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Demonstrator of Time Services based on European GNSS signals: the H2020 DEMETRA Project / Defraigne, P., Tavella, P., Sesia, I., Cerretto, G., Signorile, G., Calonico, D., Costa, R., Clivati, C., Cantoni, E., De Stefano, C., Frittelli, M., Formichella, V., Biserni, E., Leone, V., Zarroli, E., Sormani, D., Gandara, M., Hamoniaux, V., Varriale, E., Morante, Q., et al.. - ELETTRONICO. - (2017), pp. 127-137. (48th Annual Precise Time and Time Interval Systems and Applications Meeting Hyatt Regency Monterey, Monterey, California 30 January - 2 February, 2017).

Availability:
This version is available at: 11583/2693323 since: 2018-05-17T11:16:05Z

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09 September 2026

Demonstrator of Time Services based on European GNSS signals: the H2020 DEMETRA Project

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BIOGRAPHY

Pascale Defraigne got her PhD in Physics at the Université Catholique de Louvain (UCL), Belgium, in 1995. She is now head of the Time Laboratory at the Royal Observatory of Belgium and chairs the working group on GNSS Time Transfer of the Consultative Committee of Time and Frequency.

ABSTRACT

During 2015-2016, a European Consortium of 15 partners from 8 different countries, developed the DEMETRA (DEMonstrator of EGNSS services based on Time Reference Architecture), a project funded by the European Union in the frame of the Horizon 2020 program. This project aims at developing and experimenting time dissemination services dedicated to specific users like traffic control, energy distribution, finance, telecommunication, and scientific institutions. Nine services have been developed. These services provide time dissemination with accuracy levels from millisecond to the sub-ns, and also additional services like certification, calibration, or integrity. Five of these services are based on the European GNSS.
After a development phase (see PTTI 2016 presentation) the full DEMETRA system has been working during six months for demonstration. The paper will report about the experimentation results, showing performances and limits of the proposed time dissemination services, aiming to foster the exploitation of the European GNSS for timing applications.

Keywords— EGNSS; time dissemination; standardized time services; demonstrator; timing; H2020;

INTRODUCTION

The DEMETRA Project [1]-[3] was conceived to demonstrate the feasibility and the possible performance of time services mainly based, but not only, on the Galileo timing signal. During the last two years a demonstrator has been built for developing, testing, and validating time dissemination services in a realistic environment.
The User Needs Analysis carried out during the project, confirmed that several different applications requires the availability of time related products and the possibility to synchronize a user clock to a reference time with a certain level of accuracy. The European GNSS Agency market analysis reported for the first time in 2015 the European GNSS timing and synchronization service as crucial for energy, telecom, and finance markets [4]:

- many Telecom and Energy networks as well as financial agents rely on GNSS for synchronisation operations and to timestamp financial transactions.

- timing & Sync service disruption could potentially have serious consequences on the operation of Telecom, Energy and Finance networks.
- need for robust Timing & Synchronization of these networks is emerging.

Working on the idea of new market segments needing time with improved accuracy, in some cases, but most often with improved robustness, resilience, certification, and redundancy, we started thinking to the possibility to develop new or innovate timing services to fulfill these identified gaps. This is the leading idea of the project supported by the European GNSS Agency in the frame of the Horizon 2020 research programme.
DEMETRA consortium brings together four European National Metrology Institutes (ORB, VTT, NPL, INRIM), one Technical University (POLITO), four industry (TAS-F, TAS-I, VEGA, DEIMOS), one SME (ELPROMA), one SME consortium (Antares, created to promote the innovation and development of SMEs in the space sector), one consulting large company (aizoOn), and one management & consulting company SME (METEC). Besides, the project is supported by the Czech metrological institution UFE, and the French space agency CNES. The DEMETRA project started in January 2015 and lasted 24 months.
Starting from the time dissemination techniques and time services of the National Metrology Institutes and of the Galileo system, and taking into account the additional needs of the different market segments, DEMETRA was conceived as a demonstrator able to develop and test 9 different timing services devoted to different markets and user needs. Each service has been developed and then integrated and validated in the DEMETRA laboratory hosted at INRIM.
The experimentation campaign results may be visualized on the DEMETRA webpage (www.demetratime.eu). From February to November 2016, the DEMETRA webpage had more than 4000 visitors. The DEMETRA experimentation included two main phases named Closed Loop and End to End campaigns. During the Closed-Loop Campaign all services components were installed and validated at INRIM DEMETRA Laboratory, including the User Terminals. Instead, in June 2016 for the End to End Campaign, each User Terminal has been moved at user premises and the tests have been repeated in order to assess the achievable performance in a realistic case, when the user terminals and the time signal generators are hosted in different and remote locations. During each campaign both nominal and stressed tests have been executed to verify the performances also in degraded conditions, since this aspect revealed to be crucial for the possible users. A picture of the demonstrator assembled in the DEMETRA laboratory is shown in Figure 1.

Figure 1: DEMETRA- Demonstrator assembled and integrated in the Laboratory at INRIM, Italy.

OVERALL ARCHITECTURE OF THE DEMONSTRATOR

Nine different time services are proposed for demonstration by the consortium partners. The demonstrator is designed in order to have a modular, flexible and scalable architecture, for example it is able to host additional timing services in future developments without any major changes in the core infrastructure.
As shown in Figure 2, the demonstrator relies on external servers as International Metrological Institutes for reference data, on the GALILEO space segment and on a geostationary satellite.
The Core Infrastructure provides common reference signals to the services and the final users.
It is composed by three main facilities:

- *Time Reference Facility (TRF),*

- *Service Provision Facility (SPF),*
- *Service Monitoring Facility (SMF).*

These are in charge of generating the physical electric signals, monitoring the services performances and allowing the interface between the elements and with the final users.

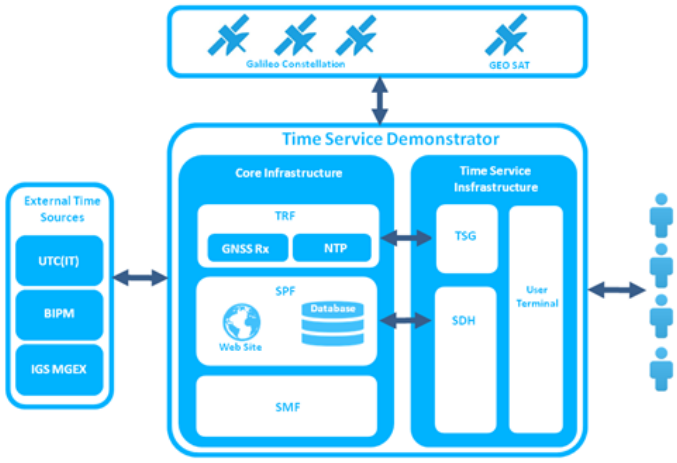


Figure 2: DEMETRA architecture

The nine time services are composed of a Time Signal Generator (TSG), a Service Data Handling (SDH) and a User Terminal (UT). The latter ones have been moved at user premises during the End to End Campaign (Jun – Oct 16).

EXPERIMENTATION RESULTS

In this section the experimental results obtained during the test campaign are reported.
The Users involved in the experimentation are part of different market sectors: telecommunications, broadcasting, finance, national metrology institutes. The experimental results were available to the Users on the DEMETRA webpage (www.demetratime.eu).
In the following some test results done during the end to end campaign are reported.

Service 01: Time broadcasting over TV/Radio links

The main aim of the *Service 01:* is to provide time dissemination to users by means of the current and future Radio and TV transmission techniques (in both the analogue and digital formats), covering wide areas (national and international level) and requiring for a millisecond accuracy performance [5].
The system is based on the dissemination of a proper code containing reference Date and Time information to the user. The user can employ two types of User Terminals (UT), depending on the required needs. A "standard" User Terminal showing Date and Time on a dedicated display only, and an "advanced" one where also 10 MHz and 1PPS electrical signals, reconstructing the reference time and frequency signals, are available.
The best performances achieved are reported in Figure 3: the difference between the reference time and the time obtained as user level is around 30 ms when dissemination in a FM mode is used. Instead in DAB mode, the performances is degraded to a delay of 3-4 s (seconds) due to random variation of the digital broadcasting.

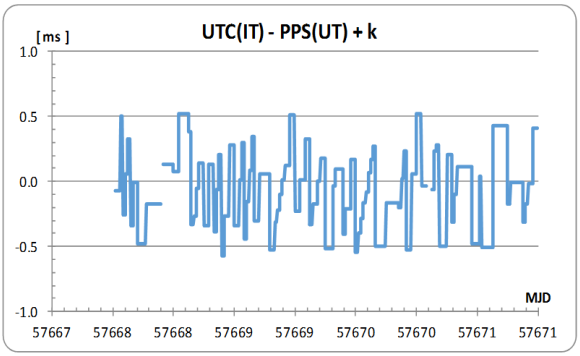


Figure 3: Time broadcasting over TV/Radio links: time offset of the User Terminal with respect to the reference time

Service 02: Certified Trusted Time Distribution with Audit and Verification using NTP

This service allows the dissemination of UTC time and frequency over Internet using NTP (Network Time Protocol) [6]. It enables remote assessment of the client clock synchronization by providing audits and reports. It distributes authenticated UTC to client in a way that the time of the client can be verified, also retrospectively, as VALID or INVALID (e.g. for the purpose of litigations in B2B transactions). The service uses public-key cryptography (PKI: Public Key Infrastructure) providing properties such as: integrity, non-repudiation, validity, and authentication. In the following some results obtained during the End to End at two National Metrology Institutes showing the frequency deviation of the clock in the two User Terminals.

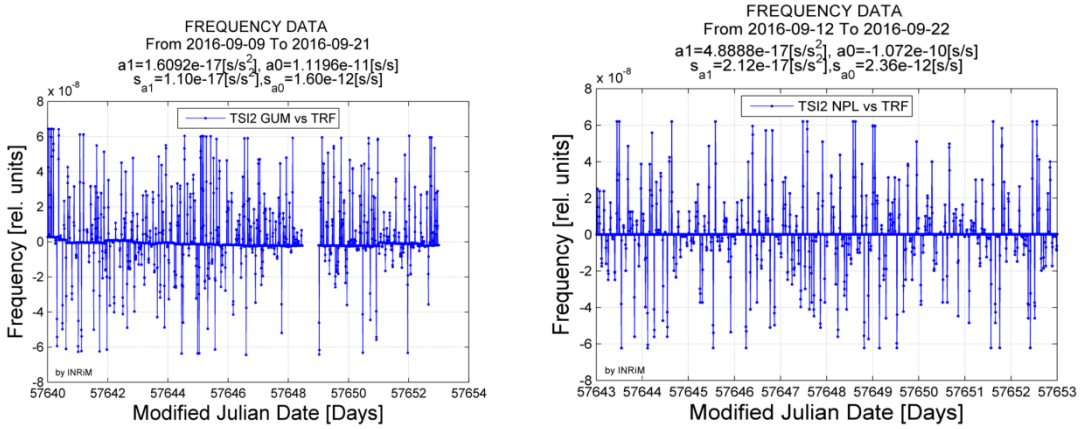


Figure 4: Trusted Time Distribution : frequency offset of the clocks in the User Terminals versus the reference signal

The variations in frequency are result of User Terminal built-in internal oscillator tunings. Frequency offset values are below 6.5 * 10^{-8}, both for the user terminal located at the Polish and British NMI, respectively GUM and NPL. The Service demonstrated an accuracy of 1 ms for LAN application and 10 ms with internet.

Service 03: Time and Frequency Distribution over Optical link:

The main driver for this service is the request from several market segments of a reliable timing service independent from the satellite based time transfer [7], [8].
The Time transfer over fiber is an answer to the requirements of resilience, traceability, accuracy and stability. The main features of the service is the delivery over fiber of a time and frequency signal directly traced to UTC.
The time standard is encoded on a laser carrier in the telecom wavelength at the master station (in this case, INRIM), then transported via fiber to the user, where the laser carrier is demodulated and by a receiving station offering a pulse per second signal, a 10 MHz reference and a time stamping if combined with an internet connection. Service 03 has demonstrated a time accuracy at subnanosecond level (as reported in Fig 5), together with a statistical instability of 100 ps already at 1 s (measurement time). The method has been shown to be robust, affordable, resilient to stress tests.

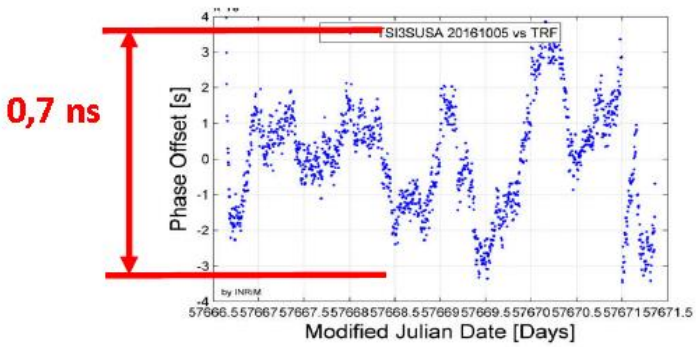


Figure 5: Time and Frequency Distribution over Optical link: Phase/Time offset of the UT located in Susa with respect to the master station in INRIM (100 km)

Service 04: Time and Frequency Distribution via GEO Satellite

Service 04 has been developed to back-up traditional synchronization systems based on GNSS. The system allows to synchronize user clocks in each user terminal by using a geostationary satellite. A set of two-way stations is used additionally to determine the station position. The proposed technology is based on consolidated telecommunication techniques (FDMA) that are applied in an innovative way, thus allowing for a reliable, competitive and cost-effective final system. Main features of the service include:

- Timing accuracy ~100ns.
- Reduction of interference with respect to GNSS-based systems.
- No dedicated satellites are required: any geostationary satellite can be used. Switching to alternative satellite is simple.

The service has been tested in collaboration with the two major Italian broadcasting operators as well as the Czech NMI as end users. By monitoring user terminals for over two months, the best achieved performance shows that the User Time offset is stably remaining in a range narrower than +/-100 ns as reported in Figure 6. Despite the occurrence of some outliers to be further investigated, the behavior of Service 04 is in line with expectations, in terms of accuracy, resilience and availability.

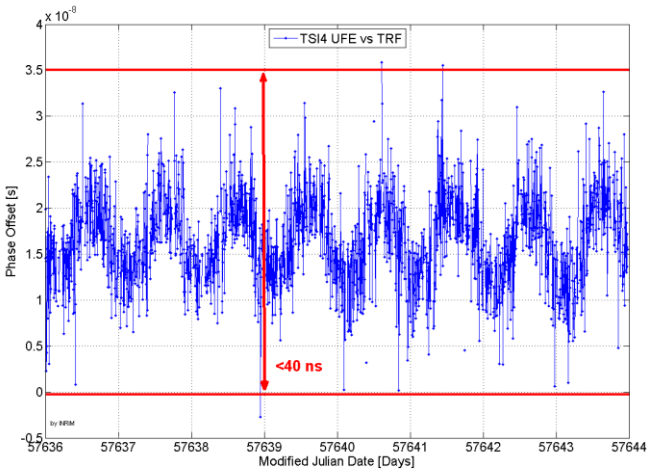


Figure 6: Time and Frequency Distribution via GEO Satellite: phase/time offset of the User Terminal with respect to the reference time

Service 05: User GNSS Receiver Calibration:

There is presently an increasing demand for calibration. Firstly the time laboratories participating to the realization of UTC need to repeat the calibration of their equipment almost every year [9]. Furthermore industrial users require more and more a time accuracy better than 100 ns. This is only achievable if the equipment is calibrated and all the involved HW delays are known with an uncertainty of few ns.
For both GPS and Galileo signals, in the frame of DEMETRA absolute calibration has been realized by CNES ([10]) for the GPS P1 and P2 signals and the Galileo E1 signal, with an uncertainty lower than 1 ns for each independent signal. Furthermore, a relative calibration with an uncertainty of 3 ns has been carried out by ORB for all the stations used in DEMETRA project for the validation of the different services. The validation was indeed based on GPS PPP, using a calibrated receiver connected to each of the user terminals.

Service 06: Certified Time Steering:

The service proposes a remote steering and synchronization of the user oscillator with a monitoring of the time offset between the User clock and the Reference Time in real time. In addition, the Service provides a certificate of the phase and frequency offsets of the user oscillator with respect to the reference[11]. The market segment is the telecommunication sector, the energy distribution, and the companies offering time tagging. All these indeed require accurate frequencies and timing (essentially is the telecommunication sector and the energy distribution) and certification (for time tagging).

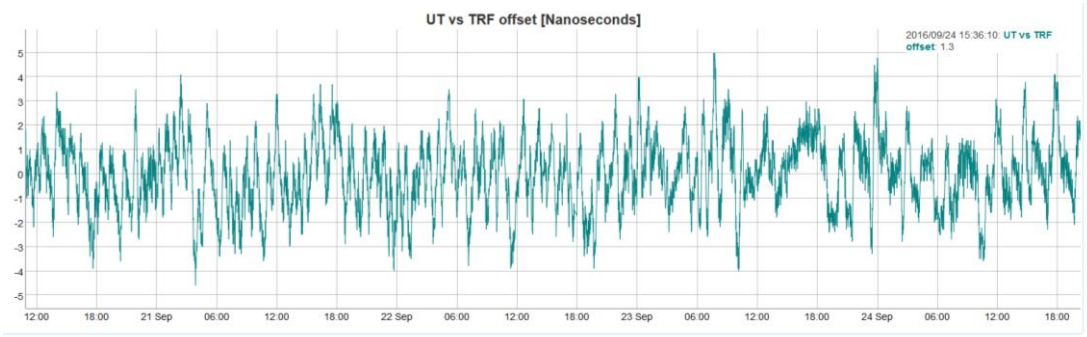


Figure 7: Certified Time Steering: time offset of the User with respect to the reference time

Service 7: Time Monitoring and Steering

The service offers the quasi real time estimation of the difference between the reference time and the time scale of the User equipped with a geodetic GNSS receiver by estimating a PPP solution every hour [12]. An alarm is sent to the user in case of phase or frequency jump detected. In addition, the service proposes a station quality monitoring in terms of multipath, satellite visibility, number of cycle slips etc… The service was tested with 7 users in the frame of DEMETRA. For some of them an additional information on the needed steering parameters to be applied to the user time scale to stay align on UTC was provided.

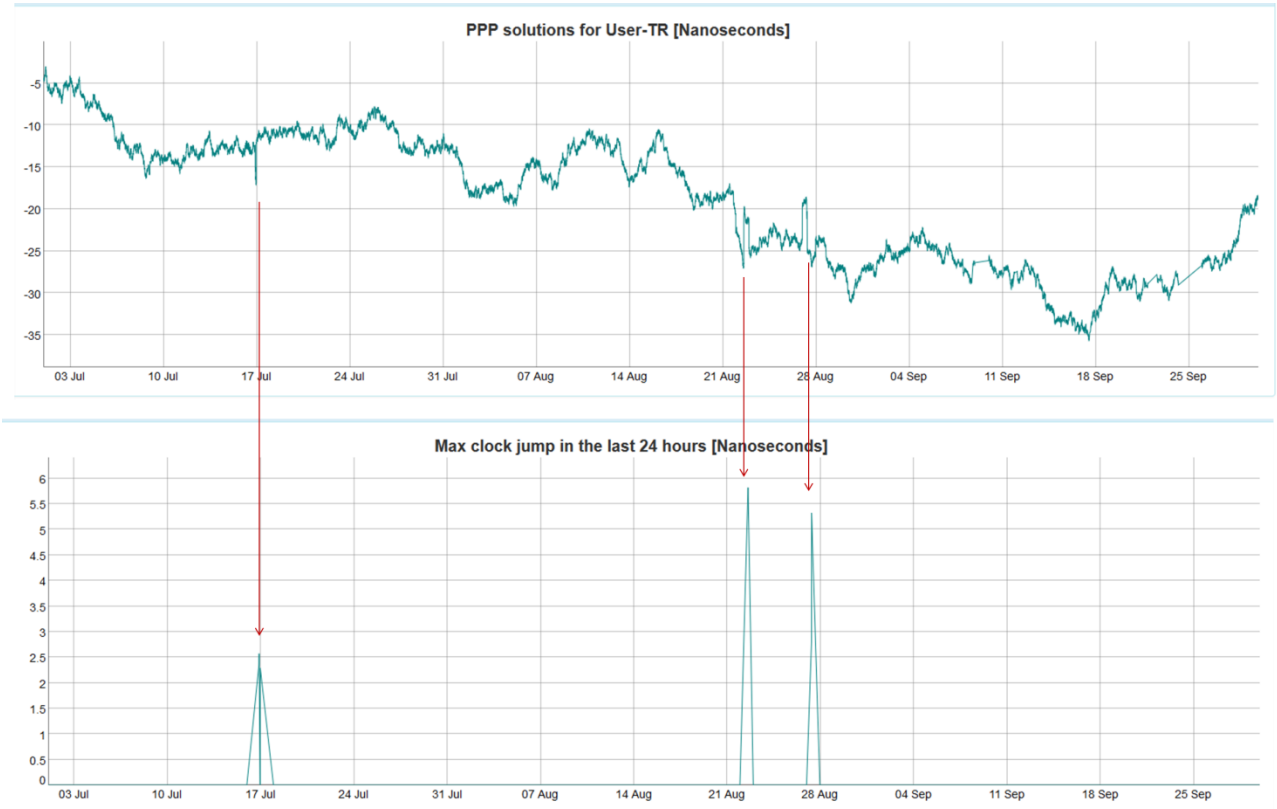
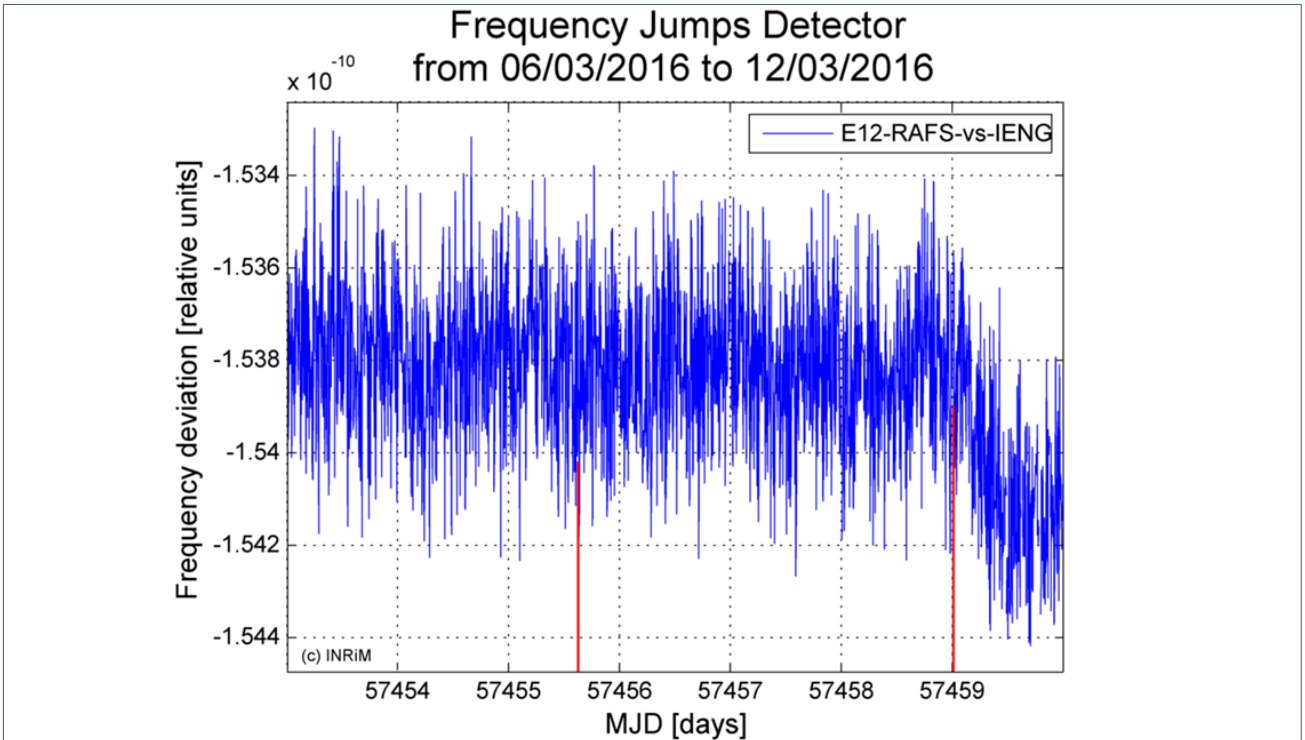


Figure 8: Time Monitoring and Steering: hourly PPP monitoring of the time offset of the User with respect to the reference and Clock jump detection obtained

Service 8: Time Integrity

The Integrity service checks for possible anomalies in the Galileo transmission of GGTO and UTC. In case of discrepancy the user is alerted, and a list of not usable satellites is produced in case of anomalies detected on space clocks [13]-[18].



###SVN###	####MJD####	#########DATE#########	###AMPLITUDE###	###UNITS###	###DETECTED ANOMALY##
E12	57455.6285	2016-03-08 15:05:00	4.72e-13	[rel.units]	Frequency Jump
E12	57459.0035	2016-03-12 00:05:00	4.86e-13	[rel.units]	Frequency Jump
E19	57456.0000	2016-03-09 00:00:00	3.22e-09	[seconds]	Phase Jump

Figure 9: Time Integrity: Space clock jumps detection and list of not usable satellites

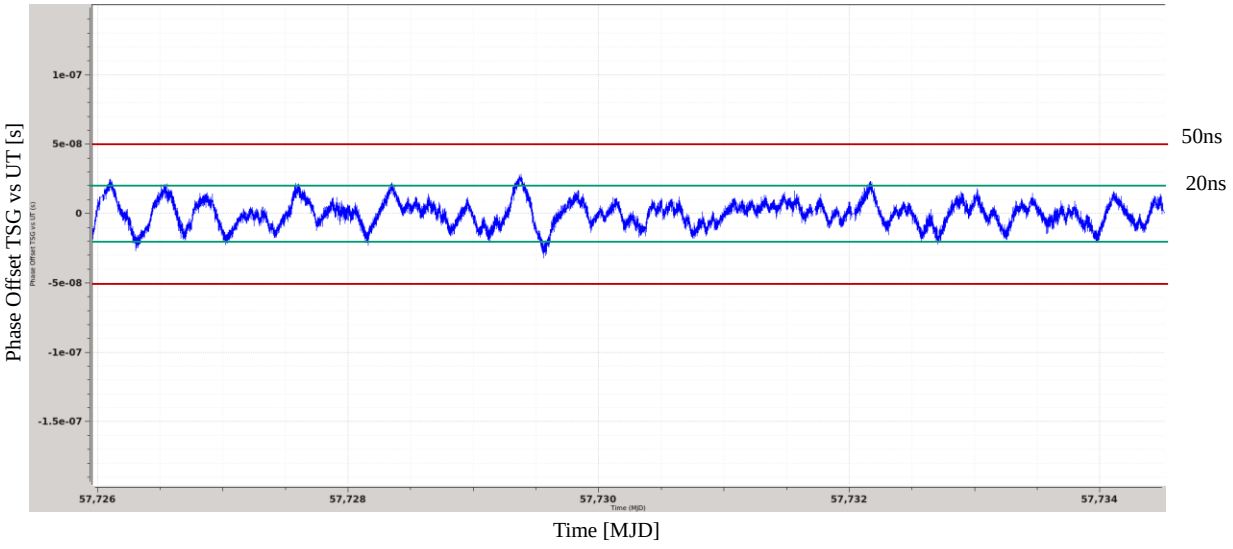


Figure 10: All-in-one Time Synchronization Solution: time/phase offset of the User Terminal with respect to the reference time

Service 9: All-in-one Time Synchronization Solution

Service 9 is based on SynchroNet, a Thales Alenia Space Italia patented system for high performance network synchronization, enhanced in this project. The Service is exploiting GNSS (GPS and GALILEO) synchronization algorithms and techniques into a higher level distributed infrastructure, matching critical systems requirements [20][21]. Main features and benefits are the capacity to accurately synchronize a scalable and distributed clock network, providing also performance and integrity indicators, availability and robustness [23].

Figure 10 shows time offset between User Terminal and the reference time. The performances achieved confirm the capacity of the system to synchronize the user clock versus the reference one at the level of a few tens of nanosecond as obtained during the Demetra experimentation phase.

DEMETRA SUMMARY PERFORMANCES:

The DEMETRA nine time services are described in [1][2][22], in this section a table summarizing the features and the achieved performances of each service are reported.

Table 1: Features and performances for each DEMETRA service

Service	Special Features	Expected Performance	Best Measured Performance Closed Loop	Best Measured Performance End to End	Comments
TS1	Standardized code time dissemination through Europe, using DAB and DVB digital transmissions standards, together with the time dissemination via FM (Frequency Modulation) signals	~ 1ms - several 10ms	~ 30 µs	~ 30 ms	performances related to a dissemination in a FM mode. In DAB mode, the performances reach 3-4 s
TS2	1) Two-way time transfer system. One-way distribution and two-way dedicated for backward real time auditing, monitoring of UTC time at user level. 2) Periodical user time audits are stored in special DATA LOG at source. After Internet disconnection the user time can be validated again. 3) Multi clock subsystem of remote clock brings new tool for examining User timekeeping features 4) Single source can deliver validated reference time	Closed Loop: <1ms LAN, End to End: < 10ms for internet	< ± 30 µs	< ± 10 ms	(End to End) <+/10ms due to link asymmetry. Link asymmetry calibration implementation under improvement.
TS3	Time/Frequency dissemination to the user (other scientific labs and industrial companies)	< 1ns	< 1ns	5ns	5 ns due to a residual of the calibration; stability < 75 ps for 100% of the time

Service	Special Features	Expected Performance	Best Measured Performance Closed Loop	Best Measured Performance End to End	Comments
TS4	The service combines the economic advantages and the wide coverage of a commercial GEO satellite signal. The system is meant as a backup solution to GNSS synchronization. The service provides the same accuracy as GNSS and improves resilience to interference.	~ 100ns	< 5 ns	~ 40 ns	Some outliers detected and under investigation for improvement
TS5	The project aim is experimenting and providing calibration procedures of Galileo receivers.	~ 5ns	~ 5ns	-	
TS6	Disciplined Oscillators via GPS/Galileo signals in real time with improved accuracy/stability characteristics.	~ 20ns	< 10ns	< ± 5 ns	
TS7	The service represents an added value for different customers, in particular Time and Frequency Labs, interested in having reliable and performing system for supporting their daily duties in the maintenance of their atomic clocks and generation of national time scales.	~ 50 ns (steering)	100% availability (PPP) Steering ~ a few ns (tested only on a few days)	100% availability (PPP) Steering ~ 20 ns	
TS8	The service is the first step testing a Galileo time integrity system.	daily/weekly products	100% availability	98% availability	
TS9	Scalable (number of terminals and terminal performances), robust to GNSS interruption, interference, and spoofing, secure synchronization (authentic, secret and integer), self SLA	Scalable with UT configuration and up to nanoseconds	~ 5 ns (50%) ~ 60 ns (100%)	~ 10 ns (64%) ~ 30 ns (100%)	

CONCLUSIONS

The Demetra project has built a demonstrator able to host and test 9 time services for 6 months, also at user location, to trial the capability of the proposed time services to fulfill the User expectations. During the project several users from the telecom, energy, broadcasting, metrological, finance, space, clock manufacturing, and scientific fields have been contacted in dedicated User workshops and also by involvement in the trial campaign. The demonstration has shown the high emerging interest for time services in different fields and has proved some new concepts as time integrity, certification, and non-repudiation that could be an added value to the future European GNSS time service.

ACKNOWLEDGMENTS

This project has received funding from the European GNSS Agency under the European Union's Horizon 2020 research and innovation programme under grant agreement No 640658.

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