Evaluation and analysis of GPS, EGNOS and UTC timescale connections

Dmitry Sidorov

Luleå University of Technology
Master Thesis, Continuation Courses
Space Science and Technology
Department of Space Science, Kiruna
Abstract

Apart from augmenting existing satellite navigation services, the goal of European Geostationary Navigation Overlay System (EGNOS) is to provide the EGNOS user with a source of accurate time and its reference to UTC. The objective of this project was to develop a method of evaluating the difference between EGNOS Network time (ENT) and independent estimation of ENT at user level in locations where EGNOS corrections are valid. For this user an estimate of the difference between its receiver time and ENT\textsubscript{USER} can be produced, using GPS measurements and EGNOS corrections. If the receiver is connected to an UTC(k), an estimation of UTC(k)-ENT\textsubscript{USER} is obtained. From the other side, based only on GPS measurements, estimation of UTC(k)-GPST may be obtained. Thus having UTC(OP)-GPST, UTC(k)-GPST and the broadcast offset ENT-UTC(OP), which is given in EGNOS Message Type 12, an estimation of ENT-UTC(k) is obtained. Combined with the previously obtained UTC(k)-ENT\textsubscript{USER} the estimation of ENT-ENT\textsubscript{USER} offset can be made. The results of this estimation are given for two stations, which participate to the International GNSS Service (IGS): one in Paris region (OPMT), another one in Torino, Italy (IENG), and are checked with the results of previous observations at OPMT, done by the Centre National d’Etudes Spatiales (CNES), using another method. The advantages and the factors, which decrease performance of this method, are described. Also other applications of combination of different offsets are possible.
TABLE OF CONTENTS

INTRODUCTION ............................................................................................................................................... 2

1. CNES .......................................................................................................................................................... 3
   1.1. GENERAL INFORMATION ........................................................................................................................ 3
   1.2. TOULOUSE SPACE CENTRE (CST) .......................................................................................................... 3
   1.3. DEPARTMENT DCT/RF/LN .................................................................................................................... 4

2. PROJECT DESCRIPTION ........................................................................................................................ 5

3. GPS OVERVIEW ........................................................................................................................................ 5
   3.1. GPS SYSTEM ARCHITECTURE ................................................................................................................ 5
       3.1.1. Space Segment ............................................................................................................................... 6
       3.1.2. Control Segment ............................................................................................................................ 7
       3.1.3. User Segment ................................................................................................................................. 7
   3.2. POSITION COMPUTATION PRINCIPLE AND SYSTEM ACCURACY .............................................................. 7

4. EGNOS OVERVIEW .................................................................................................................................. 8
   4.1. INTRODUCTION ....................................................................................................................................... 8
   4.2. DESCRIPTION OF THE MAIN EGNOS FUNCTIONS ................................................................................... 9
   4.3. EGNOS ARCHITECTURE ........................................................................................................................ 9
   4.4. EGNOS TIME FUNCTION ..................................................................................................................... 11
       4.4.1. RIMS Clock Synchronization and Generation of ENT ............................................................................. 12
       4.4.2. ENT, GPST and UTC, Leap Second Introduction .............................................................................. 13
   4.5. EGNOS BROADCAST MESSAGES, MESSAGE TYPE 12 .......................................................................... 13
       4.5.1. ENT-UTC(OP), MT12 Generation ............................................................................................. 14
       4.5.2. MT12 Description, ENT-UTC(OP) Computation Algorithm ...................................................... 14

5. CGGTTS FILES ........................................................................................................................................ 16
   5.1. GPS RECEIVER CONNECTION SCHEMES AT OPMT AND IENG ............................................................ 17
   5.2. CGGTTS DATA FILES TREATMENT – REF-GPST OFFSET COMPUTATION ALGORITHM ...................... 18

6. ENT-ENTUSER ASSESSMENT ................................................................................................................. 19
   6.1. ENT-ENTUSER ASSESSMENT PRINCIPLE .............................................................................................. 20
       6.1.1. UTC(k)-ENTuser Assessment ......................................................................................................... 20
       6.1.2. ENT-UTC(k) Assessment ............................................................................................................. 20
       6.1.3. ENT-ENTuser Assessment .............................................................................................................. 21
   6.2. ENT-ENTUSER EVALUATION, RESULTS ................................................................................................ 21
       6.2.1. ENT-ENTuser Long-term Observation at Different Sites ............................................................. 21

CONCLUSIONS ................................................................................................................................................ 28

ACKNOWLEDGEMENTS .............................................................................................................................. 29

REFERENCES .................................................................................................................................................. 30
INTRODUCTION

The mankind evolution today requires intensive use of automated high-tech systems in various branches. Today’s integration of space communication and navigation systems into the daily life activities has reached immensely high level. Nevertheless, the steady growth in demands and requirements, which are set for the space systems, forces its further development and amelioration of the provided services. Speaking about satellite navigation systems, today they are no longer exclusively used for their original defence missions, but for civil applications, such as aeronautical, terrestrial and maritime transportation, as well as in any other applications, which require precise, integrated positioning and timing. The extremely accurate time function is particularly useful in synchronizing telecommunication networks and time-stamping banking transactions.

The present study was done in the field of European Geostationary Navigation Overlay System (EGNOS) at the Toulouse site of CNES, the French Space Agency, during a five-months internship.

In particular, the attention is devoted to EGNOS time function, system time assessment and its delivery to a user. In order to evaluate the accuracy of the latter, a special technique has been developed and its performance has been estimated during the testing phase.

After a brief description of the Centre National d’Études Spatiales and its various sites, the document presents a short introduction to space navigation systems, in particular, the U.S. GPS (Global Positioning System) and EGNOS, pointing out the principal aspects of the latter, which relate to system time generation (EGNOS Network Time – ENT), its steering to GPS system time and to UTC – Universal Time Coordinated. A particular attention is devoted to EGNOS broadcast Message Type 12, which carries the offset between ENT and UTC.

Afterwards a chapter is devoted to GPS system time assessment at two laboratories, participating to the International GNSS service (IGS) network, located in Paris region, France (OPMT) and in Torino, Italy (IENG). The way of data processing, provided by the laboratories is briefly described in this section.

The next part concerns the actual accuracy of ENT delivery to a user, where the period of two months of data (from March 30 to June 1, 2009) was analysed and if there were any anomalies in the obtained results, their origins were revealed, based on diversified analysis of available data.

The document describes just the mechanism of data processing, which was done using a special tool, developed by the author in Scilab programming language. Most of the graphs, which are put into the document, have been produced by the mentioned tool. Its description is not provided here but in a specific document written for CNES.
1. CNES

1.1. GENERAL INFORMATION

The Centre National d'Etudes Spatiales (CNES), founded in 1961, is a government agency responsible for shaping and implementing France’s space policy in Europe, it plays an important role in inventing space systems to the future, bringing space technologies to maturity and guaranteeing France’s independent access to space.

Its strong point is that it works in close cooperation with the main national organisations such as France Telecom, the Direction Générale de l'Aviation Civile, the Ministry of Defence, Météo-France, IGN Ifremer, the Centre National de la Recherche Scientifique (CNRS) and Universities with the aim of ensuring and coordinating French participation in projects conducted in cooperation with other countries, especially the United States, Russia, Japan and the European Space Agency.

Through its ability [1] to innovate and its forward-looking vision, CNES is helping to foster new technologies that will benefit society as a whole, focusing on:

- access to space
- civil applications of space
- sustainable development
- science and technology research
- security and defence

The CNES is located in four different sites, where different tasks are performed. Three sites are located in France (Paris and its region, Toulouse), while the fourth one, the launching facility, is based in Kourou, French Guiana.

Its head office is in Paris and the CNES Chairman and the assistant general managers are in position there together with the centralized managements.

The Launcher Directorate, instead, is installed in Evry, in Essonne (Paris region) and this plant houses all the teams involved in the development of several space projects and their ground facilities, and in research and technology in the propulsion and launcher fields.

Moreover, a privileged site, the Guiana Space Centre (CSG), is installed in Kourou, French Guiana where it enables any orbit inclination to be reached, from north to east in full safety thanks to its special position (5° 14’ north of the equator) that constitutes a decisive advantage for launches to geostationary orbits. As well, managed by CNES, the Guiana Space Centre houses the European Space Agency’s launch installations and the operational directorate of Arianespace.

Last site is the Toulouse Space Centre that is described hereafter and where this internship project was implemented in five months period.

1.2. TOULOUSE SPACE CENTRE (CST)

Opened in 1968, CST was the result of the policy of decentralization of French high-tech industry from the Paris region to the provinces.

Today CST plays the key role in research and development and support of a variety of space missions, performed by Europe. It employs approximately 2500 people (60% of engineers and frameworks, 20% of technicians and 20% of administrative staff, two thirds of them having a CNES status, others working under an external contract) on a zone of 56 hectares in the scientific complex of Rangueil in the South of the Toulouse city. The whole of the
buildings represents a surface of 65,000 $m^2$ floors (27,000 $m^2$ on the ground). So, the CST is unique in terms of its size and also in terms of the diversity of its activities and it is the most important technical centre of the CNES. It gathers all the means as a personnel and material necessary to the realization of a space program, except for the activities relating to the launchers which are localized in Paris area, with Evry.

Additionally, the CST is equipped with all the laboratories (mechanic, electronic, optic, etc.) required to prepare space bound experiments and exceptional test installations for material and equipment to be subjected to the extreme conditions of space.

Another leading mission entrusted to the Toulouse plant is the control and final orbit acquisition of satellites. This is a series of tricky operations which consists in taking over control of a satellite immediately after launch and guiding it to its final orbital position.

At this key site for space research, the centre develops complete space systems with its partners in industry and the scientific community, right up to their entry into operational service.

![Figure 1. Toulouse Space Centre (CST).](image)

### 1.3. DEPARTMENT DCT/RF/LN

The internship has been developed in the Localization and Navigation department (LN), also integrated in the Radiofrequency sub branch (RF), under the direction and supervision of the tutor engineer Norbert Suard in close cooperation with a second engineer, Jérôme Delporte, from the Time department (RF/HT).

The LN Department is in charge of the studies in architecture and engineering within the domain of the navigation and localization (including Galileo, GPS, EGNOS, SAR over Galileo). It is responsible for the identification and acquisition of competencies and needs for developing activities at the system level and evaluation of operational performances. These activities come from external clients, from ESA or others contractors.
2. PROJECT DESCRIPTION

European Geostationary Navigation Overlay System (EGNOS) is currently operational, but the improvements are regularly done in the System, as well as in techniques and software to evaluate its performance. Based on previous studies and investigations [2] it was decided to continue research in the field of global timescale connections and therefore new tasks have been worked out. The main goal of the internship was to implement some new ideas, which would facilitate further development.

So, the tasks of this project are briefly summarized below:

- The primary task was to evaluate the difference between EGNOS Network Time (ENT, system time) and ENT, received at the user level (ENT\textsubscript{USER}).

  It should be mentioned that a constant bias (ENT-ENT\textsubscript{USER}) was observed and the idea was to use another means of ENT-ENT\textsubscript{USER} assessment, in order to try to eliminate sources of this bias.

- Currently ENT-ENT\textsubscript{USER} offset can be estimated only in one location – Paris Observatory. It was decided to develop a tool, which would be able to compute this offset for another, k-laboratory, equipped with a GPS receiver and where UTC(k) is implemented.

3. GPS OVERVIEW

3.1. GPS SYSTEM ARCHITECTURE

The Global Positioning System (GPS) is a space-based radio-navigation system defined as a minimum of 24 GPS satellites orbiting the Earth at an altitude of approximately 20,160 km, the navigation payloads which produce the GPS signals, a network of ground stations, data links, and associated command and control facilities. GPS permits land, sea, and airborne users to determine their three dimensional position, velocity, and time, 24 hours a day in all weather, anywhere in the world.

Formally known as the Navstar Global Positioning System, GPS is rapidly becoming an integral component of the emerging Global Information Infrastructure, with applications ranging from mapping and surveying to international air traffic management and global change research. The growing demand from military, civil, commercial, and scientific users has generated a commercial GPS equipment and service industry that leads the world.

Its architecture is traditionally illustrated subdividing it in three segments: the space segment, the control segment and the user segment (as visible on Figure 2).
3.1.1. SPACE SEGMENT

The space segment [3] had been initially planned so as to realize a constellation of 24 satellites (21 operative and 3 of backup) spread on 6 orbital planes inclined at an angle of 55° with respect to the equatorial plane and positioned in intervals of longitude between the ascend nodes of 60°; every satellite transmits, in broadcast, the codes of distance at radio frequency and the navigation data; currently the number of satellites is variable from a minimum of 24 to a maximum of 32 depending on the respective conditions of operation; the 24 satellites nominally are distributed in a symmetrical manner in each of the 6 orbital planes; in reality such a distribution, throughout the ages, has been continuously modified in order to supply an adaptive coverage depending on the requirements of accuracy in the various zones of the planet: the present configuration, apparently irregular, guarantees the diffusive coverage of the positioning service with an accuracy commensurate to mean local requirements. Moreover, the 3 satellites in reserve (to spare) can eventually be moved in order to obtain additional radio coverage in some zones of the planet (essentially for military scopes). With reference to the current constellation, Figure 3 shows the GPS constellation, where each orbital plane is labelled with one letter (A to F) and each satellite (within the same orbital plane) with a number from 1 to 4.

The satellites are identified by means of PRN-numbers (Pseudo-Random Noise). Each GPS satellite has its own unique PRN-number.

The orbits of GPS satellites are approximately circular (null eccentricity) with radius of approximately 26.560 km and nominal period of 12 sidereal hours: every satellite moves therefore with a speed of the order of 4 km/sec passing on the same point twice in a day. The constellation has been planned and designed so that for any observer on the land surface, every satellite turns out in sight for approximately 5 of these 12 hours: such a configuration guarantees in every moment the presence over the horizon at least four satellites which send to Earth the necessary data, ensuring the positioning of the receiving station. In fact the number of visible satellites remains comprised between 7 and 9 for 90% of the time.

The main functionalities realized from the generic satellite are here in succession:

- to maintain and to provide a very accurate time signal using oscillators at caesium and rubidium (the accuracy comprised between $10^{-13}$ and $10^{-14}$ sec);
- to transmit information to the earth users through signals of opportune type (interface with the user segment);
- to receive, to store and to elaborate the information transmitted from a ground network station (interface with the control segment); the transported signalling information can concern eventual manoeuvre commands directed to the retrorockets in order to bring corrections to the satellite orbit.

The GPS positioning method presupposes that the user knows or can calculate, referencing it to a certain measure past instant, the position of the observed satellites; because of the not null relative speed and of the elevated delay of signals propagation, a satellite cannot communicate the own position in instantaneous way: for this reason it sends a synthetic parameters set that allows the calculation of its position (ephemeris).
3.1.2. CONTROL SEGMENT

The control segment has the function to control the orbital motion of the satellites (tracking), the functioning, within the tolerance limits, of the clocks and to communicate to the satellites the navigation messages to transmit in broadcast. The control is performed [4] by the “master control station” (Schriever AFB), located on the Schriever Air Force Base, about 20 km south of Colorado Springs, five additional monitoring stations (on Hawaii, Ascension Islands, Cape Canaveral, Diego Garcia and Kwajalein) were set up for monitoring the satellites. Later twelve more monitor stations of the NGA (National Geospatial-Intelligence Agency) were added to the grid and now every satellite can be seen from at least two monitor stations. This allows calculating more precise orbits and ephemeris data, including integrity monitoring of the satellites and thus the whole system.

3.1.3. USER SEGMENT

This segment is constituted by the users (civil and military) of GPS; a GPS receiver demodulates signals emitted from GPS satellites in order to estimate, in real time, the own position in an opportune three-dimensional reference system; an additional functionality, that concurs to obtain more accurate measures of position, counts that the receiver can collect data for a compensation in real time or afterwards (differential GPS). The receivers presented on the market use various decoding techniques of received signals to reach in a generalized manner, various levels in the accuracy of position assessment; the most modern and diffuse ones use both the carrying L1 radios and L2 of GPS signal.

3.2. POSITION COMPUTATION PRINCIPLE AND SYSTEM ACCURACY

The position computation in GPS is based on the measurement of time, which is required for the signal to propagate from the satellite to the receiver.

Very briefly the basic principle is explained hereafter.

The point in space is defined by four variables – three coordinates x, y, z and the time t. Therefore, having at least four satellites in view, one can determine the distance from the three satellites and compute unique point in space, while the fourth one is the source of correct time (Figure 5).

Nevertheless, satellite orbit parameters are not constant and degrade over time. The signals, which are sent by the satellites, are affected by atmosphere, receiver noise; multipath errors are also common in urban environments. Moreover, accuracy of atomic clock onboard the satellite is limited.

Today’s GPS Standard Positioning Service (SPS), which is available to a typical user, sets the following accuracy level of position determination: 13 meters 95% All -in-View Horizontal Error and ≤ 22 meters 95% All -in-View Vertical Error [6]. Typical contribution of different effects in system performance is represented in Table 1.
4. EGNOS OVERVIEW

4.1. INTRODUCTION

EGNOS, the European Geostationary Navigation Overlay Service, is a specific payload on GEO satellites and ground based system that augments the existing satellite navigation services provided by the American Global Positioning System (GPS) and the Russian Global Navigation Satellite System (GLONASS) for those users who are equipped with an appropriate receiver.

The European Tripartite Group - consisting of European Space Agency (ESA), the European Commission and Eurocontrol - has implemented [8], via the EGNOS project, the European contribution to the Global Navigation Satellite System (GNSS-1), which provides and guarantees the availability of navigation signals for aeronautical, maritime and land mobile trans-European network applications. On behalf of this Tripartite Group, ESA was responsible for the system design, development and qualification of an Advanced Operational Capability (AOC) of the EGNOS system.

GNSS-1 (Figure 6) can include a wide variety of augmentation systems: Satellite Based Augmentation Systems (SBAS) which are regional augmentations based on satellite broadcasting such as EGNOS, Ground Based Augmentation Systems (GBAS) as well as Receiver Autonomous Integrity Monitoring (RAIM) or Aircraft Autonomous Integrity Monitoring (AAIM). Moreover, it is the first European implementation for GNSS and in fact it is one of four inter-regional Satellite-Based Augmentation Services (SBAS) that complement GPS and GLONASS. The other three are the United States WAAS, Wide Area Augmentation System, developed by the US Federal Aviation Administration (FAA) over North America, the Japanese Multi-transport Satellite-based Augmentation System (MSAS) over

Table 1. GPS signal error sources and performance summary [7].

<table>
<thead>
<tr>
<th>Error source</th>
<th>Typical error contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>satellite clock errors</td>
<td>less than 6 m</td>
</tr>
<tr>
<td>ephemeris errors</td>
<td>less than 8 m</td>
</tr>
<tr>
<td>ionospheric delays</td>
<td>up to 10 m</td>
</tr>
<tr>
<td>tropospheric delays</td>
<td>less than 3 m</td>
</tr>
<tr>
<td>receiver noise</td>
<td>less than 2.5 m</td>
</tr>
<tr>
<td>multipath errors</td>
<td>less than 2.5 m</td>
</tr>
</tbody>
</table>

Performance summary for 95% of time

<table>
<thead>
<tr>
<th>Typical error</th>
</tr>
</thead>
<tbody>
<tr>
<td>horizontal – 6 m</td>
</tr>
<tr>
<td>vertical – 8 m</td>
</tr>
</tbody>
</table>
Japan Flight Information Region (FIR) and the Indian GAGAN (GPS Aided GEO Augmented Navigation) implemented and supported by Indian Space Research Organization (ISRO) and Airports Authority of India (AAI) to provide the seamless navigation service for all the phases of flight over Indian airspace.

The European system significantly improves the accuracy of GPS, typically better than 5 m, offers a service guaranteed by means of the ‘Integrity Signal’ and provides additional ranging signals. It is operated on the GPS L1 frequency, and thus is receivable with standard GPS front-ends. The EGNOS coverage area is the European Civil Aviation Conference area (ECAC), but could be readily extended to include other regions within the broadcast area of the geostationary satellites, such as Africa, Eastern countries, and Russia. EGNOS meets, in combination with GPS, many of the current positioning, velocity and timing requirements of the land, maritime and aeronautical modes of transport in the European region. Of the three user communities, civil aviation requirements are the most mature and the most stringent (in terms of integrity and continuity) and hence the definition of EGNOS is mostly driven by civil aviation mission requirements. These requirements are defined by the International Civil Aviation Organisation (ICAO). Furthermore, ICAO requires that an SBAS is compliant to internationally defined and agreed standards at various levels in the system in a manner to insure compatibility at user level and interoperability at service level between the various SBAS implementations. It is the first element of the European satellite-navigation strategy and a major stepping stone towards Galileo, Europe’s own global satellite navigation system for the future. EGNOS operator is now entered in the phase of its certification to provide legal services, the commissioning of certified services is planned in mid 2010.

4.2. DESCRIPTION OF THE MAIN EGNOS FUNCTIONS

The three principal services provided by EGNOS are here below [9]:

- GEO Ranging: Transmission of GPS-like signals from GEO satellites (INMARSAT-3 AOR-E, INMARSAT-3 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.

4.3. EGNOS ARCHITECTURE

The EGNOS architecture is highly redundant, generating wide-area differential corrections and alerting users within six seconds if something goes wrong. It is composed of four segments: ground segment, space segment, user segment and support facilities.

The EGNOS Ground Segment consists of GNSS (GPS, GLONASS, GEO) Ranging and Integrity Monitoring Stations (called RIMS), which are connected to a set of redundant control and processing facilities called Mission Control Centres (MCCs). The system is based on more than 35 RIMS sites located mainly in Europe, and four MCCs located at Torrejon (E), Gatwick (UK), Langen (D) and Ciampino (I). Each satellite has to be monitored by multiple RIMS before corrections and integrity messages are generated. Four Mission Control Centres process data from these RIMS to generate the WAD corrections and integrity message for each satellite. Only one of these MCCs is active and operational, the other MCCs are hot spares that can be activated if a problem occurs. So, the MCCs
determines the integrity, pseudo-range differential corrections for each monitored satellite, and ionosphere delays and generates the GEO satellite ephemeris. This information is sent in a message to the Navigation Land Earth Station (NLES), to be uplinked along with the GEO ranging signal to GEO satellites. The latter downlinks this 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).

The system uses two NLESs (one primary and one back-up) per GEO navigation transponder located at Torrejon (E), Fucino (I), Aussaguel (F), Scanzano (I) and two at Burum (NL). Figure 7 shows the current and planned sites for the various EGNOS ground-segment elements [10].

The **EGNOS Space Segment** is composed of geostationary transponders embarked on board of the GEO satellites with global Earth coverage. The EGNOS AOC system is based on the Navigation Transponder of the Inmarsat-3 AOR-E (PRN120) and IOR (PRN126) and the ESA Artemis (PRN124). Each satellite transmits the EGNOS Signal In Space (SIS) and therefore acts on one hand as a ranging satellite (GPS like, each with its own PRN) and on the other hand as a source of SBAS corrections.

The **EGNOS User Segment** consists of an EGNOS standard receiver, to verify the signal-in-space (SIS) performance, and a set of prototype user equipment for civil-aviation, land and maritime applications. This prototype equipment will be used to validate and eventually certify EGNOS for the different applications being considered. EGNOS users should be able to track at least two geostationary satellites. It takes less than six seconds to notify users about a problem with one of the satellite constellations once it has been monitored by the RIMS network.

![Figure 7. Current sites definition for the EGNOS ground segment elements.](image-url)
Then, last but not least, the EGNOS Support Facilities include the Development Verification Platform (DVP), the Application Specific Qualification Facility (ASQF) located in Torrejon (E), and the Performance Assessment and System Checkout Facility (PACF) located in Toulouse (F). These facilities are needed to support system development, operations and qualification and, in particular, PACF is not only in charge of assessing EGNOS performances, but also coordinates the operations, maintenance and upgrade activities. PACF also provides the system second level maintenance service and manages the third level maintenance with industry.

4.4. EGNOS TIME FUNCTION

The role [12] of time is of paramount importance in EGNOS. Any synchronization error would be derived into navigation error and so EGNOS system intends to answer to these stringent constraints generating a very stable EGNOS Network Time (ENT) that will be steered to GPS Time (GPST) with an accuracy estimated to be better than 3 ns, synchronizing EGNOS RIMS clocks to ENT with an accuracy of 3 ns and transferring ENT accurately to GEO satellites with the long-loop process.

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

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 the offset of individual satellite clocks from the nominal satellite system time-scale. These corrections are accurate 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 to disseminate them to system users, the EGNOS system performs four 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.
In order to make more clear the time links between GPS, GLONASS, GEO and different subsystems of EGNOS, these connections are represented on the following figure, Figure 9. The limitations on the connections are developed in the respect of the EGNOS time requirements scheduled from European Space Agency ESA and summarized in Table 2:

Table 2. EGNOS time requirements [11].

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>[ENT - GPS time] offset ≤ 50 ns (5σ)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>[GEO Time* - GPS time] offset ≤ 50 ns (5σ)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>[GEO Time* – ENT] accuracy ≤ 10 ns (3σ)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>[ENT - UTC(OP)] accuracy ≤ 10 ns (3σ)</td>
<td></td>
</tr>
</tbody>
</table>

(*) GEO Time refers to the equivalent time scale on-board the GEO.

4.4.1. RIMS CLOCK SYNCHRONIZATION AND GENERATION OF ENT

The RIMS clock synchronization is performed using the composite-clock technique, where 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.

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. But, 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, instead, the stability of ENT becomes the stability of the implicit ensemble mean of all the RIMS clocks and this has the important side effect of increasing the ability of the system to detect and isolate clock failures. However the composite clock technique has to deal with time transfer data that add noise and potentially outliers to the system.

4.4.2. ENT, GPST AND UTC, LEAP SECOND INTRODUCTION

Since ENT is steered to GPST and the difference between the two timescales is in the order of nanoseconds, the difference between GPST and UTC will be discussed now, while ENT may be easily derived applying the corresponding offset.

<table>
<thead>
<tr>
<th>Leap second</th>
<th>GPST</th>
<th>GPST</th>
<th>UTC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>57</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td></td>
<td>58</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td></td>
<td>59</td>
<td>59</td>
<td></td>
</tr>
<tr>
<td></td>
<td>00</td>
<td>666</td>
<td></td>
</tr>
<tr>
<td></td>
<td>01</td>
<td>00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>02</td>
<td>01</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 10 Leap second introduction mechanism*

Currently, GPST is ahead of UTC by 15 seconds. Therefore, it is necessary to take into account the current number of leap seconds while calculating offset values.

It should be noted that the exact number of leap seconds is provided in a specific message (MT12), therefore, having the updated information from EGNOS, the user is able to extract all necessary data, in order to estimate UTC with a very high accuracy.

4.5. EGNOS BROADCAST MESSAGES, MESSAGE TYPE 12

Like every SBAS system, EGNOS broadcasts positioning and navigation information to its users using navigation satellite constellation and geostationary satellites, which broadcast additional messages to the ones, broadcast by the navigation satellite constellation.

Message types with short description of its contents are provided in Table 3.
As it is seen, EGNOS broadcasts various messages, containing precise orbit correction parameters (fast- and long-term corrections), as well as ionosphere corrections. Message Type, which is used for time correction and which will be used further in calculations is Message Type 12 (MT12).

### 4.5.1. ENT-UTC(OP), MT12 GENERATION.

As it has been noted before, one of the RIMS in EGNOS is directly connected to a UTC(k). This RIMS is located in Paris and is connected to UTC(OP), therefore the offset between the two clocks may be estimated.

Since the EGNOS Network time (ENT) is the composite of all of the RIMS clocks, the relation between ENT and UTC(OP) may be obtained. The principle of ENT-UTC(OP) estimation is shown on Figure 11. The difference ENT-UTC(OP) is then treated in MCC, where MT12 message is formed and is transmitted using NLES to the geostationary satellite, afterwards it is broadcast by the GEO-satellite to EGNOS users.

---

**Figure 11. ENT-UTC(OP) estimation principle**

---

### 4.5.2. MT12 DESCRIPTION, ENT-UTC(OP) COMPUTATION ALGORITHM.

So, EGNOS Network Time (ENT) is the unique time, this time is broadcast by the EGNOS SIS and in addition the EGNOS system broadcasts the difference between ENT and UTC. This difference is included in GEO navigation message type 12, where there is also a 3-bit indicator, used to indicate the UTC time standard from which the offset is computed and which is also used to indicate if the message is invalid (in case of a failure). The list of UTC Standard identifiers and their meaning is represented in Table 4.

So, the purpose of the **Type 12 Message** is to provide time users with an accurate source of time referenced to UTC as it is not intended for navigation.

Regarding the parameters relating EGNOS time to UTC(OP), they shall be updated by the MCC at least once every three hundred seconds while the MCC is able to upload the data, otherwise the accuracy of the UTC parameters will degrade over time.
Table 4. UTC Standard Identifiers.

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

In particular, the MT#12 includes: (1) the parameters needed to relate EGNOS Time to UTC(OP), and (2) notice to the user regarding the scheduled future or recent past (relative to Navigation message upload) value of the delta time due to current number of leap seconds \( \Delta t_{LSF} \), together with the week number \( \text{WN}_{LSF} \) and the day number \( \text{DN} \) at the end of which the new leap second becomes effective \( \Delta t_{LS} \), Figure 12.

In practice, while computing ENT-UTC offset on a daily basis, there is no need to track the leap second introduction because it is always introduced at the beginning of a UTC day, but what is just important to take into account, is the GPS week number and the day number, as well as current number of leap seconds, which is updated with every MT12. It should be noted that GPS week starts from Sunday, which means that the first day of the week, Sunday, refers to \( DN=1 \).

All MT12 messages from three geostationary satellites (PRN120, PRN124 and PRN126) are collected and are put in special daily files, which are then available on one of the internal CNES servers.

So, each MT12 message contains the information sufficient to assess ENT-UTC(OP) offset. The general principle of this evaluation is illustrated on Figure 13. The main parameters, provided in MT12 message contain such data as the reference point time \( (t_0) \) and the coefficients of the first order polynomial \( (A_0, A_1) \). Therefore, the offset at each point \( (t_e) \) can be represented by equation \( (4.1) \):

\[
\Delta t_{\text{UTC(OP)}} = A_0 + A_1*(t_e - t_0) \quad (4.1)
\]

Figure 13. Illustration of the offset computation principle.

It should be mentioned that the reference point \( t_0 \) is just some point in time, described in seconds in GPS week, or to be more precise, which may be defined either in the past or in the future concerning the point \( t_e \). It may happen as well that from one to another MT12...
message the reference point remains the same, but there are only the polynomial coefficients, which change. It also erroneous to assume that \( t_0 \) is always defined in the same day as the \( t_e \). It occurs sometimes that \( t_0 \) is given for another week (preceding or successive). So, in order not to make errors in offset computations, the track of the change of the week number in the message is always necessary.

5. **CGGTTS FILES**

Laboratories, which participate to UTC often have GPS/GLONASS receivers, connected to their highly accurate atomic clocks. Therefore, each of these laboratories is capable to refer its time to the one transmitted by the navigation satellites. The time difference between the clocks can be estimated very precisely and is required to be presented in 0.1 ns. This time offset may be estimated for each GPS satellite, which is in the field of view. Basically, the principle of time computation can be described in the following way [13]:

1. Pseudo-range data are recorded for times corresponding to successive dates at intervals of 1 second. The date of the first pseudo-range data is the nominal starting time of the track. It is referenced to UTC and appears in the data file under the acronyms MJD and STTIME.

2. Least-square quadratic fits are applied on successive and non-overlapping sets of 15 pseudo-range measurements. The quadratic fit results are estimated at the date corresponding to the midpoint of each set.

3. Corrections [13] are evaluated at the dates, corresponding to the results of 2. and applied to these results.

4. Clock corrections for access to GPS time, as derived from a 2\(^{nd}\)-order polynomial (usually written as \( a_0 + a_1 t + a_2 t^2 \)) whose coefficients are contained in the GPS message, are evaluated at the dates corresponding to the results of 2 and applied to the results of 3.

5. The nominal track length corresponds to the recording of 780 short-term measurements. The number of successive and non-overlapping data sets treated according to 2, 3 and 4 is then equal to 52. For full tracks, the track length, TRKL, is taken equal to 780 s.

6. At the end of the track, a number of additional least-squares linear fits are performed, the results of which are a number of estimates, described in [13], including estimate quantity of the results of 4 to be measured, REFGPS, indicating the computed time difference between the reference clock and the broadcast GPS time.

The data are then recorded into the file of the CGGTTS format. The example of such file, provided by Paris Observatory (OP) is represented on Figure 14.

The file header consists of the records, which include:

- File format version;
- Revision date of the header file, REV DATE;
- Type, serial number, first year of operation and software number of the GPS time receiver, RCVR;
- Number of the channel used to produce the data included in the file, CH;
- Type, serial number, first year of operation and software number of Ionospheric Measurement System, IMS;
- Laboratory, where the observations are performed, LAB;
Coordinates of the GPS antenna in m, X, Y, Z;
Designation of the reference frame of the GPS antenna, FRAME;
Any comments about the coordinates, COMMENTS;
INT DLY: internal delay, entered in the GPS time receiver, in ns,
CAB DLY: delay coming from the cable length from the GPS antenna to the main unit, entered in the GPS time receiver, in ns,
REF DLY: delay coming from the cable length from the reference output to the main unit, entered in the GPS time receiver, in ns;
Identifier of the time reference entered in the GPS time receiver, REF;
Header check-sum, CKSUM;

5.1. GPS RECEIVER CONNECTION SCHEMES AT OPMT AND IENG

According to the goal of the project, it is necessary to use data from the laboratories, which participate to the International GNSS Service (IGS). Briefly, these laboratories (also called IGS stations) make measurements of GPS broadcast data and send them to IGS.

Two stations were taken: one, located in Paris Observatory (OPMT) and another one in Torino, Italy (IENG), both are member of IGS.

Paris observatory is equipped with one GPS antenna, connected to a GPS time receiver, which, in its turn, is physically connected to the hydrogen maser atomic clock, Figure 15 (a). This chain collects data and generates CGGTTS files. Since the hydrogen maser clock is also referenced to UTC(OP) – the caesium clock, another set of CGGTTS files may be produced. Thus, there are two sets of CGGTTS files with different REF-field and different offset values. But what is important to know, is that the data, which are sent to the IGS are referenced to hydrogen maser atomic clock. Another dataset is used for other purposes (will be discussed later in this document).

Connection scheme in Torino, Italy, is different. There is only one reference clock, UTC(IT), to which two GPS receivers are connected. But still, two sets of measurements can be made, since two receivers are in use.

---

Figure 14 Example of data file in CGGTTS format.

---
Figure 15 (b) demonstrates GPS connection scheme at IENG, Torino, Italy.

Here are two chains: chain 1 (GPS antenna 1 – GPS receiver 1 – UTC(IT)) and chain 2 (GPS antenna 2 – GPS receiver 2 – UTC(IT)). The data only from the second chain are sent to the IGS.

5.2. CCGTTS DATA FILES TREATMENT – REF-GPST OFFSET COMPUTATION ALGORITHM

So, CCGTTS files contain measurements from all of the satellites, which are in the field of view of the receiver antenna. Data from several satellites are processed simultaneously and are then recorded into the file.

In order to compute the exact date, to which the measurement correspond, the start of the measurement (STTIME) and the corresponding track length (TRKL) should be taken into account. The actual date (the time instant), to which correspond the time offset is the middle point of the track, which is defined according to [13] as:

\[
\text{DATE} = \text{STTIME} + \frac{\text{TRKL}}{2} - 0.5 \text{ s}
\]

Therefore, since in the CCGTTS file several records are possible with the same DATE, it is reasonable to take a composite offset value of all these PRN. The preliminary approach was to compute the mean offset value and then manipulate with a sequence of unique points in time, where only one offset value corresponds to each DATE (time instant). Unfortunately the further analysis revealed weak point of this way of calculation. It has been noticed that there were periods of time when for some PRN the offset changed suddenly by several hundreds of nanoseconds, but it came back after a while.

This illustrates that the malfunction is possible, though it is not clearly evident, where it happened: either on the satellite or on the receiver side. Such malfunctions may affect much the final estimation of mean offset value, calculated of all PRN. The example of such a problem is represented on Figure 16.

There are around 6-7 satellites visible at each DATE, and all of them show similar offset values, as proved by the standard deviation graph, represented on Figure 17. Suddenly at about 8 o’clock in the morning one of the satellites starts showing incorrect data and everything returns to normal state after five hours. As it is seen on Figure 17, the mean offset value is affected immediately, resulting in a drop by around 10 nanoseconds.
As long as such problems may lead to considerable errors in time calculation, they should be filtered out. In order to solve this task, the median filter was used instead of simple calculation of the mean. Median value was used in further computations only when there were data available from four or more satellites at the same DATE. In all other cases the mean value was used.

As it is seen from Figure 17, the median curve is very close to the mean one during the whole day except when the outlier is present. The observation during other days also proves that median value is very close to the mean one, and at the same time median filter is a good solution for the problem, discussed above.

6. **ENT-ENT\textsubscript{USER} ASSESSMENT**

In order to monitor EGNOS performance, CNES has developed a special tool EPO – EGNOS Performance Observatory. The tool uses GPS raw measurements that are collected through the IGS network together with EGNOS messages, and as one of the results, finally gives the offset between the ENT and the ENT\textsubscript{USER}, where ENT – is the EGNOS Network time (system time), while the ENT\textsubscript{USER} – is the time, which is computed by EGNOS user, based on the received messages.
In fact, the ENT-ENT\textsubscript{USER} offset is expected to be zero, but previous observations, made with OPMT using EPO have shown that there was a constant bias in the order of 4.9 ns [2].

6.1. ENT-ENT\textsubscript{USER} ASSESSMENT PRINCIPLE

6.1.1. UTC(K)-ENT\textsubscript{USER} ASSESSMENT

So, though one of the final results of EPO is ENT-ENT\textsubscript{USER}, it was decided to estimate this offset by other means. This was done for two reasons: in order to validate EPO and to be able to calculate ENT-ENT\textsubscript{USER} offset not only for one receiver in Paris Observatory, but also for some other different stations. As an example, the laboratory in Torino, Italy was chosen (IENG).

One of the data files, which is used in current method, is an intermediate file, which is created by EPO during the calculation of ENT-ENT\textsubscript{USER}. This file, includes the offset between UTC(k) and ENT\textsubscript{USER}. To be able to compute this offset, the following data are used: global compressed RINEX navigation file (brdc), international terrestrial reference frame file (ITRF), antenna reference file, ionospheric grid map, satellite configuration file, receiver line delays, Hatanaka-compressed observation data and EGNOS messages, Figure 18.

Additional corrections, which are shown as a dashed box on Figure 18, are optional. For example, if UTC(k) is not directly connected to the receiver, but to another clock source, then a file, containing offsets between the two clocks is required.

In case of Paris Observatory, as it has already been mentioned, the receiver is not directly connected to UTC(OP), but is connected to Hmaser clock, therefore, it is required to know the difference between OPHmaser and UTC(OP).

Receiver line delays are taken from the header of CGGTTS file, which is provided by the laboratory.

The result of the calculation is a sparse file, which contains UTC(k)-ENT\textsubscript{USER} offsets for one chosen day. This file is then used for further computations.

6.1.2. ENT-UTC(K) ASSESSMENT

The mechanism of ENT-UTC(k) offset computation using two CGGTTS files, which include UTC(OP)-GPST and UTC(k)-GPST, and the t-file, which contains ENT-UTC(OP) offset, may be described by the following equation:

\[
\text{ENT-UTC(k)} = \text{[ENT-UTC(OP)]} + \text{[UTC(OP)-GPST]} - \text{[UTC(k)-GPST]} \quad (6.1)
\]
The first term in this equation is obtained from MT12 message, the second one – from CGGTTS file from OPMT, which is referenced to UTC(OP), Figure 15 (a), and the last term is computed from the CGGTTS file from k-laboratory.

Figure 19 represents an example of ENT-UTC(k) assessment, described by equation (6.1).

![Figure 19. ENT-UTC(k) assessment results example.](image)

Actually, the described calculations are a bit more complicated task than it seems from the first sight. The offsets in two CGGTTS files are usually computed for different time instants and moreover, the MT12 messages are sent at their own variable frequency. Therefore it was decided to take MT12 reception times as reference points and to compute REF-GPST offset values at these instants, using interpolation.

6.1.3. ENT-ENTUSER ASSESSMENT

It is not hard to notice that having both UTC(k)-ENTUSER and ENT-UTC(k) offsets for the same day, the ENT-ENTUSER offset can be easily estimated:

\[
\text{ENT-ENT}_{\text{USER}} = \text{ENT-UTC}(k) + \text{UTC}(k)-\text{ENT}_{\text{USER}} \tag{6.2}
\]

The actual computation of the offset, though, again requires some pre-processing of the input files, and is not just applying a simple equation, but the principle is the same as the computation of ENT-UTC(k) offset. In order to be able to make any calculations, it is necessary to compute the offsets of UTC(k)-ENTUSER, which are given in the mentioned sparse file, at time instants of MT12 reception, and this should be done by interpolation.

6.2. ENT-ENTUSER EVALUATION, RESULTS

6.2.1. ENT-ENTUSER LONG-TERM OBSERVATION AT DIFFERENT SITES

In order to draw any conclusions, it is necessary to make long-term assessments of ENT-ENTUSER at different sites and compare the results.
First, ENT-ENT\textsubscript{USER} offset observation was made at OPMT. The period from March 30, 2009 to May 31, 2009 (MJD 54920-54982) was taken and the observation results are presented on Figure 20. Here only the daily mean, median and standard deviation values are shown, which are computed based on all available offset values collected on a daily basis.

![Figure 20. ENT-ENTuser, as estimated at OPMT for the period from March 30, 2009 to May 31, 2009. The same data are presented on both graphs, but y-axis scale is different.](image)

As one can see, mean/median ENT-ENT\textsubscript{USER} offset values are rather stable and are between 4-6 ns except May 22, 2009. The histogram of standard deviation values on Figure 20 reveals some outsider points (marked with red colour), when standard deviation was considerably higher than in other days. These points correspond to MJD 54952, 54955, 54956, 54973. In particular, MJD 54973 (May 22, 2009) draws the attention, because the mean offset value of ENT-ENT\textsubscript{USER} suddenly rises up to 50 µs during this day.

Going deeper into study of this phenomenon, and looking into CGGTTS file from OPMT for May 22, 2009, one can notice an anomaly (Figure 21, a, b), which happened at OPMT between 11 and 12 hours in the morning on May 22. The sudden change of the offset is seen in both datasets at OPMT, Figure 21 (a, b), but everything seems to be stable at IENG (UTC(IT)-GPST graph is presented on Figure 21 (c)).

Figure 21 (d) shows the ENT-UTC(OP) offset from MT12 message, which is generated based on the data from RIMS in Paris, directly connected to UTC(OP) and which is independent from the GPS data. So what is seen is that MT12 messages were provided during this event, but there were no valid MT12 messages soon after noon, which corresponds to a break in the data at the same moment at OPMT Figure 21 (a). This problem is under investigation.

So, the analysis of the available data allows to conclude that probably there was a hardware malfunction with the reception chain first and with the link between the receiver and caesium clock soon after that at OPMT during the day MJD 54973.

![Figure 21. ENT-ENTuser offset, as estimated at OPMT for the period from March 30, 2009 to May 31, 2009.](image)

**Statistical data for the whole period (based on daily median values)**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean value of median values, ns</td>
<td>4,936</td>
</tr>
<tr>
<td>Median value of median values, ns</td>
<td>4,935</td>
</tr>
<tr>
<td>Standard deviation of median values, ns</td>
<td>0,458</td>
</tr>
</tbody>
</table>
Figure 21. Anomaly analysis of ENT-ENT\textsubscript{USER} offset assessment on May 22, 2009, MJD 54973 (a, b, c, d, e) and on April 18, 2009, MJD 54952 (f, g, h, i, j).

For MJD 54973: figures a and b show REF-GPST assessment at OPMT, while c shows REF-GPST assessment at IENG, MT12 offset is on d and finally e is ENT-ENT\textsubscript{USER} offset, as estimated at OPMT.

For MJD 54952: figures f and g show REF-GPST assessment at OPMT, while h shows REF-GPST assessment at IENG; MT12 offset is on i and finally j is ENT-ENT\textsubscript{USER} offset, as estimated at OPMT.
Figure 22. Anomaly analysis of ENT-ENT\textsubscript{USER} offset assessment on April 21, 2009, MJD 54955 (a, b, c, d, e) and on April 22, 2009, MJD 54956 (f, g, h, i, j).

For MJD 54955: figures a and b show REF-GPST assessment at OPMT, while c shows REF-GPST assessment at IENG, MT12 offset is on d and finally e is ENT-ENT\textsubscript{USER} offset, as estimated at OPMT. For MJD 54956: figures f and g show REF-GPST assessment at OPMT, while h shows REF-GPST assessment at IENG; MT12 offset is on i and finally j is ENT-ENT\textsubscript{USER} offset, as estimated at OPMT.
The other days, when the standard deviation of ENT-ENT\textsubscript{USER} offset is higher are April 18, 21 and 22, 2009 (MJD 54952, 54955, 54956). The look down into these days shows that there were problems with the receiver at OPMT, Figure 21 (f-j), Figure 22.

Indeed, during these three days one can notice strange variations of REF-GPST offset values at OPMT, which are not seen at IENG. Since the same GPS dataset is used to produce two CGGTTS files at OPMT Figure 15 (a), the bad reception has an effect on both datasets, which reflect similar pictures, Figure 21 (f, g) and Figure 22 (a, b and f, g). At the same time REF-GPST offset estimated at IENG is much more stable, Figure 21 (h) and Figure 22 (c, h).

If one checks the MT12 messages and looks into ENT-UTC(OP) offset, then there are also no significant variations, Figure 21 (i) and Figure 22 (d, i), which indicates that UTC(OP) remained stable during these days.

So, there is only one possible reason for such ENT-ENT\textsubscript{USER} offset fluctuations during the mentioned days, Figure 21 (e, j) and Figure 22 (e, j): bad GPS signal reception at OPMT, which had an impact on the final offset evaluation.

ENT-ENT\textsubscript{USER} offset was also estimated based on the data of IENG. The following graphs show the offset evaluation during the period from March 30, 2009 to June 1, 2009 (MJD 54920-54983), Figure 23.

The anomaly with a very big value of ENT-ENT\textsubscript{USER} offset has been already explained above and its origin comes from bad signal reception at OPMT, Figure 21 (a, b). The examination (not described in this document) of the other days with high standard deviation of ENT-ENT\textsubscript{USER} (MJD 54928, 54929, 54933, 54950–54952, 54954–54957, 54966, 54968, 54971, 54972) reveals that during these days there was also bad reception of GPS signal at
OPMT, which resulted in bad estimation of UTC(OP)-GPST offset and caused deviations in ENT-ENT\textsubscript{USER} evaluation.

Figure 24 allows to compare standard deviations of the REF-GPST offsets, estimated at OPMT and IENG. In general, standard deviation for UTC(IT)-GPST for this period is smaller than that for UTC(OP)-GPST, moreover, one can notice that, the days, which are marked in the previous paragraph also correspond to days with high value of standard deviation for UTC(OP)-GPST offset on Figure 24.

Figure 24. Standard deviation of UTC(OP)-GPST and UTC(IT)-GPST offsets for the period from March 30, 2009 to June 1, 2009.

ENT-ENT\textsubscript{USER} offset at OPMT is rather stable during the whole period of observation. As one can notice, it is hardly ever out of 4–6 ns region, Figure 20, and is usually in the order of 5 ns.

However, at IENG several periods with constant ENT-ENT\textsubscript{USER} offset can be traced on the graph on Figure 23.

The first period starts from the beginning of the observation period, March 30 and finishes on April 4, when standard deviation is below 2 ns level and the offset is around 3,5 ns (marked in blue colour on the graph).

The second and the third periods start from April 13 to April 28 and from May 23 to June 1 (marked in green colour on Figure 23). The ENT-ENT\textsubscript{USER} offset is around 5,2 ns, while the standard deviation is always less than 2 ns, which indicates that the offsets, computed during these days are well clustered and do not differ much from the mean and median values.

Since UTC(OP)-GPST offsets are used directly in computation of ENT-ENT\textsubscript{USER} offsets (equations ( 6.1 ), ( 6.2 )), the accuracy of the first one affects estimation of the second one. It should be said that this is the UTC(OP)-GPST estimation in OPMT, which limits the performance of the current method of ENT-ENT\textsubscript{USER} evaluation.
Figure 25 shows the difference between two estimations of $\text{ENT-ENT}_{\text{USER}}$ offset at OPMT and IENG.

![Difference in ENT-ENTuser estimation at OPMT and IENG](image)

**Figure 25. Difference in ENT-ENTuser estimation at OPMT and IENG for the period from March 30, 2009 to May 31, 2009.**

Statistical data on assessment of both offsets are represented in Table 5.

**Table 5. ENT-ENTuser offset estimation comparison at OPMT and IENG.**

<table>
<thead>
<tr>
<th>ENT-ENT$_{\text{USER}}$ offset</th>
<th>as estimated at OPMT</th>
<th>as estimated at IENG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean value, ns</td>
<td>4,936</td>
<td>4,527</td>
</tr>
<tr>
<td>Median value, ns</td>
<td>4,935</td>
<td>4,946</td>
</tr>
<tr>
<td>Standard deviation, ns</td>
<td>0,458</td>
<td>1,398</td>
</tr>
</tbody>
</table>

Though ENT-ENT$_{\text{USER}}$ offset estimation at IENG is much less stable than that at OPMT, for the observation period of two months the mean offset values at both sites are rather close to each other. The difference between the two is 0,409 ns. While speaking about median values, they are almost the same, different by some 0,011 ns.

Still, there is an offset between ENT and the time, estimated by a user ($\text{ENT}_{\text{USER}}$) and it is 4,5 – 5 ns, which might be due to calibration of the instruments, used in this assessment method. Longer observation is required, in order to make more accurate evaluation.

It should be noticed that the bias, discussed above, is similar to the one, computed with an internal CNES software tool – EPO (EGNOS Performance Observatory), which is equal to 4,9 ns in May 2009 [14] and to 5,4 ns in June 2009 [15], as estimated at OPMT. This proves that the method is very efficient for these kinds of assessments.
CONCLUSIONS

At this end it is time now to make a summary of the work, which has been done within the scope of this project and to point out the obtained results.

In order to achieve the goal of the project, to assess the difference between EGNOS Network Time (system time) and the time, received at the user level, ENT_{USER}, and therefore to evaluate EGNOS Time Function performance, the data from two stations, which participate to the IGS network were analysed: from the one in Paris Observatory (OPMT) and another one in Torino, Italy (IENG).

For each station the two offsets were computed: \( UTC(k)-ENT_{USER} \) (based on Hatanaka compressed RINEX data, precise GPS satellite ephemerides and EGNOS corrections) and \( ENT-UTC(k) \) (based on EGNOS Message Type 12, REF-GPST offsets, computed at OPMT and IENG). Finally, \( ENT-ENT_{USER} \) offset was estimated at both sites and compared with the same offset, computed for OPMT using CNES internal software tool – EPO (EGNOS Performance Observatory).

All this has been made through a routine, which represented a combination of Scilab code and Unix shell script, therefore corresponding skills were obtained.

The approach was to make a long-term observation at different sites and to compute statistical parameters (mean, median, standard deviation offset values) on a daily basis. Afterwards, if something appeared to be strange, the particular days were analysed in details. The period from March 30 to June 1, 2009 was observed, which revealed that:

- The mean offset value, computed using current method for OPMT and estimated for two months observation period is very close to the one computed using CNES internal software tool (EPO) and is equal to \(-4.9\) ns, which validates the accuracy of current method;
- The mean and median offset values at both sites (OPMT and IENG) computed for the observation period from March 30 to June 1, 2009 are close to one another, though ambiguousness of the results, estimated at IENG shows that longer observation is necessary, to make more thorough analysis;
- Since the data from OPMT (UTC(OP)-GPST) participate in all calculations, currently this is the principle factor, which limits performance of this method: some hardware failures occurred in Paris Observatory during the observation period, which immediately affected \( ENT-ENT_{USER} \) offset estimation;
- The use of the median filter in UTC(k)-GPST offset and similar assessments in many cases allows to eliminate or decrease effect on the resulting value of the outliers, at the same time showing high proximity to the results, obtained using mean value calculation.

Moreover, what is also very important is that:

- The method is applicable to any site, located within EGNOS coverage area, therefore allowing to improve \( ENT-ENT_{USER} \) offset estimation;
- The method may be also used for \( ENT-GPST \) offset assessment, using the following equation: \( ENT-GPST = [ENT-UTC(OP)]_{MT12} + [UTC(OP)-GPST]_{CGGTTS} \) file. \( ENT-GPST \) offset was also evaluated during the internship and the results are presented in a specific document, written for CNES.
- Using two CGGTTS files, assessment of \( UTC(k_1)-UTC(k_2) \) offset is possible. This is done, applying the following equation: \( UTC(k_1)-UTC(k_2) = [UTC(k_1)-
A special Scilab routine was developed, which performed this task.

- By analyzing the offset, provided in MT12 messages, ENT-UTC(OP) or EGNOS Time Function performance was evaluated in the scope of the internship. ENT-UTC(OP) offset extrapolation by one day, or 86400 seconds was done, which is the validity time of each MT12 message. The corresponding long-term observation was made and the obtained results were analyzed. This work is described in a specific document, written for CNES.

- Part of the work, done during the five-month internship, will be reused for publications in coming months. In particular, some results will be presented at ION-GNSS (the Institute of Navigation – Global Navigation Satellite System) conference and a paper, describing ENT-ENT\textsubscript{USER} and ENT-GPST assessment methods will be published and presented at PTTI (Precise Time and Time Interval) meeting in November 2009. Moreover, some results will be also used in a contribution to ITU (International Telecommunication Union).

**ACKNOWLEDGEMENTS**

This project would not have been possible without the support of many people.

The author is grateful to Norbert Suard, under whose guidance this work has been implemented in the department DCT/RF/LN in CST and who has given a number of valuable advices to the author.

Special thanks also to Jerome Delporte, from the Time department (RF/HT), who provided with the data and who was always ready to answer any question, concerning the project.

The author wishes to thank the stuff of CNES, especially the head of the Navigation and Localization department DCT/RF/LN, Jerome Legenne, and all its members, Alain Brissaud, Cyrille Boulanger, Bernard Bonhoure, Marc Jeannot, Jean Marechal and Solange Sailliard, for their help and support and for the nice atmosphere, which they created from the very first moment.
REFERENCES

[10] Performance Assessment and Check-Out Facility - PACF EGNOS, CNES.