{MT12}(t)$$

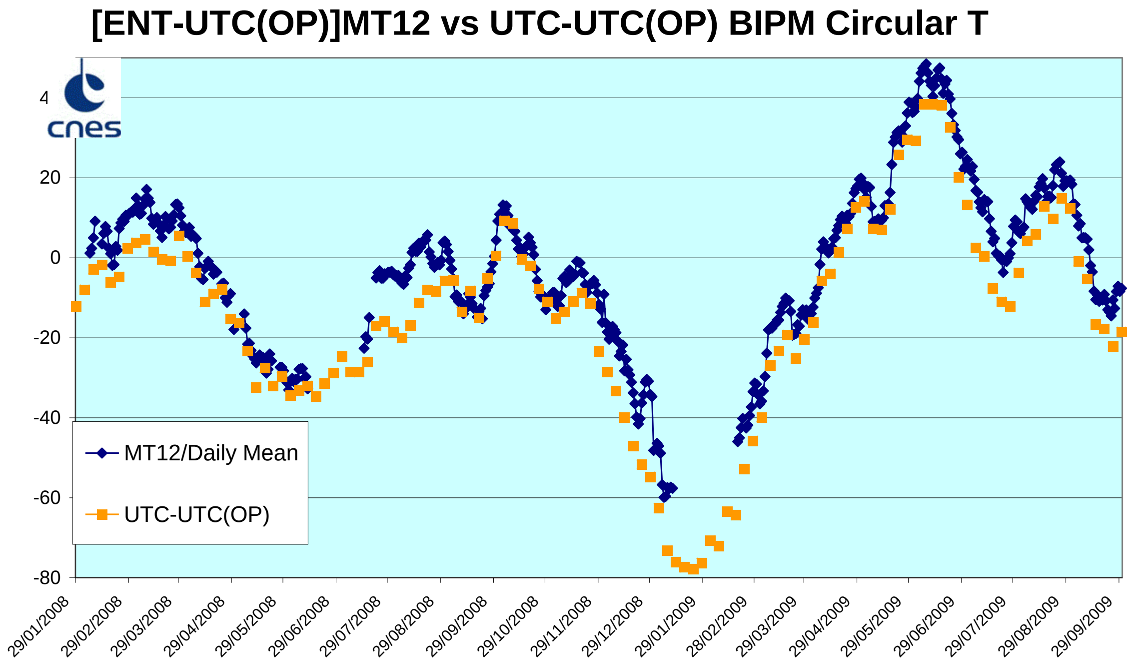

Figure 5. UTC – UTC (OP) compared to the daily mean of broadcast ENT – UTC (OP).

Assuming the daily mean of $[ENT - UTC(OP)]_{MT12}$ is close to its value at 00:00:00 UTC, we are able to provide an estimation of UTC – ENT that we refer to as UTC – ENT via UTC (OP). The uncertainty of this result is in the range of a few ns (quadratic sum of the uncertainties in our process and in the BIPM Circular T).

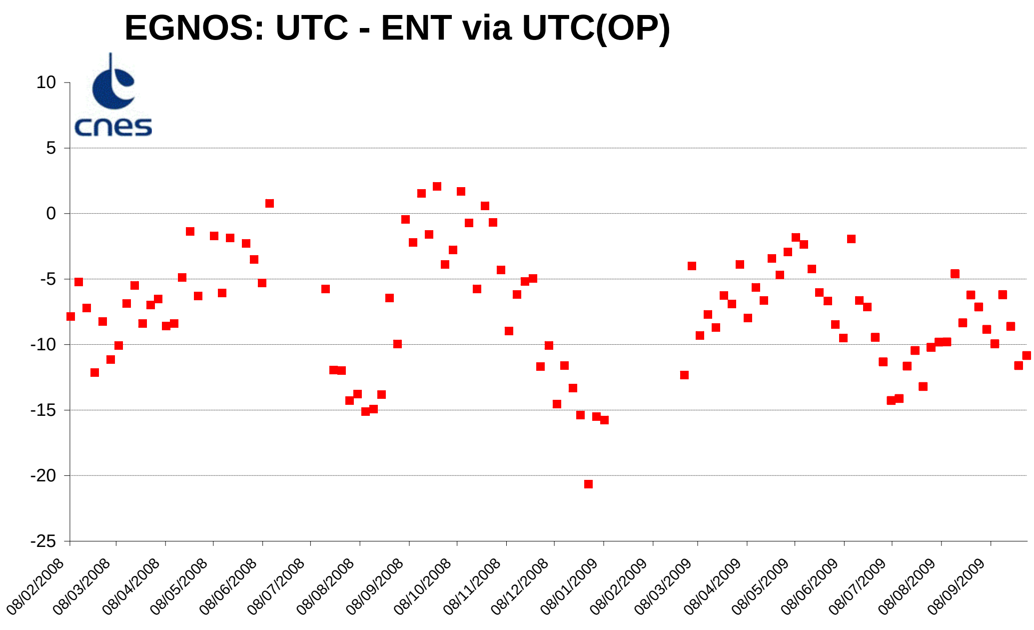

Figure 6. UTC - ENT via UTC (OP).

From this set of data (104 samples), we can deduce that the mean of UTC – ENT is -7.4 ns, the minimum and maximum values are respectively -20.7 and 2.1 ns, and the standard deviation is 4.5 ns.

The Figure below is the Allan deviation of the above time offset UTC-ENT:

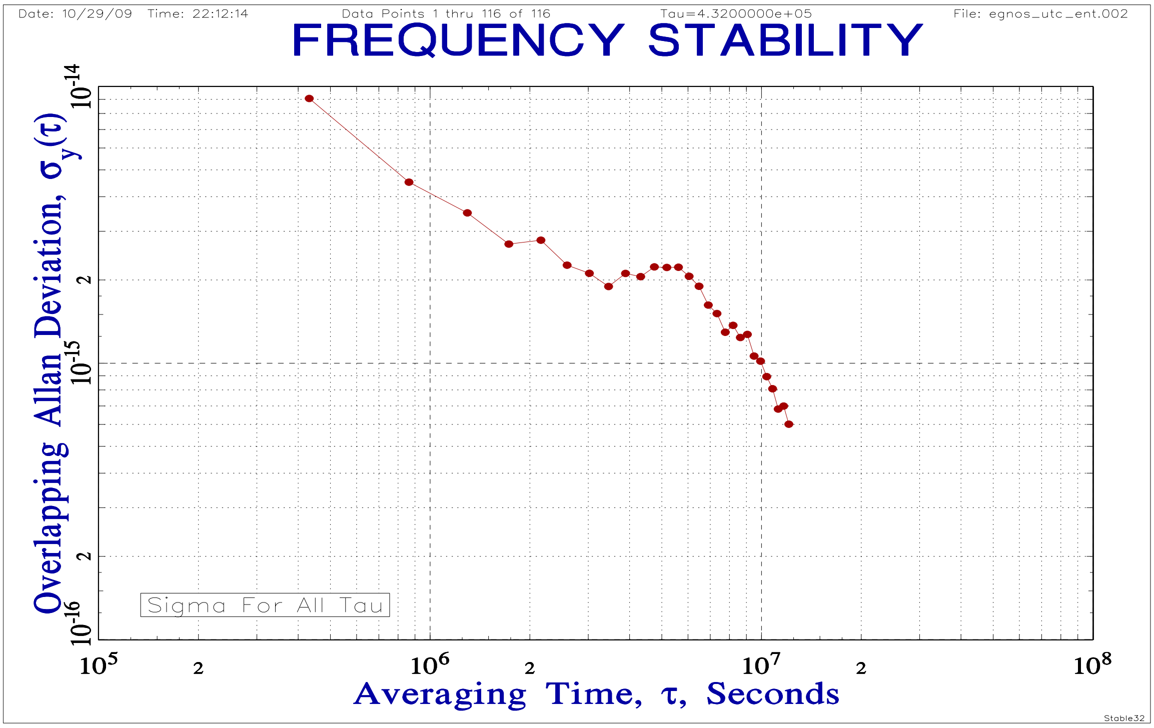

Figure 7. Allan deviation of UTC – ENT.

GPST AND ENT COMPARED IN DIFFERENCED TIME

The previously computed fluctuations of UTC – ENT have been compared to UTC – GPST as provided by BIPM in the Circular T (C0). UTC – GPST being given each day, a linear interpolation has been used in order to get a daily value of UTC – UTC (OP) and to perform the comparisons in that section.

The variations observed in UTC – ENT are highly correlated with UTC – GPST. This is not surprising since the EGNOS CPF algorithm has to ensure the steering of ENT to GPST; nevertheless, a bias of some nanoseconds is observed.

We can now evaluate ENT – GPST as –(UTC–- ENT) + (UTC – GPST), considering that UTC - ENT via UTC (OP) is the best available approximation of UTC – ENT (as analyzed previously).

From this set of data (102 samples), we can deduce that the mean of ENT-GPST is 7.2 ns, its minimum and maximum values are respectively 3.8 and 11.0 ns, and its standard deviation is 1.7 ns. These figures allow us to think that the requirement #1 of Table 1 is probably achieved.

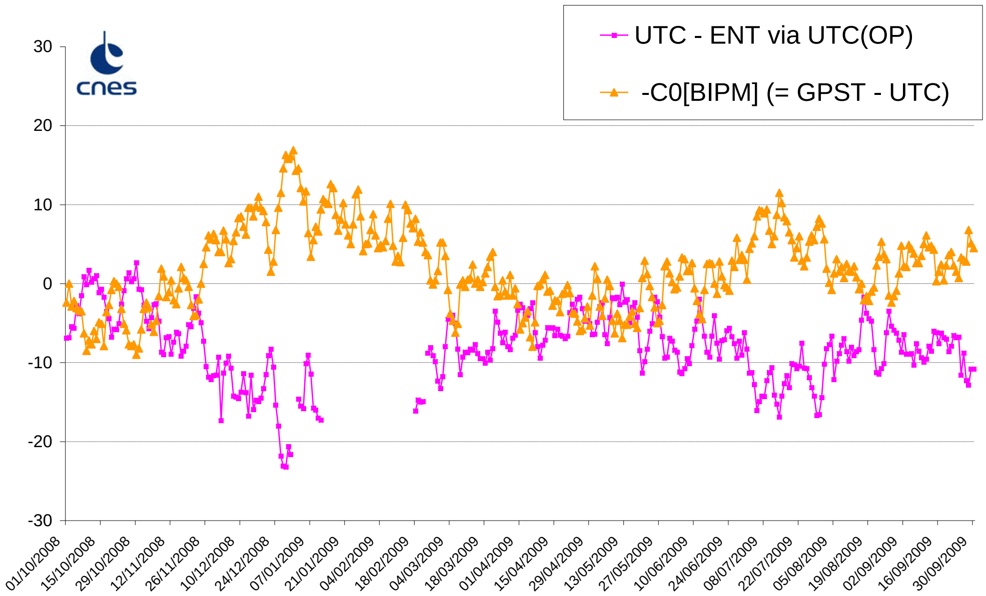

Figure 8. UTC - ENT compared to GPST – UTC.

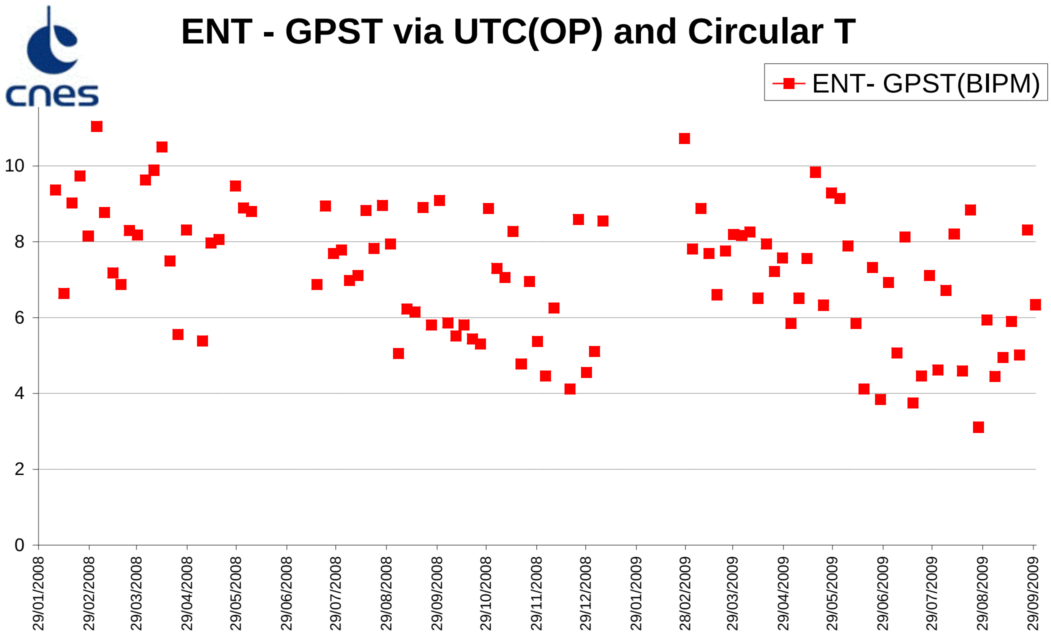

Figure 9. ENT – GPST using UTC (OP) and BIPM Circular T.

Since ENT is to be steered to GPST, the above mean should be close to zero, yet we have a significant bias. Considering this bias and knowing that EGNOS corrections are based on the GPS broadcast TGD per satellite, it is not impossible to think that part of these biases comes from the calibration process between USNO/UTC and JPL/TGD **[11]**; in any case, this bias is in the same range as the ones presented in **[11]** and no analysis (to our knowledge) has been performed to confirm or not this possibility.

Another way to compute this time offset ENT – GPST is the following one:

ENT – GPST = **ENT – UTC (OP)** obtained from MT12
+ **UTC (OP) – GPST** obtained from OP CGGTTS files

The receiver used in that case is the same one as OPMT, but the CGGTTS files are modified to relate the measurements to UTC (OP). The figure below summarizes the obtained results:

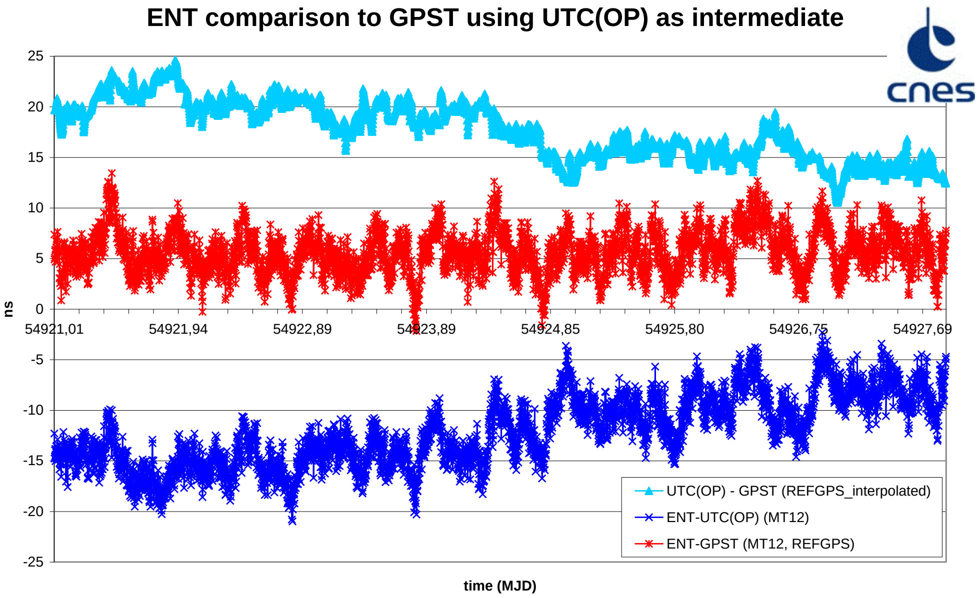

Figure 10. ENT – GPST using OP CGGTTS files.

From this set of data, the mean value of ENT – GPST obtained is 5.2 ns. Note that this computation was carried out on a much shorter period (1 week) than the previous one. These results are close to the ones of Figure 9 and it confirms a bias between ENT and GPST in the range of 5 to 7 ns. Such a bias is obtained using two different receivers at the Observatoire de Paris and two different methods to relate to GPST (BIPM Circular T is using the GPS data taken from a TTR-1 receiver, corrected for IGS precise orbits, clocks, and ionosphere map, while this second method uses an Ashtech Z-12 T and the GPS broadcast messages).

INDEPENDENT EVALUATION OF ENT - UTC

METHOD

The method consists in an independent estimation of ENT at the user level. In that case, we use the GPS measurements of a receiver connected to a UTC (k). We apply EGNOS corrections and station delays on these measurements, so that we get ENT_{user} – UTC (k). If we use UTC (OP) **[4]**, we can therefore compare $[ENT_{user}$ – UTC $(OP)]_{OPMT}$ to $[ENT$ – UTC $(OP)]_{MT12}$.

If we use another UTC (k) **[12]**, as we get $[ENT_{user}$ – UTC (k)], we have to determine also the difference between UTC (k) and UTC (OP) to be able to compare to $[ENT$ – UTC $(OP)]_{MT12}$, and this can be done by using the CGGTTS files, the usual method for GPS Common-View time transfer.

The general model for EGNOS measurements uses the C/A pseudo-range observable (C1 observable in the RINEX files). The reference orbit and clocks come from the GPS broadcast ephemeris.

The following formulation is used (one epoch and one GPS):

$$C_1 = D^{EGNOS} + e + \left(h_{rec}^{EGNOS} - h_{GPS}^{EGNOS}\right)$$

where:

- C_1 is the C/A pseudo-range measurement
- D^{EGNOS} is the geometrical distance between the transmitter and the receiver L_1 centers of phase, including the troposphere delay
- e is the ionosphere propagation delay on the L1 GPS frequency
- h_{rec}^{EGNOS} and h_{GPS}^{EGNOS} are respectively the receiver and transmitter clock offsets expressed in the EGNOS reference time.

D^{EGNOS} is computed using the GPS broadcast ephemeris corrected with the data from the EGNOS messages. The troposphere delay is estimated with a standard mapping function and a fixed zenith troposphere delay of 2.37 m. The receiver center of phase is obtained using the IGS station log for OPMT station and the ITRF solution for the corresponding marker coordinates. e is estimated using the EGNOS ionosphere message. h_{GPS}^{EGNOS} is computed using the slow and fast corrections obtained from the EGNOS messages applied on the GPS broadcast clock value corresponding to a single frequency user (use of the broadcasted TGD values).

Then, at a given epoch and for each GPS in view, we obtain an estimation of h_{rec}^{EGNOS} from the above equation. All these estimates are averaged (median value robust estimation) over a 15-minute interval to minimize the pseudo-range measurement noise effects. This produces an estimation of the offset between the receiver clock and the EGNOS time defined by the EGNOS messages.

OPMT DATA

The calibrated GPS time receiver "OPMT" located in the Observatoire de Paris is used for this analysis and its GPS raw measurements (RINEX files) are collected through the IGS network. This receiver is not directly connected to UTC (OP), but is connected to a hydrogen maser whose time offset is measured versus UTC (OP) on an hourly basis. These time offset values are given in the so-called LZOP files. These values can be interpolated by a simple linear model over 1 day for down sampling. The values of the different time propagation delays of OPMT station are extracted from the CGGTTS daily file (GZOP file).

Figure 11 shows the daily mean and median values of the difference between the two estimations of ENT – UTC (OP) as a function of the day-of-year since 1 December 2008, when our tool developed for the qualification of ESR2.2 has been used for a continuous assessment.

From this set of results (241 samples of daily means), we can deduce that the mean of the daily means is 4.9 ns, the minimum and maximum values are 3.5 and 6.3 ns, and the standard deviation is 0.5 ns. This difference $[\text{ENT} - \text{UTC (OP)}]_{\text{MT12}} - [\text{ENT}_{\text{user}} - \text{UTC (OP)}]_{\text{OPMT}}$ should be zero, but this is not the case because of:

- the uncertainty in the calibration of the OPMT IGS station (estimated to be in the range of 3.3 ns, 1 σ)
- the uncertainty in the calibration of the EGNOS RIMS PARA and the equipment used to connect it to UTC(OP)
- the actual difference between ENT and ENT_{user}.

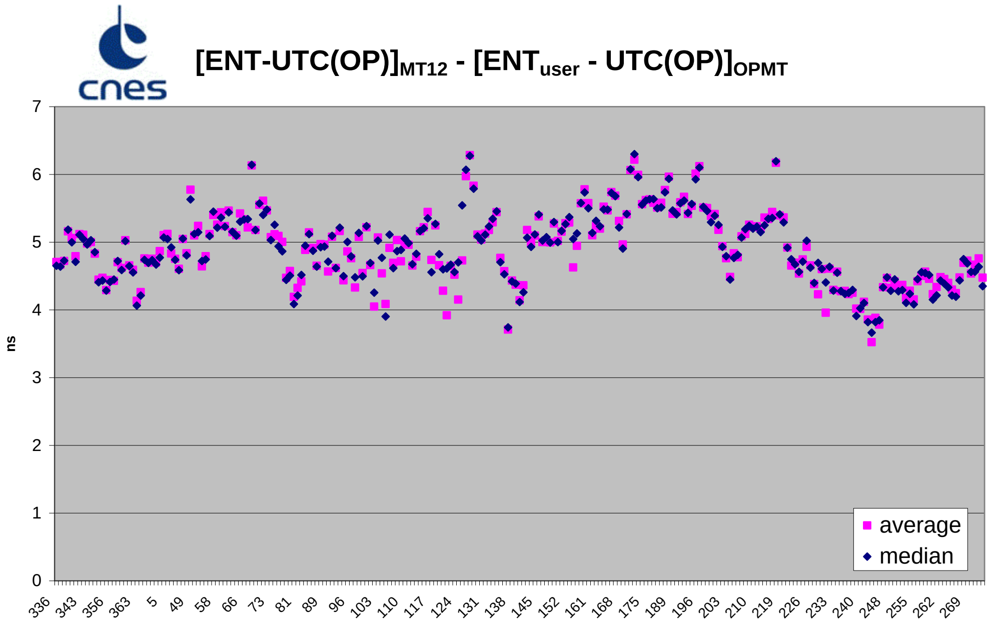

Figure 11. Daily mean and median values of [ENT – UTC (OP)]$_{MT12}$ – [ENT$_{user}$ – UTC (OP)]$_{OPMT}$.

Each daily mean of [ENT – UTC (OP)]$_{MT12}$ – [ENT$_{user}$ – UTC (OP)]$_{OPMT}$ is determined with an associated standard deviation presented in the figure below:

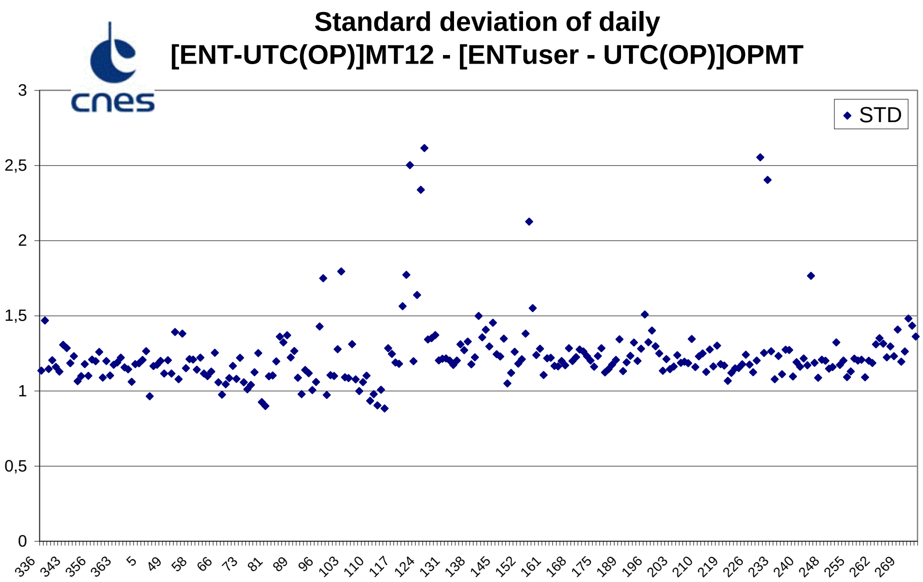

Figure 12. Daily standard deviation of [ENT – UTC (OP)]$_{MT12}$ – [ENT$_{user}$ – UTC (OP)]$_{OPMT}$.

It has been demonstrated that the daily standard deviations above 1.5 ns correspond to periods with some possible GPS reception problems at OPMT **[12]**.

Now, if we compute the same statistics on a monthly basis, we get the following results:

Table 3. Monthly results of
$[ENT – UTC (OP)]_{MT12}$ – $[ENT_{user}$ – UTC $(OP)]_{OPMT}$.

Month	Mean	Median	σ
09/2009	4.4	4.3	1.3
08/2009	4.6	4.6	**1.7**
07/2009	5.3	5.3	1.3
06/2009	**5.5**	5.6	1.3
05/2009	4.9	5.0	1.6
04/2009	4.8	4.9	1.5
03/2009	5.1	5.0	1.2
02/2009	5.3	5.2	1.3
01/2009	4.9	4.8	1.2
12/2008	4.7	4.7	1.2

The requirement #4 from Table 1 states that the accuracy of the broadcast [ENT – UTC (OP)] be less than 10 ns (3 σ). Considering that:

- the uncertainty on $[ENT – UTC (OP)]_{MT12}$ is below the uncertainty on ($[ENT – UTC (OP)]_{MT12}$ – $[ENT_{user}$ –UTC $(OP)]_{OPMT}$)
- the OPMT internal delay uncertainty is 9.9 ns (3σ)
- the daily mean value is below 6.3 ns with a maximum standard deviation of 4.5 ns (3σ), or the monthly mean value is below 5.5 ns with a maximum standard deviation of 5.1 ns (3σ).

we can conclude that the uncertainty on $[ENT – UTC (OP)]_{MT12}$ is below 10 ns (3σ), which means that the corresponding EGNOS requirement is achieved.

IENG DATA

The calibrated GPS time receiver "IENG" located in Istituto Nazionale di Ricerca Metrologica (INRiM) in Torino, Italy, is used for this analysis and its GPS raw measurements are collected through the IGS network. The method consists in applying EGNOS corrections on the IENG GPS measurements, which yield ENT_{user} – UTC (IT), and then in computing a GPS Common View with OPMT data by simply comparing the CGGTTS files. The IENG calibration delays used in the computation of ENT_{user} – UTC (IT) are the ones indicated in the CGGTTS file header. The noticeable point here is that the IENG station delays are in principle not needed, since they cancel out in the whole process.

We can, therefore, compute $[ENT – UTC (OP)]_{MT12}$ – {$[ENT_{user/IENG}$ – UTC (IT)] + [UTC (IT) – UTC (OP)]}, which we also refer to as ENT - ENT_{user} as estimated at IENG. This experimental assessment has been done from the 30 March 2009 (MJD 54920) to 1 June 2009 (MJD 54983).

From this set of results (62 samples), we can deduce that the mean of the daily means is 4.2 ns, the minimum and maximum values are respectively 0.1 and 7.3 ns, and the standard deviation is 1.6 ns. These results are in the same range as those obtained with OPMT data in the previous section. We notice, however, important variations of ENT – ENT_{user} as estimated at IENG, which are in fact due to some possible GPS reception problems on the OPMT side that affect the estimation of UTC (OP) – UTC (IT).

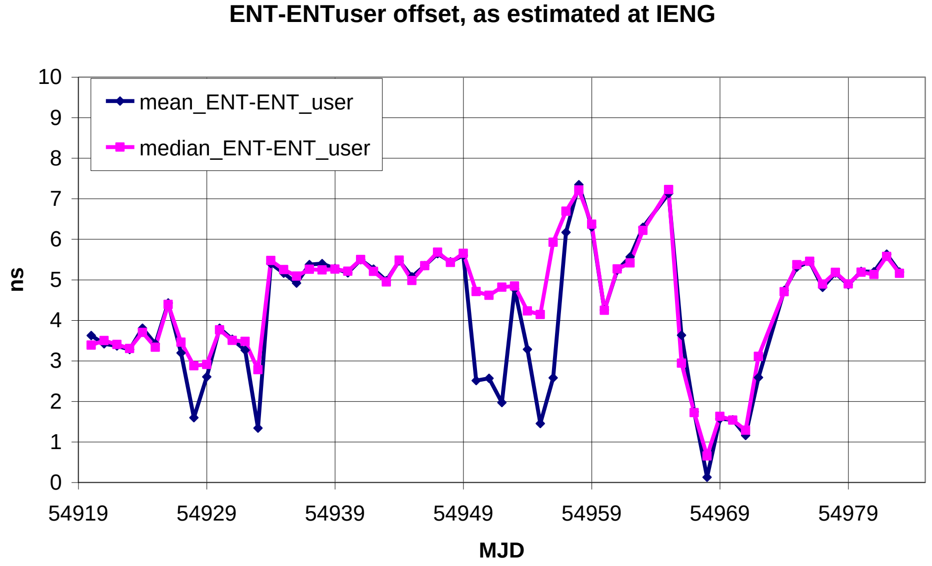

Figure 13. Daily mean and median value of
$[ENT - UTC(OP)]_{MT12} - \{[ENT_{user/IENG} - UTC(IT)] + [UTC(IT) - UTC(OP)]\}$.

The figure below displays the daily standard deviations of ENT - ENT_{user} as estimated at IENG:

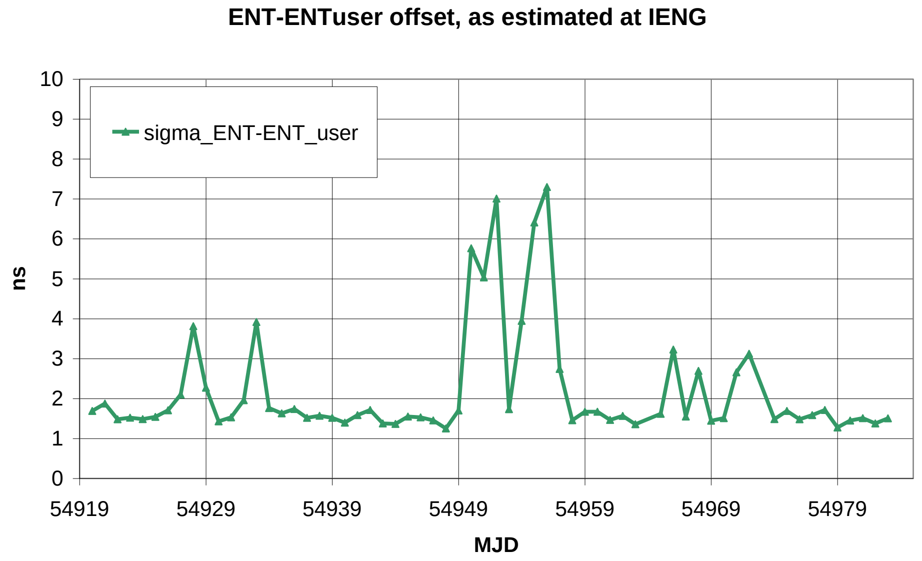

Figure 14. Standard deviation of
$[ENT - UTC(OP)]_{MT12} - \{[ENT_{user/IENG} - UTC(IT)] + [UTC(IT) - UTC(OP)]\}$.

The days where the standard deviation is higher than 2 ns are the same as the ones already pointed out in the previous section. The higher variability observed here is probably due to the fact that, here, both L1 and L2 data are used (to obtain the CGGTTS files), while only C1 is used in the $[ENT - UTC(OP)]_{MT12} - [ENT_{user} - UTC(OP)]_{OPMT}$ evaluation.

UTC – UTC (OP) EVOLUTION

Using the BIPM Circular T data **[10]** from 30 December 2006 (MJD 54099) to 30 September 2009 (MJD 55104), the evolution of UTC-UTC (OP) is shown below:

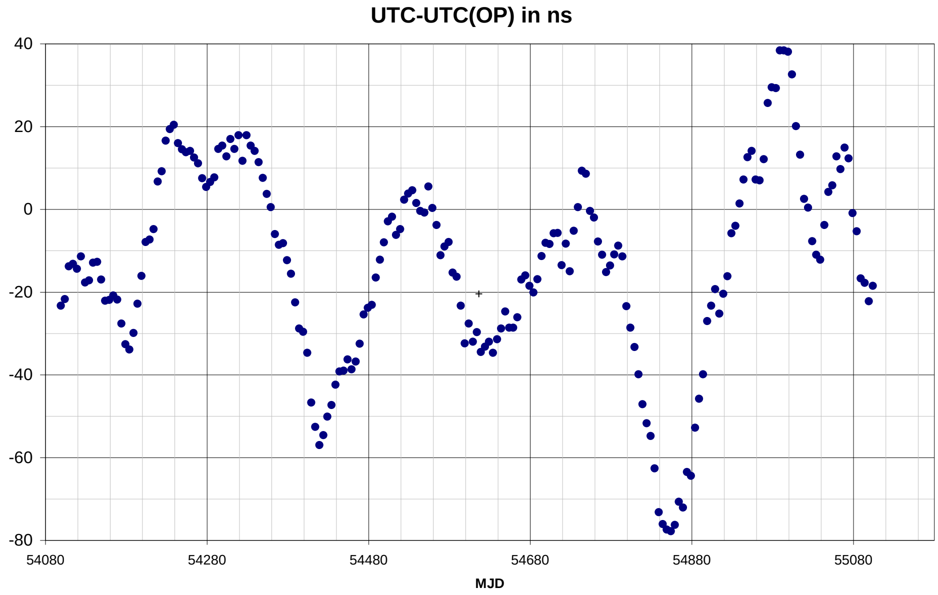

Figure 15. UTC – UTC (OP).

From this set of data (202 samples), we can deduce that the mean of UTC-UTC(OP) is -13.3 ns, the minimum and maximum values are respectively -77.8 and 38.4 ns, and the standard deviation is 23.8 ns.

A modernization of the French time scales TA (F) and UTC (OP) is ongoing **[13]**. The goal is to produce a new UTC (OP) signal, based on a hydrogen maser signal for short-term stability. This H-maser signal will be steered first on an ensemble clock computed from cesium standards and second on the Primary Frequency Standards of the laboratory, for the middle- and long-term stability as for the accuracy of the signal with respect to the SI second. It is expected that this new UTC (OP) will stay closer to UTC with respect to that currently achieved.

CONCLUSION

EGNOS is now broadcasting the information allowing any users within its coverage area to compute their own PVT (Position, Velocity, Time) in a reference time scale that is currently referenced and close to UTC (OP) by using the offset that is included in each EGNOS Message Type #12.

The synchronization in real time to this reference has proven to be very efficient: we provide here an independent method that assesses the accuracy of the broadcast offset to be less than 10 ns (3σ). The broadcast offset of ENT to UTC in real time is now totally dependent on the current quality of UTC (OP). But even without the implementation of the modernization of UTC (OP), the performances of this synchronization are already very good: the monthly prediction performance of UTC – UTC (OP) is estimated to be about 20 to 25 ns. With the modernized French time scales, we can expect this prediction performance to be in the range of a few nanoseconds, making ENT an excellent real-time approximation of UTC available all over EGNOS service area.

In the different types of assessments that have been reported here, different biases have been pointed out in the range of 4 to 7 ns, depending on the method used. If part of them comes doubtlessly from the uncertainty in the calibration of the equipment used in EGNOS or in the independent assessment, it is not impossible that part of them also relates to the observations made between TGD and GPS timing biases **[11]**.

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REFERENCES

[1] J. Benedicto, 1998, *"EGNOS: The European Satellite Based Augmentation to GPS and GLONASS,"* in Proceedings of the ENC-GNSS Conference, 20-23 October 1998, Toulouse, France.

[2] D. Flament, 1998, *"EGNOS, the European Based Augmentation to GPS and GLONASS – Mission and System Architecture,"* in Proceedings of the ENC-GNSS Conference, 20-23 October 1998, Toulouse, France.

[3] P. Fenton, 2000, *"The use of the Wide Area Augmentation System (WAAS) as a time transfer system*," in Proceedings of the ION National Technical Meeting, 26-28 January 2000 (Institute of Navigation, Alexandria, Va.).

[4] J. Delporte, N Suard, and P. Uhrich, 2009, *"Performance Assessment of the Time Difference between EGNOS-Network-Time and UTC,"* in Proceedings of the European Frequency and Time Forum (EFTF) and IEEE Frequency Control Symposium (FCS) Joint Conference, 20-24 April 2009, Besançon, France, pp. 399-404.

[5] P. Uhrich *et al.*, 2005, *"The French Time Reference UTC (OP) and the Connection of the EGNOS Network Time,"* in Proceedings of the European Frequency and Time Forum (EFTF), 21-24 March 2005, Besançon, France, pp. 539-544.

[6] B. Charlot, *"EGNOS interface control document for UTC interface,"* DRD 0112/0032, Iss. 2.A.

[7] DO2209 Release D, *"Minimum Operational Performance Standard for Global Positioning System/Wide Area Augmentation System Airborne Equipment,"* Section A.4.4.15.

[8] *http://asqf-gnss.com/WebPortal/Egnos/Pages/Home.page*

[9] E. Zacheo, 2008, *"EGNOS and GALILEO performances evaluation: EGNOS Time – UTC Time"*, CNES Internship Report, February 2008.

[10] *http://www.bipm.org/jsp/en/TimeFtp.jsp?TypePub=publication#nohref*

[11] D. Matsakis, 2007, *"The Timing Group Delay (TGD) Corrections and GPS Timing Biases,"* in Proceedings of the ION 63rd Annual Meeting, 23-25 April 2007, Cambridge, Massachusetts, USA (Institute of Navigation, Alexandria, Va.).

[12] D. Sidorov, 2009, *"Evaluation and Analysis of GPS, EGNOS, UTC Timescales Connection,"* CNES Internship Report, September 2009.

[13] P. Uhrich, D. Valat, and M. Abgrall, *"Current developments of French time scales TA (F) and UTC (OP),"* in Proceedings of the European Frequency and Time Forum (EFTF), 23-25 April 2008, Toulouse, France.