Smartphone application for the near-real time synchronization and monitoring of clocks through a network of GNSS receivers

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***Abstract*— The promising potentialities for time and frequency transfer of a network solution of geodetic GNSS receivers located in National Timing Laboratories aiming at comparing their time scales at the maximum level of precision is presented.**[1]

I. INTRODUCTION

In time metrology, different techniques are used for time and frequency transfer, basically TWSTFT (Two Way Satellite Time and Frequency Transfer), GPS CV (Common View) and GPS AV (All in View) [1].

In recent years, many national timing laboratories have collocated geodetic GPS receivers together with their traditional GPS/GLONASS CV/AV receivers and TWSTFT equipments. Time and frequency transfer using GPS code and carrier-phase, is an important research activity for many institutions involved in time applications, basically due to the fact that carrier phase measurements generated are two orders of magnitude more precise than the GPS code data. This was recognized when the International GNSS Service (IGS) and Bureau International des Poids et Mesures (BIPM), formed a joint pilot study to analyze the IGS Analysis Centers clock solutions and recommend new means of combining them. In addition, the CCTF (Consultative Committee for Time and Frequency), in 2006, passed a recommendation "Concerning the use of Global Navigation Satellite System (GNSS) carrier phase techniques for time and frequency transfer in International Atomic Time (TAI)". Moreover, the BIPM in 2002 started a project named TAIP3 [2] aiming at the use of the phase and code GPS measures.

Many of geodetic GNSS receivers hosted in national timing laboratories, operate continuously within the International GNSS Service (IGS) and their data are regularly processed by IGS Analysis Centers. Whereas participating stations must agree to adhere to certain strict standards and conventions which ensure the quality of the IGS Network, a number of products and tools have been developed in order to allow time and frequency transfer without taking part to the IGS.

One standalone GPS carrier phase analysis technique is Precise Point Positioning (PPP), in which dual frequency code and phase measures are used to compare the reference clock of a single receiver to a reference time scale. Several works [3],[4],[5],[6] were carried out to evaluate the time and frequency transfer capabilities of PPP, leading the BIPM to start a pilot experiment which aims to evaluate the possibility to regularly compute some TAI links with the PPP algorithm, to obtain an improved statistical uncertainty [7]. The PPP algorithm used for the BIPM pilot experiment has been developed by the Natural Resources Canada (NRCan) [8].

In this paper we want to investigate a possible network solution, similar to the IGS analysis center solutions, that can be easily managed by a network of timing centers to solve in a unique system all the clock differences (besides other quantities) to understand the feasibility and the advantages of this approach in time and frequency transfer. The investigation is based on a web-based tool named *magicGNSS* (magicgnss.gmv.com), which is a suite of GNSS software products developed by GMV in Madrid, that allows the users to perform a wide range of calculations and analyses related to GNSS, from the evaluation of performances at user level, to the computation of precise GNSS orbits and clocks, including the calculation of precise receiver coordinates. The time and frequency transfer capabilities or the network solution (named Orbit Determination & Time Synchronization, ODTS) are evaluated and compared to PPP solutions as well as to other

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1 This work is mainly based but not exclusively on the paper G.Cerretto, P.Tavella, A.Perucca, A.Mozo, R. Piriz, M. Romay, "Time and Frequency Transfer through a network of GNSS receivers located in Timing Laboratories", in Proc. of EFTF/IEEE FCS, April 2009, Besançon, France.

time transfer results. A dedicated *magicGNSS* web page allows the visualization of estimated clocks in near-real time, including an adaptation of such web page to smartphone screens. Examples of web and smartphone visualization are presented below.

II. MAGICGNSS

magicGNSS is a web application for high-precision GNSS data processing. It allows the calculation of GPS satellite orbits and clocks, and also of station/receiver coordinates, tropospheric delay and clocks. The user can upload his own station data (RINEX measurement files) or use data from a global network of pre-selected *core stations* from IGS.

magicGNSS is available at http://magicgnss.gmv.com. A one-month trial account can be requested online for free. After the trial period, the usage of *magicGNSS* is subject to a yearly fee. In Table I, the characteristics of the *magicGNSS* account are summarized.

TABLE I. CHARACTERISTICS OF MAGICGNSS ACCOUNT

	magicGNSS account
Available algorithms	PPP, ODTS, COMP
Disk quota	10 Gb
Core station data	from 2008/01/01
IGS products[(1)]	from 2008/01/01
Navigation messages[(2)]	from 2008/01/01
User station data in ODTS	yes
Max. no. of stations in ODTS	60
Max. no. of stations in PPP	60
Max. data span in PPP	5 days
Max. data span in ODTS	5 days
Ftp upload	yes
Deletion of user station data	never
Usage of public station data	PPP and ODTS
Share your station data	yes
Technical support by email	next-day basis

[(1)] Orbits and clocks needed for PPP and COMP

[(2)] Needed for ODTS initialization

With *magicGNSS*, the user can analyze results in a convenient way through comprehensive PDF reports and organize the processing scenarios and history within his account in an easy way with a generous disk quota [9]. At present, *magicGNSS* supports GPS and GLONASS data both in ODTS and PPP, while Galileo processing is planned for the near future. One of the most interesting characteristics of *magicGNSS* is the easy way to use it. Inside *magicGNSS* account, one has just to click on *New* to define a new scenario (network), then click on *Save*, and then click on *Run* to process the data and generate results.

The algorithms that process station data to generate products in *magicGNSS*, are called ODTS, which stands for *Orbit Determination & Time Synchronization*, and PPP. ODTS is a *network solution* requiring a set of stations distributed worldwide. PPP is a *single-station solution* (although several stations can be processed together for convenience). In ODTS the stations must be static, while PPP supports static and kinematic processing. The advantages of a network solution like ODTS as compared to PPP are that the estimates of each station can benefit from the measures of all stations being in principle more robust and precise. In addition, all clock differences are available in a single solution instead of asking a time consuming series of PPP single station solutions.

There are two types of station data within *magicGNSS*: *core station* data and *user station* data. For ODTS, the server maintains data from 36 IGS core stations distributed worldwide. Current *core station* data is available with a latency of typically one hour. The user can also upload his own station data (daily, hourly, or 15-min RINEX files) via the web or ftp. Batch upload and automation are possible using ftp. Normal or compressed data files can be uploaded, and if the RINEX file does not have P1, the C1 code will automatically be converted to P1 using the CC2NONCC tool from IGS. Station data uploaded and shared by other users can also be processed.

The GPS and GLONASS operators inform the users about events affecting satellite availability by publishing messages named NANUs. *magicGNSS* automatically downloads NANUs as they are issued and extracts the relevant information so that only healthy satellites will be considered in the data processing.

An additional module, called COMP, allows comparing *magicGNSS* products with IGS and among themselves.

In Table II, *magicGNSS* generated products are indicated.

TABLE II. MAGICGNSS PRODUCTS

Product	ODTS	PPP	Format	Accuracy (RMS)
Report	✓	✓	pdf	N/A
Satellite orbits	✓	✕	sp3	~2/6/4 cm[(*)]
Satellite clocks	✓	✕	clk	~0.15 ns
Station clocks	✓	✓	clk	~0.15 ns
Station tropo	✓	✓	txt	<1 cm (zenith)
Station coords	✓	✓	snx	<1 cm

[(*)] In the Radial/Along/Normal directions

III. DATA PROCESSING AND PRODUCTS

The basic ODTS and PPP input measurements are pseudorange (code) and phase L1-L2 dual-frequency iono-free combinations. On L1, the P1 code is used in order to be consistent with IGS. The raw input code and phase measurements are decimated and used internally by ODTS and PPP at a typical rate of 5 minutes (down to 30 sec can be also used). The core measurements are smoothed using the phase with a *Hatch* filter, thus reducing the code error from the meter lever to typically 25 cm.

ODTS and PPP are based on a batch least-squares algorithm, that minimizes measurement residuals solving for orbits, satellite and station clock offsets, phase ambiguities and station tropospheric zenith delays. In the case of PPP, satellite orbits and clocks are not solved for, but fixed to IGS products (*ultra-rapid*, *rapid* or *final*) or GMV internal products (that support GPS and GLONASS). For this reason PPP is not a total independent technique, conversely to ODTS that, autonomously, provides all products.

Clocks are calculated as snapshot values, i.e., as instantaneous values at the measurement time epoch, without correlation with previous estimates. Clocks are estimated at the same rate as the measurements (typically every 5 minutes).

In ODTS, satellite and station clock offsets are estimated with respect to a reference clock, provided by one of the stations. In PPP, the station clock is referred to the IGS Time scale (IGST), as derived from the satellite clocks in the IGS products. From subsequent differentiation, the differences between station clocks can be inferred.

The satellite and Earth dynamics are based on high-fidelity models that follow IERS recommendations. Modelled effects include a full Earth gravity model, Sun, Moon and planetary attractions, solid Earth tides, ocean loading, and solar radiation pressure (SRP), including eclipses. Radiation force discontinuities during eclipse entry/exit are smoothed in order to improve orbit accuracy. The satellite attitude is modelled as a generic nadir-pointing yaw-steering law applicable to all GNSS satellites. In ODTS, the orbit fit is based on the estimation of the initial state vector (position and velocity) and 8 *empirical* SRP parameters. Earth Rotation Parameters (ERPs) are automatically downloaded from the IERS server, but they can also be estimated by ODTS itself. The tropospheric correction is based on the estimation of a zenith delay per station (a constant value every hour), using a mapping function to account for the satellite-station signal elevation. Small effects such as relativity and carrier-phase wind-up are also modelled.

For the core stations, a priori station coordinate values come from ITRF or IGS solutions, and they can be refined within the ODTS process. For user stations, the precise coordinates from PPP can be used as input values for ODTS. Satellite and station antenna offsets and phase centre variations are taken into account, the latest ANTEX file from IGS is always used.

IV. Description of the ODTS algorithm

The ODTS processing can be summarized as follows:

1. Given a satellite position and velocity at a certain starting epoch, an orbit can be produced on the basis of dynamic information, by numerical integration of the equations of motion of the satellite over a certain period. Furthermore, the partial derivatives of the satellite position with respect to the estimated dynamical parameters are produced.
2. For the epochs within that period at which tracking data is available, a tracking observation can be reconstructed numerically, using the known station position, the satellite position coming from the integrated orbit, and precise models for the effects affecting the tracking signal propagation. Also, the partial derivatives of the reconstructed measurements with respect to the estimated parameters are produced.
3. The measurement residuals (difference between the pre-processed tracking observations and the associated calculated observations) are computed.
4. The sum of squares of all available residuals is minimized by estimating corrections to the various model parameters in a least squares sense. To accomplish that, the computation of the partial derivatives of the expected measurements with respect to the estimated parameters is needed.

The process described is iterated until one of the following criteria is met:

- the number of iterations exceeds a certain threshold defined by configuration;
- the RMS of the weighted measurement residuals is below a certain threshold defined by configuration;
- the difference between two consecutive solutions is below a certain margin established by configuration.

The next sections describe those steps in detail.

Orbit Computation

The orbit propagation consists of computing the satellite state vector for a whole integration arc, given an initial state vector at the epoch t_0 and a model of forces acting on the satellite. The solution of the problem is achieved by integrating the equations of motion, which can be expressed in matrix form as follows:

$$\frac{d\vec{y}}{dt} = \vec{f}(t, \vec{y})$$
$$\vec{y}(t_0) = \vec{y}_0$$

being

$$\vec{y} = \begin{pmatrix} \vec{r} \\ \vec{v} \end{pmatrix}, \quad \vec{y}_0 = \begin{pmatrix} \vec{r}_0 \\ \vec{v}_0 \end{pmatrix}$$

$$\vec{f}(t, \vec{y}) = \begin{pmatrix} \vec{v} \\ \vec{a} \end{pmatrix}$$

where $\vec{r}$ and $\vec{v}$ are the satellite position and velocity, $\vec{a}$ is the acceleration and $\vec{y}_0$ is the state vector at the epoch t_0.

The numerical integration of this differential equation is performed using a 8^{th}-order Gauss-Jackson method.

The state vector $\vec{y}_0$ at the end of the estimation arc is one of the sets of parameters that have to be estimated during the ODTS process. After a preliminary integration using an approximate state vector (from navigation messages), the integration is always performed backwards, using the estimated state vector at the end of the arc as initial value.

The integration process is based on physical models, which provide the satellite acceleration at each moment in time, as a sum of all the contributions, namely earth and third body gravity, solar radiation pressure and relativistic correction to acceleration.

Measurement modelling

The main goal of this part of ODTS is to provide the least squares module with the measurement residuals and partial derivatives of the measurements with respect to the parameters to be estimated.

This process has three parts, which have to be performed observation by observation:

- compute the measurement expected from the computed satellite orbit, the (possibly estimated) station positions and an estimation of the different biases between the direct measurement and the geometric station-satellite distance: tropospheric delay, satellite and station clock biases, phase ambiguity, plus a relativistic correction,

- compute the residual, that is, the difference between the actual measurement and the expected one,

- get the partial derivatives of the expected measurement with respect to all the estimated parameters, using the partial derivatives of the orbit with respect to the dynamical parameters computed in the orbit integration.

The GNSS measurements accepted by ODTS can be of four different types:

- Raw iono-free pseudorange.
- Smoothed iono-free pseudorange.
- Iono-free carrier phase.
- Ambiguity-free iono-free carrier phase.

The tropospheric delay can be configured to be removed either in pre-processing (which means they are "tropo-free") or estimated within the ODTS process.

Note that the GNSS measurements have to be corrected to be referred to the centre of mass of the satellite, and not to the satellite antenna phase centre.

Expected measurement computation

All the computations are performed in the Inertial Reference Frame. To obtain the geometrical range d (in meters) for a measurement at reception time τ, the following operations are necessary:

- compute actual reception time $\tau - b_{sta}$, where b_{sta} is the station clock bias

- compute station position at reception time: $\vec{x}(\tau - b_{sta})$

- compute travel time: $\Delta t = d_0/c + \Delta/c$, where Δ is the total correction to the travel time, in meters, due to different biases, and c the velocity of light.

- satellite emission time is approximately

$$(\tau - b_{sta}) - \Delta t = (\tau - b_{sta}) - d_0/c - \Delta/c,$$

where d_0 is an initial value for the geometric range which is chosen to be ρ (the actual measurement), since the convergence is faster. Note that it would also converge to the solution taking $d_0=0$ instead of $d_0=\rho$.

- compute satellite position at emission time:

$$\vec{r}(\tau - b_{sta} - d_0/c - \Delta/c)$$

- get geometrical range:

$$d = \left\| \vec{x}(\tau - b_{sta}) - \vec{r}(\tau - b_{sta} - d_0/c - \Delta/c) \right\|$$

This formula has to be iterated to obtain the correct value:

$$d_{n+1} = \left\| \vec{x}(\tau - b_{sta}) - \vec{r}(\tau - b_{sta} - d_n/c - \Delta/c) \right\|$$

Finally, the expected measurement (in meters) is just the final travel time (in meters), corrected by the effect of the clock biases:

$$\rho_{\exp} = d + \Delta + \delta t_{rel} + b_{sta} - b_{sat}$$

where b_{sat} is the satellite clock bias, and δt_{rel} is the relativistic correction to the satellite clock.

When the measurement is carrier-phase, the formula is slightly different:

$$\varphi_{\exp} = d + \Delta + \delta t_{rel} + b_{sta} - b_{sat} - Amb$$

where Amb is the estimated ambiguity (pass-dependent bias).

The corrections included in the term $\Delta = D_{Tropo} + c \cdot \Delta t_r$ are:

- D_{Tropo} - tropospheric delay, either computed in pre-processing or to be estimated in ODTS.

- Δt_r - relativistic correction to the travel time.

Note that δt_{rel} and Δt_r are different terms: the first one is a correction to the satellite clock, and Δt_r is the correction to the travel time.

Station and satellite position computation

For the process described above, we should be able to get the satellite and station position at any time. In the case of the satellite, we just use the orbit obtained by the orbit integrator at fixed steps, and interpolate at required time using Lagrange of order 8.

The station positions passed to ODTS are in ECEF coordinates. These are not the geodetic marker coordinates, but the antenna phase centre. In order to get the station position in the inertial frame, the Earth Rotation Matrix is also interpolated by Lagrange at required time: [*ERM(t)*]. The station position in IRF (Inertial Reference Frame) results from applying the Earth Rotation Matrix to the estimated station position in ECEF:

$$\vec{x}_{STA\_IRF} = [ERM(t)]\vec{x}_{STA\_ECEF}$$

The station position is subject to periodic variations due to solid tides, ocean loading and atmospheric loading. ODTS only retains the first contribution, the instantaneous deformation of the solid Earth under the tidal potential of the Sun and the Moon. The vector displacement of the station due to degree 2 Solid Earth Tides expressed in the inertial reference frame is given by:

$$\Delta\vec{x}_j = \sum_{k=1}^{2} \frac{GM_k a_e^4}{GM_\oplus \left\|\vec{x}_{P,k}\right\|^3} \left\{ h_2 \vec{x}_j \left(\frac{3}{2} \left(\vec{x}_{P,k} \cdot \vec{x}_j \right)^2 - \frac{1}{2} \right) + 3 l_2 \left(\vec{x}_{P,k} \cdot \vec{x}_j \right) \left[\vec{x}_{P,k} - \left(\vec{x}_{P,k} \cdot \vec{x}_j \right) \vec{x}_j \right] \right\}$$

where:

GM_1	Gravitational constant of the Sun
GM_2	Gravitational constant of the Moon
R_e	Equatorial radius of the Earth
$\vec{x}_{P,1} = \vec{x}_{Sun}$	Inertial position of the Sun
$\vec{x}_{P,2} = \vec{x}_{Moon}$	Inertial position of the Moon
h_2	Degree 2 Love number (= 0.6026)
l_2	Degree 2 Shida number (= 0.0831)

This formula comes from the IERS 1996 conventions, and corresponds to the elastic Earth approximation.

Clock biases

A satellite or station clock is supposed to be a realization of its local time, but in fact it has a bias with respect to the true time *t (*which a perfect clock would provide) :

$$\tau = t + b$$

where τ is the time lecture of the clock and b is the clock bias.

The clock bias is estimated by the least-square process for each observation epoch. The relativistic effect on the satellite clocks has been also considered, whose most important part is the eccentricity correction:

$$\delta t_{rel} = + \frac{2\vec{r} \cdot \vec{v}}{c^2}$$

Corrections to travel time

In the previous description of the measurement reconstruction, the term Δ consists of the several corrections to the travel time, namely:

<u>Tropospheric delay</u>:

The tropospheric delay can be either computed by the pre-processing algorithm or estimated in ODTS.

In the first case, the delay is just taken from the observations input structure.

In the second case, the tropospheric zenith delay is the parameter to be estimated during the ODTS process. The tropospheric delay for a given elevation angle is obtained from the zenith delay by a mapping function, chosen by configuration between the Saastamoinen model and an external model.

The Saastamoinen model has the following mapping function:

$$D = \frac{D_Z - 0.002277 * B * (\cot E)^2}{\sin E}$$

where E is the elevation angle and D_Z is the zenith delay. The correction term B depends on the station altitude, and can be interpolated from a table.

<u>Relativistic correction:</u>

This is the correction due to general relativity theory, whose most important effect is the Shapiro delay.

Note that the ionospheric delay is not computed, since the ODTS input observable is iono-free.

Residuals computation

The residuals are the difference between the expected measurements $\rho_{\exp}$ and the actual measurements ρ obtained at the receivers. If there were no measurement noise, and if our orbits, clocks and corrections were the exact ones, the residuals should be zero. If our estimation of orbits, clocks and our corrections are accurate, the residuals contain essentially the measurement noise. The residuals computation is simply, for any measurement type:

$$res = \rho - \rho_{\exp}$$

$$res = \varphi + ambiguity - \varphi_{\exp}$$

V. TIME AND FREQUENCY TRANSFER EVALUATION SCENARIO

A preliminary evaluation of the time transfer capabilities of *magicGNSS* has been carried out selecting a network of 8 GNSS stations belonging to Time and Frequency laboratories, as indicated in Table III. Note that 7 stations are located in Europe and one in the USA, thus we are facing not a global network with worldwide coverage but a so-called *regional* network.

Hourly RINEX files generated by the participating stations and uploaded into a dedicated *magicGNSS* account, have been processed by means of the ODTS algorithm, with respect to the clock of the PTB station chosen as reference.

A comparison with the estimates generated by the *magicGNSS* PPP algorithms, using the IGS *rapid* products, has been performed in terms phase offsets and Allan deviation.

For the present work, the following period has been considered:

- 2012 April 19th (MJD 56036 , DOY 110) - 2012 April 22th (MJD 56039 , DOY 113) included

TABLE III. LABORATORIES CONSIDERED IN THE WORK

Lab.	*Country*	*Station*	*Receiver type*	*Reference*
ORB	Belgium	BRUS	Ashtech Z-XII3T	UTC(ORB)
INRiM	Italy	IENG	Ashtech Z-XII3T	UTC(IT)
PTB	Germany	PTBB	Ashtech Z-XII3T	UTC(PTB)
ROA	Spain	ROAP	Septentrio PolaRx2	UTC(ROA)
SP	Sweden	SP01	Javad	UTC(SP)
SP	Sweden	SP02	Javad	UTC(SP)
SP	Sweden	SPT0	Javad	Maser
USNO	U.S.A	USN3	Ashtech Z-XII3T	UTC(USNO)

VI. RESULTS

The figures presented in this section are results of the *magicGNSS* ODTS clock solution and the *magicGNSS* PPP computation (using IGS *rapid* products). Figure 1. shows the phase offset estimates issued from the ODTS algorithm using the UTC(PTB) time scale as reference, while Figure 2. shows the overlapped Allan deviation obtained from the ODTS clock estimates.

Figure 3. and Figure 4. show respectively the same entities (i.e., the phase offset clocks estimates and the overlapped Allan deviation), but obtained with *magicGNSS* PPP algorithm instead of ODTS. Please note that the PPP algorithm uses the IGS time scale as reference, consequently, in order to compare the ODTS and PPP algorithms, the UTC(PTB) solution from PPP has been subtracted from all other clocks from PPP.

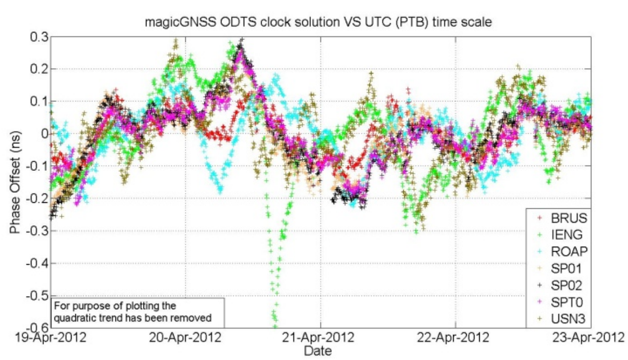

Figure 1. Baseline clock estimates as obtained with *magicGNSS* ODTS algoritm using UTC(PTB) time scale as reference

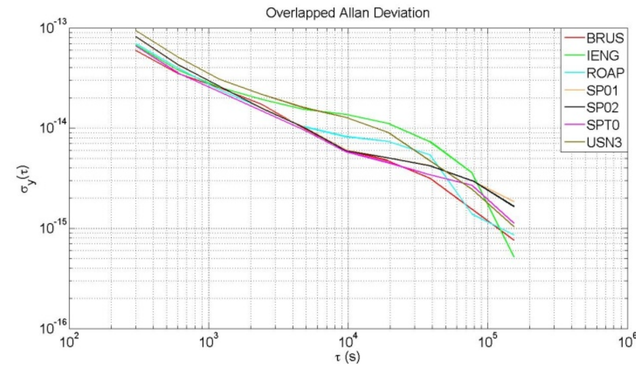

Figure 2. Overlapped Allan deviation of the clock estimates as obtained with *magicGNSS* ODTS

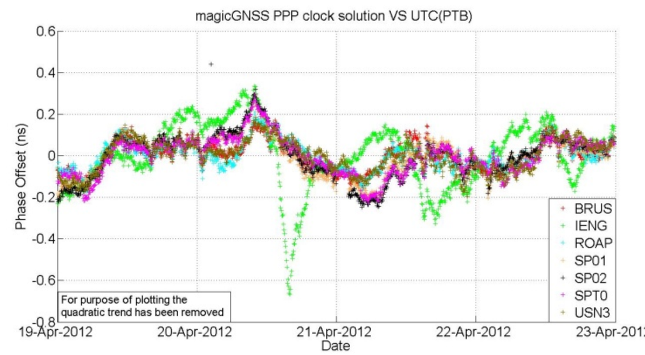

Figure 3. Baseline clock estimates as obtained with *magicGNSS* PPP algorithm using UTC(PTB) time scale as reference

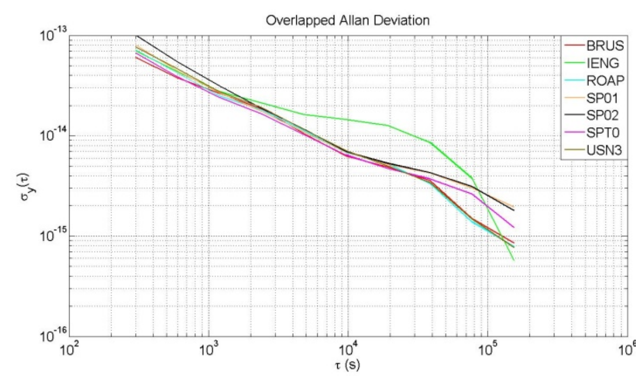

Figure 4. Overlapped Allan deviation of the clock estimates as obtained with *magicGNSS* PPP algorithm

The trend comparison between Figure 1. and Figure 3. (for this purpose the quadratic trend has been removed) and between Figure 2. and Figure 4. show a good overall agreement among the estimates generated by the ODTS and PPP algorithms. In both cases, the phase offset analysis show the same behavior: the variations are comprised between -0.4 ns and -0.7 ns, and the main variations are visible on the two plots.

Only the Allan deviation comparison shows a visible difference between the PPP and ODTS algorithms, notably, comparing the USN3 and ROAP results. For USN3 the difference is probably due to the fact that this station is the only station which is not on the European continent. However, except USN3 and ROA for which a slight difference is depictable, the global behavior of the other stations is approximately the same irrespective of the algorithm used.

In order to evaluate the difference between the two algorithms, the estimates obtained from the ODTS algoritm has been subtracted from the estimates obtained from the PPP computation. The result is shown in Figure 5.

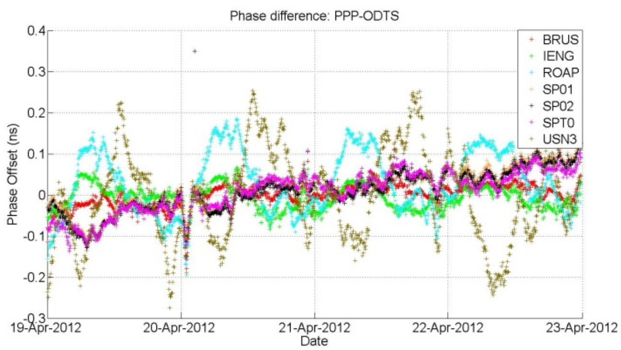

Figure 5. Clock estimates difference between the *magicGNSS* PPP algorithm and the *magicGNSS* ODTS alogorithm

Figure 5. shows that the variations between the two algorithms are always comprised between -0.3 ns and 0.3 ns, moreover this interval can be dived by 2 excluding ROAP and USN3 stations which show higher daily variations. We note, also on Figure 5. a very low drift, however this one does not perturb significantly the ODTS estimates.

To conclude about these results, even in case of a limited network of 8 stations, the ODTS technique offers clock comparisons with precision which is comparable to the state of the art techniques, such as PPP using IGS products.

However with respect to ODTS, for PPP two disadvantages can be pointed out, namely the dependency on external products (IGS) and latency of those products. In principle, RINEX data from all time and frequency laboratories can be uploaded in real time and a global clock synchronization with ODTS achieved in near real time. Latency can be improved using 15 min RINEX files; fast execution time (1 min). Also take note that any clock noise is added due to the sat clock interpolation (30-sec rate is possible).

The ODTS algorithm presents very good results and aspects to use this one to monitoring time scales with a high precision and reactivity.

VII. Operational Aspects

Within the *magicGNSS* account, a Scheduler is available to automate ODTS or PPP processes. The user can choose how often the executions shall be done (from every day to every hour), and how many minutes after the integer hour the execution is to be started. This last feature has been envisaged in order to accommodate for late arrival of RINEX files.

In the experiment described in this paper, each of the timing laboratories upload their hourly RINEX files to the *magicGNSS* server using a shared *magicGNSS* account. This is done via ftp protected by username and password. The laboratories take care of the ftp upload automation, and ultimately it is their responsibility the smooth and continue RINEX file upload. Then, on the server side, the ODTS is executed every hour 20 minutes after the hour (this gives plenty of time for RINEX upload). The ODTS execution time for 8 station and 2 days of data is only around 1 minute, therefore clock results for the last hour are available around 21 minutes past the hour.

A dedicated *magicGNSS Timing* web page allows the visualization of estimated clocks in near-real time. This web page presents the clock results from ODTS executions coming from the Scheduler, as described above. The *Timing* web page focuses on station clock results exclusively, thus all the ODTS complexity is hidden and other estimated parameters (orbits, troposphere, etc.) are ignored (however the standard full PDF report from ODTS is also available in case troubleshooting is necessary). The *Timing* web page is shown in Figure 6.

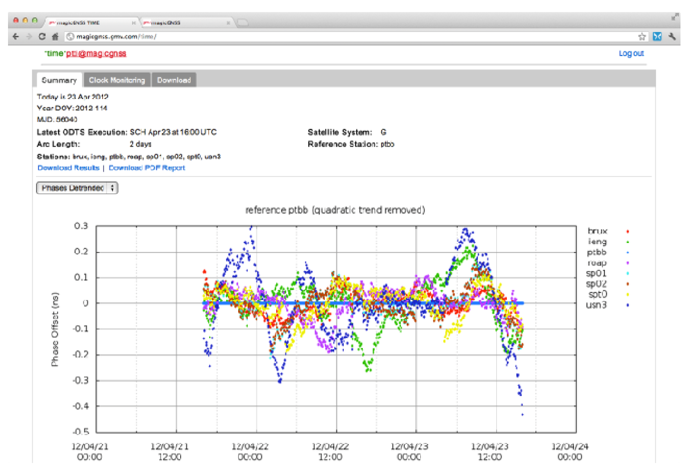

Figure 6. The *magicGNSS Timing* web page

The *Timing* page contains three areas: “Summary”, “Clock Monitoring”, and “Download”. The “Summary” area contains the clock results of the latest ODTS execution, with plots for phase offset, frequency, and Allan deviation. Individual clocks or all clocks together can be visualized. The Summary page refreshes every few minutes so that the page shows at any time the latest results. This is useful for example to display this page continuously on a computer display at the lab.

The “Clock Monitoring” area is similar to the “Summary” area but instead of the latest results it allows dynamically plotting multiple days of the past clocks evolution, also in terms of phase offset, frequency, and Allan deviation, for one or several clocks. It is also possible to change the Reference Clock dynamically without the need of re-executing ODTS.

Finally, the "Download" area allows downloading via ftp all the clock estimates generated by ODTS over the days, in CLK RINEX format (daily files). These daily files are actually feeding the dynamic plots generated under "Clock Monitoring".

The *Timing* web page has been optimized for visualization on smartphone screens, and all the functionality is available on the go. An example is shown in Figure 7. The phone app allows the lab operator to monitor the clocks also when out of the office or home, and in such a way quickly react to possible anomalies.

Figure 7. The *Timing* web page on a smarthphone screen

VIII. CONCLUSION

The presented work represents an investigation about the time/frequency transfer capabilities of the ODTS algorithm included in *magicGNSS*. Results show promising performances. More investigations are in progress taking into account different periods and different types of network, looking also at the robustness and reliability of the algorithm.

IX. AKNOWLEDGMENTS

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