Results of GIOVE Data Processing to Allow Evaluation of Principal System Performance Drivers

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BIOGRAPHY

Michael Kirchner is Engineer for Navigation Systems at EADS Astrium Satellites. He studied Geodesy at the Dresden Technical University, Germany and Chalmers Technical University, Gothenburg, Sweden. After graduation in 2002 he was responsible for a near real time tropospheric sounding project and quality assessment of GNSS data at the University FAF Munich. He joined EADS Astrium in 2005 and is mainly working in system performance and processing algorithms related activities for Galileo.

Roland Schmidt studied geodesy at the Technical University of Munich, Germany. After graduation in 1998 he joined the Department 1 Geodesy and Remote Sensing of the GeoForschungsZentrum Potsdam (GFZ). He was mainly working on the recovery of the static and time-variable gravity field of the Earth from GRACE mission data and became one of the originators of the GFZ-owned EIGEN gravity model series. In 2007 he received a PhD in geodesy from the University of Bonn, Germany. Since 2008 he is with EADS Astrium and is working as a system engineer for navigation in system performance and processing algorithms related activities for Galileo.

Johann Vilzmann graduated at the Technical University of Munich in Electrical Engineering. He joined EADS Military Aircraft (former Daimler-Benz Aerospace) in 1997. He was working in System Engineering and Software Engineering (including safety critical software) in the Eurofighter project. In 2004 he joined EADS Astrium and contributed to the Phase C0 of the Galileo Ground Mission Segment. Within the BayPAF and GPMAF projects he was responsible for the coordination of the technical activities.

ABSTRACT

The two GIOVE test satellites of the European Satellite navigation system Galileo are used to characterize technologies and processes crucial for the system. The continuous tracking data have been evaluated over a longer period in time to characterize different performance figures. The paper gives an insight in the work performed to process Galileo data and shows results characterizing the performance in terms of satellite orbits and clock corrections including a critical discussion of the quality of those results. Since the availability of independent results which could be used for reference is very limited other methods of quality evaluation are applied such as evaluation of overlapping data periods, usage of laser ranging measurement as independent source of measurement and clock stability giving an impression in the predictability of the clock.

INTRODUCTION

The European Global Satellite Navigation System Galileo is on its way being realized. At present, the two GIOVE test satellites of the Test Bed version 2 have an accumulated life time of more than four years. Together with the experimental ground segment set up by ESA the Test Bed is in many aspects representative for the final Galileo System.

Galileo is going to provide state-of-the-art navigation services. In order to mitigate potential risks for the construction of the entire system critical technologies are already under evaluation and so is the overall performance which can be obtained by the Test Bed. The globally collected navigation signals are processed to obtain basic products allowing to assess the major system performance drivers.

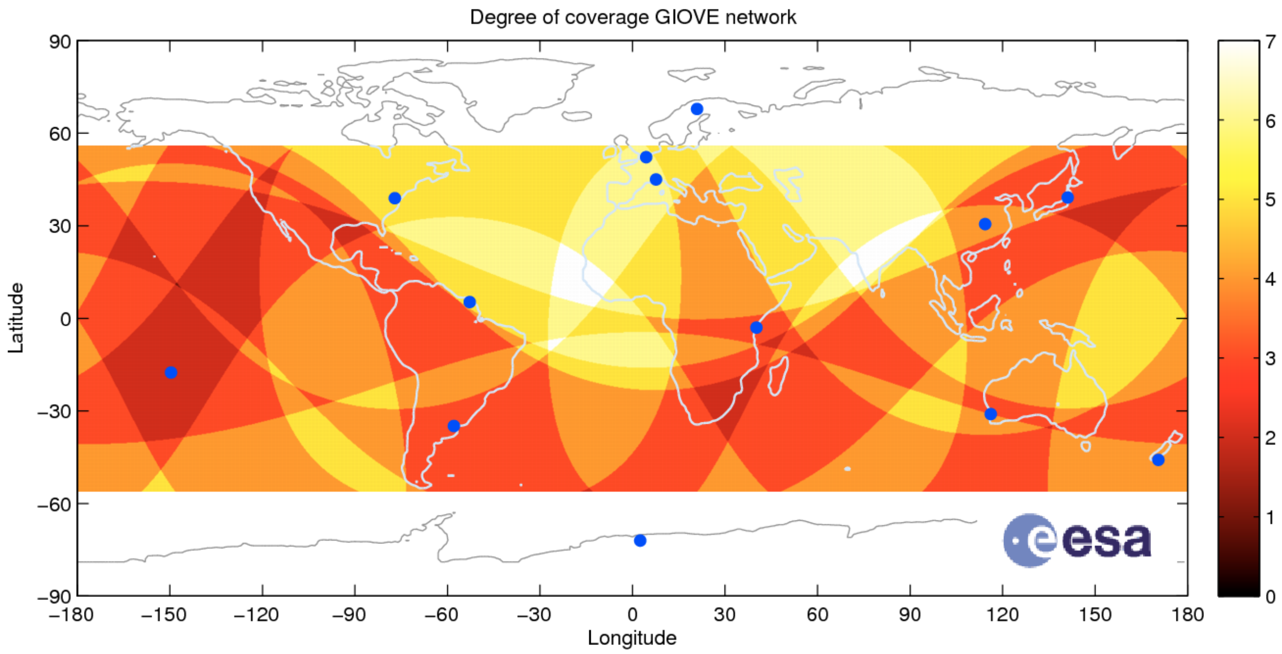

Figure 1: ESA GIOVE Mission ground tracking network and degree of coverage.

GIOVE MISSION EXPERIMENTATION

The Galileo System Test Bed V2 with its two test satellites GIOVE-A and GIOVE-B is an essential preparatory step for the Galileo In-Orbit Validation (IOV) phase. Related activities are concentrated in the frame of GIOVE Mission, an initiative of the European Space Agency covering spacecrafts, Ground Control Centres, GIOVE Processing Centre and the ground tracking network of global coverage.

According to [3] the mission of the two satellites is not only to secure the frequencies allocated by the International Telecommunication Unit for the European radio navigation plans in time but also to test and verify most critical technologies. This includes the navigation signal generator as well as space atomic clocks. In particular the passive hydrogen maser on GIOVE-B is the first maser ever flown in space and its characterization is crucial for the program.

During GIOVE Mission experimentations (conducted by ESA) the satellites broadcast signals that are characteristic for the future Galileo system allowing to demonstrate their novel features. Beside a verification of their high level of resistance against interference and multipath under real conditions also the development and test of user receivers is supported before the final Galileo satellites are available. An important field of study is to confirm that no inter-system interferences with GPS exist for the signals.

GIOVE-A built by SSTL was the first satellite launched on 28 December 2005 which was important for securing the frequency allocations. With this target being achieved the launch of GIOVE-B built by Astrium Germany was postponed to 26 April 2008 in order to allow for a modification of the signal generator to implement the final Galileo signals which have been finally agreed only a few months before that date.

An important part of the experimentation is the GIOVE ground mission segment containing the GIOVE Processing Centre and the Galileo Experimental Sensor Stations for tracking the data. The network of sensor stations contains 13 sites with quite a homogeneous global distribution (see blue dots on Figure 1).

Figure 1 shows additionally the colour coded Degree of Coverage (DOC) of the tracking network. It represents the number of ground stations the satellite is in view of when it is on a certain location over the Earth. A masking angle of 10° was applied for the determination of DOC. The degree of coverage helps to get an impression about the degree of freedom within the data processing and parameter estimation. For the satellite clock offset estimation an observation of the satellite is necessary which ensures a continuous tracking by the network, i.e. DOC-1. For dynamic orbit recovery, i.e. estimating the Keplerian elements using an underlying force model, limited observation periods and DOC are in principle feasible. However, such minimum configuration does not provide any redundancy. Therefore longer observation periods with DOC values above this minimum add additional degrees of freedom to the processing enabling least squares parameter adjustments and outlier detection. Despite the present GIOVE network DOC is above the minimum it is still very limited. Especially for periods of single or dual station failure or data unavailability the DOC drops down and no reliable parameter estimation particularly for the clock offset might be possible.

STUDY CONTEXT

The formal performance characterization of the GIOVE satellites and ground infrastructure is conducted by ESA in the frame of GIOVE Mission experimentation. They cover orbit determination, time synchronization and stability evaluation, ionosphere parameter adjustment, inter-system bias estimation, sensor station and network characterization. In total they represent a large set of principal system performance drivers for which the GIOVE Mission architecture is already representative for the Galileo system. The results are used for Galileo System development to iteratively refine the performance predictions for the Galileo system in order to come closer to the real system performance. With GIOVE test satellites and its experimental ground infrastructure early performance figures and assumptions can be justified based on reliable information. This helps in harmonizing the end-to-end consistency between the early experimentation results and the system design and development status.

Performance evaluations in the frame of GIOVE Mission experimentations are based on experimental algorithms of the Galileo Ground Mission Segment. Apart from some modifications these are the algorithms also to be used for the Galileo system later on and can thus be assumed to be quite representative.

The activities performed by Astrium for GIOVE performance characterization are not linked to GIOVE Mission experimentations. Instead they are based on an independent processing infrastructure developed in the frame of BayNavTech (cf. [1] and [2]). Despite of applying state-of-the-art processing algorithms and widely accepted conventions the detailed processing strategies are different. As results are derived independently to the results derived in the frame of GIOVE Mission experimentations while the input data are identical the high stability and close agreement between the results of the two sources provide an additional verification for the most critical parameters.

Among the system performance parameters mentioned above orbit determination and prediction accuracy and the clock stability are important ones as they directly drive the end user performance to a large extent. They shall be focused in the paper and their accuracy is compared to the results of the GIOVE Mission experimentations. The interested reader can find results of the latter published in the papers [7] and [8].

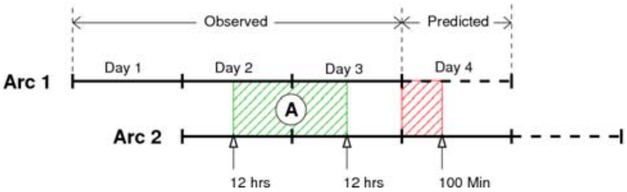

Figure 2: Arc Definition and Orbital Overlap

PROCESSING APPROACH

For the estimation of GIOVE orbit and clock parameters an orbit determination and time synchronization process (ODTS, cf. [2] and [6]) is used. It is based on the dynamic approach, exploiting Galileo and GPS measurements collected by the network of 13 Galileo Experimental Sensor Stations (GESS).

Within this study 3-day ODTS results are generated i.e. we estimate GIOVE orbits respectively satellite and GESS phase clock offsets over a three days period. As illustrated in Figure 2 the start of each arc is shifted by one calendar day, to give sufficient overlap for internal assessment of the ODTS results. The observation data consists of the two-frequency data in the L1-L2 (GPS) respectively L1-E5 and L1-E6 bands (Galileo) to form ionosphere-free linear combination measurements. In order to save computation time the data sampling is reduced from the original rate of 1 Hz to 5 min spacing. The data reduction is performed via a simple data extraction. No data filtering is applied.

The orbit parameters consist of classical Keplerian elements at the initial epoch of the 3-day arc, i.e. for each satellite semi-major axis, orbit inclination, eccentricity, ascending node, perigee and argument of latitude are estimated with respect to the selected force model. This one covers contributions from the Earth's static gravity field (central term plus spatial variations up to wavelengths of about 2000 km) over time-variable gravity forces (tides of the Solid Earth and oceans, third body accelerations from Sun, Moon and solar planets) to the impact from the solar radiation pressure. For the latter parameters consisting of constant and orbit-periodic terms in direction of the direct pressure, in direction of the solar panel and the complementing orthogonal component are estimated per arc.

For the clocks the main output are epoch-wise estimates of the phase clock offsets of the GIOVE satellites and the GESS ground stations. On the level of the observations the major parameters are ambiguities of the Galileo and GPS phase measurements.

Important input parameters, such as systematic contributions from, e.g., inter-frequency biases (also known as differential code biases), precise GESS coordinates or phase centre-offsets of the satellites' L-band antenna are taken from available manufacturers' values respectively are determined in appropriate pre-processing steps. Other features like the GESS motion due to plate tectonics or the attitude of sender satellites is considered directly in the ODTS by appropriate models.

In the current configuration with only two spacecraft disseminating Galileo signals it is not possible to synchronize the GESS and GIOVE clocks over the entire constellation at all times by using only Galileo data. To remove the singularity the ODTS process is therefore split in two consecutive steps. In the first step the phase clock offsets of the GESS are derived from the collocated GPS measurements introducing the so-called final IGS products for the GPS constellation (i.e. GPS sender satellites' orbits and clocks) as known reference. In the following, proper ODTS step the pre-determined GESS clock offsets are kept fixed, thus yielding GIOVE satellite orbits and clocks offsets which are aligned to the IGS reference.

It is clear that after the full implementation of the Galileo system such procedure to remove the present singularity in the time synchronization will become less critical as a sufficient number of satellites aligned to Galileo system time are available.

Concerning the quality assessment of the obtained ODTS results internal and external quality checks are applied. On the internal level, consistency checks in terms of statistics of residuals of the microwave observational data as well as statistics of the orbit differences of the overlapping processing periods are used. Another internal consistency check is the selection of different dual-frequency signal combinations out of the available signals for processing of common periods. Although several experiments have been conducted no results are presented here since the results are well in agreement with those from the RMS of observational data and overlap statistics.

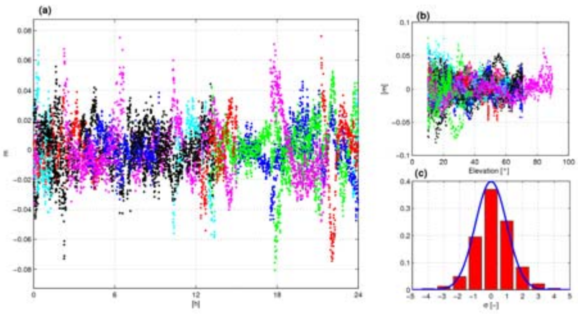

Figure 3: Galileo ionospheric-free (L1-E5) Phase Residuals GIOVE-B, 17-July-2008 (DOY 199)

With respect to an external quality evaluation Satellite Laser Ranging (SLR) data collected by the ground station network of the International Laser Ranging Service (ILRS) is used extensively. Since the SLR data is completely independent from the Galileo system it provides valuable information on the outer accuracy of the ODTS products.

Finally, the evaluation of OTDS results over longer time spans allows for characterizing the service performance for longer time intervals, thus avoiding misinterpretation of particular behaviour or not representative results. Within this study results for GIOVE-A/B covering the period February 2, 2008 to December 31, 2008 for GIOVE-A respectively May 7, 2008 to December 31, 2008 for GIOVE-B are presented.

In the given time series of results gaps occur from time to time. These depend on the availability of the Galileo data from the individual satellites which is in many cases influenced by simple operational issues such as changes in the dissemination patterns, re-configurations of the GESS or spacecraft manoeuvres. In this way, occasionally degraded results are in many cases attributable to known causes and reflect imperfections in the operations of the ODTS (requiring manual interactions at such instances), rather than principle limitations of GIOVE data.

RESULTS GIOVE ORBIT DETERMINATION

On the level of the orbital residuals a typical example is shown for GIOVE-B (day 17-July-2008, Day of Year 199) in Figure 3. The plot (a) depicts the temporal distribution of the residuals of the ionosphere-free linear combination data from the L1-E5 signals for all 13 GESS over a 24 hour period. As can be seen the distribution of the residuals is dominated by white noise characteristics though some systematic patterns are also visible. These correspond to larger residuals at low elevations occurring during signal acquisition and loss of signals at the end of pass. This feature is highlighted when plotting the residuals per elevation as shown in plot (b) of Figure 3. Despite such systematic effect the deviation of the residual distribution from a normal distribution is only small (cf. plot (c) of Figure 3). The overall RMS of the displayed phase residuals is 1.7 cm. Note that the noise level of ionospheric-free observables is typically increased through the linear combination by a factor of three compared to single frequency data. In addition, one should note that in the ODTS process an elevation-dependent weighting is applied to the code and phase observables to counteract the increased disturbance of signals at low elevations. The residuals in Figure 3 are plotted for the un-weighted case.

For GIOVE-A identical results are obtained (not presented) and the overall level of the residual statistics for both satellites is stable over the entire investigated period.

As a second measure for the internal consistency Figure 4 shows the RMS statistics of the differences of the 1-day orbit overlaps as defined in Figure 2 for GIOVE-A. The upper, middle and bottom plot of Figure 4 depict the RMS of the differences for the radial, the along-track and the cross-track component, respectively. As it is typical for MEO satellites the orbit consistency is best for the radial component, followed by the cross-track and the along-track component which shows the largest deviations. Ignoring RMS statistics larger than 1 m one obtains global RMS values of 7 cm for the radial component, 23 cm RMS for the along-track and 16 cm RMS for the cross-track component.

The 1-m criteria has been selected arbitrarily to exclude overlaps considered as outliers. For the time series obtained for GIOVE-A one part of such outliers is clearly attributed to the change in the master clock from FM4 to FM5 around Day of Year 227 (14-08-2008), where the stabilization of FM5 takes several days (see Figure 10). However, after the stabilization period the quality of the orbit increases to the same level as for the period before using the FM4 frequency normal.

Other parts of the outliers can be attributed to the more or less frequent satellite manoeuvres of GIOVE-A (epochs indicated by vertical orange lines). During such periods the poor agreement in the orbit overlaps is due to the reduced amount of data attributed to the intentional interruptions of transmission of Galileo signals and the impact from spacecraft manoeuvre which is presently not modelled in the ODTS.

For the other remaining periods the degradation in the orbital overlap is not fully investigated, but several potential causes can be considered. In some (few) instances these may be due to occasional interruptions in the operations of the ground stations leading to data gaps. Another cause lies in variations of the observation geometry sometimes showing significant variability in the Dilution of Precision (DOP) from arc to arc. It is clear that the impact from such feature will be compensated to a large amount by using the dynamic approach; however, some portions may still remain.

Concerning the potential impact of eclipses on the orbit determination process (cf. gray-shaded areas in Figure 4) no clear correlation with degraded orbit overlaps can be inferred. However, a rigorous assessment of the impact of eclipses on the ODTS is still to be conducted. In that context, potential refinements of the Solar Radiation Pressure (SRP) model could allow for additional improvements, though no dramatic gain is expected for the orbit quality. In any case it should be noted that even the present quality of the orbit would already meet user

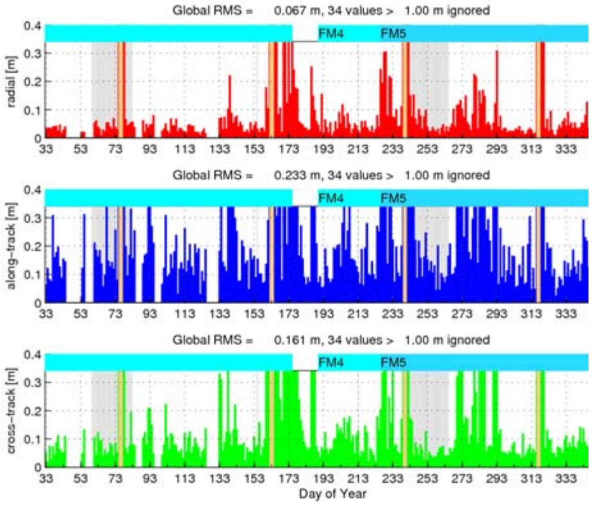

Figure 4: Orbital Overlaps GIOVE-A (1 day)

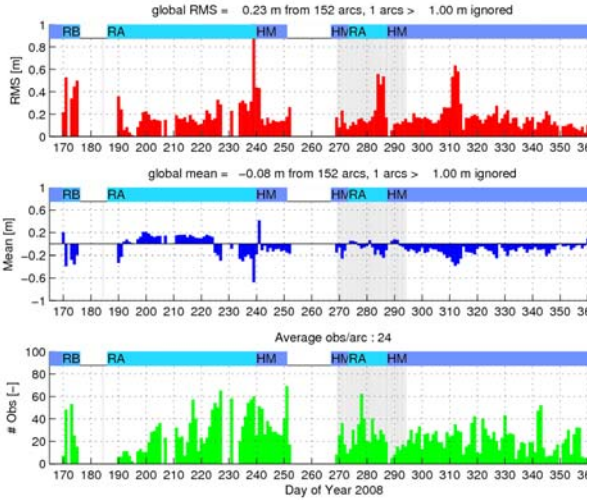

Figure 5: RMS SLR Residuals GIOVE-B

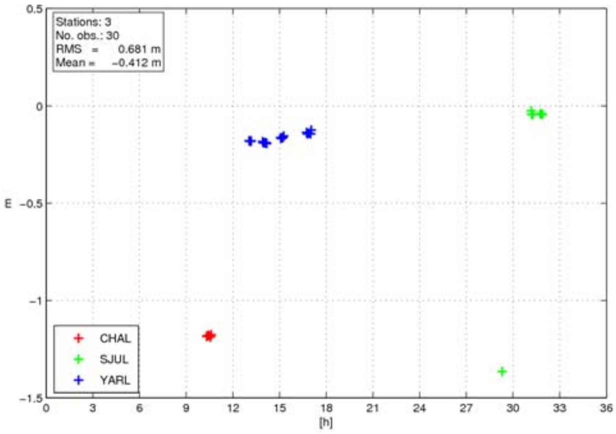

Figure 6: Time Series of SLR Residuals GIOVE-B for Day 312 of Year 2008 (November 7, 2008)

requirements. Projecting the orbit errors onto the Worst-User-Location (WUL) the RMS orbit errors at WUL amount to 7 – 10 cm RMS which is well acceptable.

For GIOVE-B highly identical results are obtained, which show the equivalent features (plots not presented for reason of space). The global statistics for the RMS of the orbital overlap differences are a bit larger: radial 8 cm, along-track 26 cm, cross-track 18 cm. However, these deviations are insignificant, but may be related to shorter time periods of constant configuration covered by GIOVE-B so far. The statistics may converge to the level for GIOVE-A as the time series further continues.

For the assessment of the outer orbit quality RMS values of residuals of SLR data are used. Such values are derived in a post-processing from the differences of the actual SLR ranging data minus the theoretical range resulting from the GIOVE orbit which was determined from the Galileo data in the previous ODTS process. In this way there is no contribution of the SLR data to the GIOVE orbit, and the assessment remains independent indeed. Systematic offsets on the actual SLR data such as signal delays by the propagation of the laser passes through the troposphere as well as the satellite attitude and the phase centre offset of the laser retro reflector array are taken into account via state-of-the-art models respectively values from the manufacturer.

The top panel of Figure 5 shows the time series of arc-wise RMS values of SLR residuals for GIOVE-B. The time series exhibits in general little variation from arc to arc with RMS values in the range of 10 – 20 cm. The global RMS value (over all arcs) amounts to 23 cm. It should be noted that SLR residuals do not reflect only differences in the radial direction, but also in along-track and cross-track direction, since the tracking occurs at all elevation angles. Passes at zenith crossing are rather the exception than the rule. In this way the SLR RMS values can be interpreted as RMS of differences in 3-d position. This implies altogether 20 cm accuracy for the GIOVE orbits, which was already indicated with the RMS of 3-d differences obtained from the orbital overlaps.

The few larger RMS values, e.g., around Day of Year 285 or Day of Year 312 are associated to outliers in the SLR data from particular SLR stations at a few instances. Inspection of the individual time series of the residuals per station indicates biases and outliers in the range measurements within individual passes. Figure 6 illustrates the situation for the SLR residuals with respect to the 3-day arc starting on DOY 312 (November 7, 2008). While for the SLR station Yarragadee (YARL, Australia) and for parts of data of station San Juan (SJUL, Argentina) the distribution of the residuals (except for a small negative bias) looks nominal, the passage from Changchun (CHAL, China) seems to have a larger bias of about 1.2 m. In addition the first part of the pass from SJUL is also off by about 1.4 m. Inspection of the elevation distribution of the individual passes does not indicate effects associated with low elevations. Such behaviour remains presently unclear. However, taking into account that such phenomenon is only observed at a few occasions, and the fact that the deviations are then observed only for individual passes during the arc, this gives confidence in the SLR results for orbit quality verification.

Performing the same analysis for GIOVE-A one obtains consistent results. The global RMS over all investigated arcs (altogether 258) amounts to 21 cm. Again, the slightly better value (compared to GIOVE-B) may be attributed to the larger sample over a longer period for GIOVE-A, and can be considered insignificant at this instance in time.

Finally, comparisons to results of external studies, e.g. [7], verify the findings in this study. Altogether it can be stated that the orbit accuracy for the GIOVE satellites is at the 20 cm level, which corresponds to an error contribution of 10 cm RMS at WUL. The latter is a quite remarkable result in view of the rather limited ground station network.

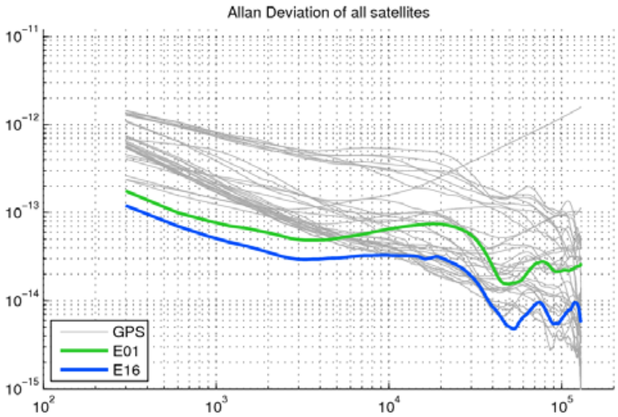

Figure 7: Allan deviation of satellite clocks for sampling times of 300s up to ~30h (E01-GIOVE-A, E16-GIOVE-B).

RESULTS OF GIOVE TIME SYNCHRONIZATION

The satellite clock error is the difference of the individual time scale generated by the satellite and the Galileo system time scale. Beside the satellite orbit the satellite clock error and its stability over time has an essential impact on the end user navigation performance. It is therefore of interest not only to determine this parameter with a high accuracy but also to assess the stability over time which is directly linked to its predictability.

For the time synchronization a proper reference need to be defined. As described above the IGS time scale was used for reference [4]. As it is a weighted average of ~65 clocks being re-aligned to GPS time neither a single clock can degrade the reference significantly nor we have to cope with artificial jumps introduced by the way the data are processed. Within a post-processing the reference can easily be transformed to e.g. GIEN or GUSN which are connected to an active H-maser by just subtracting the resulting time-scales on an epoch basis.

It shall be noted that the end user performance mainly relies on the quality of satellite clock error prediction and not necessarily on the outer accuracy of the estimation. Systematic errors in the clock estimation do not degrade the end user performance as long as they are consistent. As there are a wide variety of clock prediction strategies which add a considerable level of uncertainty to the data performance assessment is - instead of applying any prediction - limited to the underlying data. Their general predictability can well be evaluated by the characterization in terms of clock stability.

The clock stability results are assessed in terms of Allan deviation over different intervals. Figure 7 presents the Allan deviation of GIOVE clocks. The excellent short and medium term stability is clearly visible. For the long term there is a decrease of stability for only certain sampling intervals which is not a typical behaviour of atomic frequency standards. The maximum coincides with half the orbit period and the minimum with the orbit period.

This behaviour is assumed to be introduced by the limited decoupling of the clock estimations and the estimated parameters for the solar radiation pressure model. As the model for the solar radiation pressure is purely empirical with harmonic parameters estimated per revolution cycle a certain correlation introduced by this strategy of orbit modelling can hardly be avoided. As in contrast to the GIOVE satellites not all of the GPS satellites show such behaviour a different reason is not unlikely: variations in the payload phase delays caused by e.g. temperature variations. They would be independent of the applied processing strategy. As the reason is not fully identified and the effect is also present for GPS further studies are ongoing to improve the de-

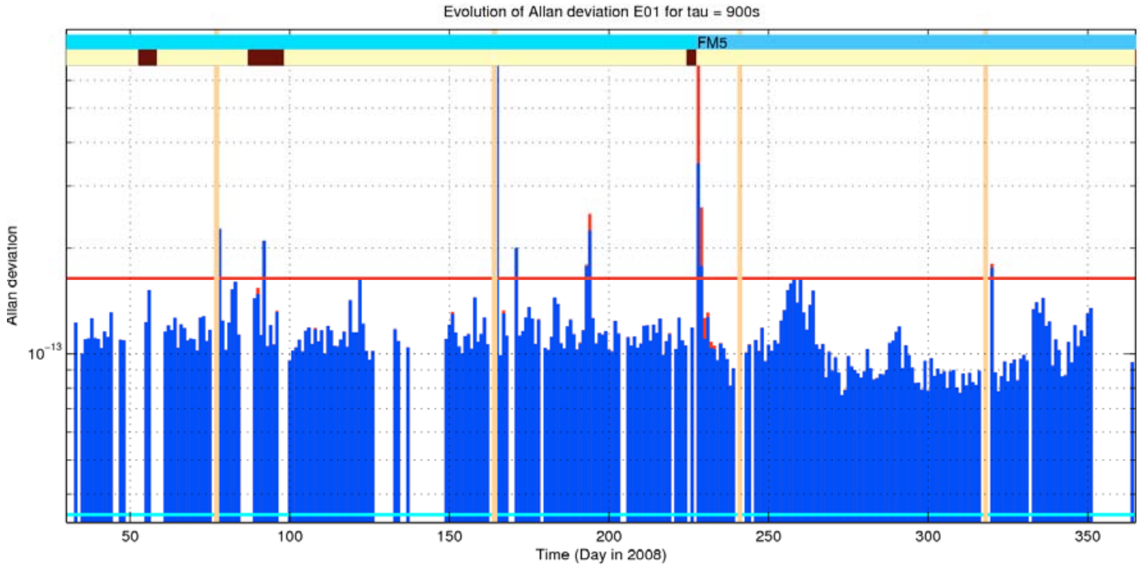

Figure 8: Evolution of Allan Deviation GIOVE-A

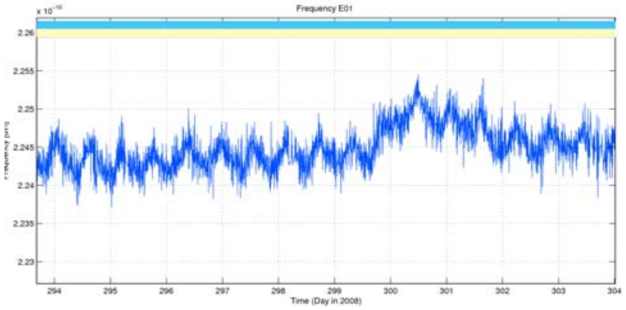

Figure 9: Clock Frequency of GIOVE-A showing the oscillation with orbital frequency.

correlation of clock and solar pressure parameters.

Figure 9 shows a close look to the clock frequency for a sample period. The oscillation with orbital period is clearly visible. Even though the origin is not completely identified the frequency stays constant. As it is well known and constant it can be taken into account for the clock prediction algorithm and it can be easily handled. A corresponding effect has been identified in the frame of GIOVE Mission experimentation (cf. [8]) where it is also not considered very critical. In contrast to the oscillation Figure 9 shows a slight irregular behaviour at day 300. Those changes of clock frequency need more consideration as they are not predictable (see below).

The navigation data for Galileo will be updated at least every 100 minutes. Therefore the stability characterization up to 6000 seconds is of most interest. The comparison to the space clocks of GPS in Figure 7 shows a clear better performance for respective periods while it is worse for some longer periods. The results presented are very similar to the results presented in [8] which confirm the adequacy of both approaches.

To get an impression about the evolution of the stability over time Allan deviation is computed from independent consecutive batches of data over a long time span. Figure 8 shows the result of GIOVE-A RAFS for 900 seconds sampling time with (blue bar) and without (red bar) frequency drift removed. The colour bar at the top indicate the active clock and the type of signal broadcast while orange lines indicate epochs of orbit manoeuvres. The red line indicates the performance threshold defined by the requirements. With very few exceptions typically around signal and clock switches or orbit manoeuvres requirements are clearly met.

Figure 10 shows the clock frequency over time. Here the limitations for the clock estimations around orbit manoeuvre periods are evident. It also shows the direct behaviour of the clock. This is a certain stabilization period of FM5 clock after the switch up to day 260 and certain larger frequency changes of FM4 clock. While the latter are not unusual for RAFS they can cause stronger deviations of the predictions from the actual behaviour causing an increase in the user range error and thus need to be assessed in detail for system performance impacts.

CONCLUSION

The paper presented that processing of GIOVE tracking data is implemented and parameters essential for providing navigation services can be derived via post-processing on a regular basis. As external references are not available other means to determine the accuracy of results are introduced which are overlap statistics and laser raging measurements. From these data it can be concluded that orbit determination shows a repeatability at the

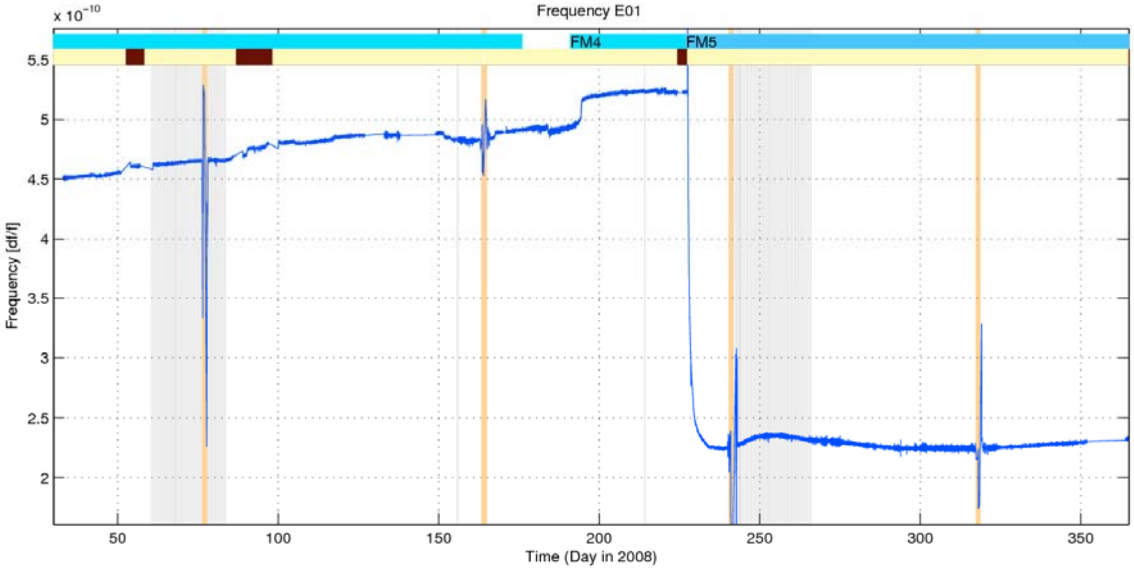

Figure 10: Clock Frequency of GIOVE-A showing clearly the effect of clock switch at day 227 and the stabilization period.

level of 20cm.

The focus for clock performance is the stability over time as this drives the prediction accuracy. The results show a clock stability which is compliant with the requirements for short to medium time spans. The stability of medium to longer time spans are significantly degraded which is assumed to be an effect of improper de-coupling of parameters estimated for clock and solar radiation pressure. Here is room for further improvement and future tests on the parameterization for the radiation pressure shall evaluate and limit the sensitivity of clock estimation.

The results for orbit and clock are very consistent with he results obtained in the frame of GIOVE Mission experimentation. Considering the sparseness of the current experimental tracking network the consistency of the results is very remarkable and further improvements are expected by a densification of the network. From the accuracy of these results valuable conclusions can be drawn for the parameters driving the performance of the future Galileo system and the system performance simulations can be refined accordingly. The results presented here could thus be considered in addition to the results of GIOVE Mission experimentation for corresponding refinements. This is of major importance at this stage of the project as it allows e.g. for replacing previous conservative assumptions by real GIOVE-based figures and by this to further improve the understanding of the performance margins in the Galileo system.

ACKNOWLEDGEMENTS

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REFERENCES

[1] BayNavTech Satellite Navigation Centre Munich Project Homepage: http://www.baynavtech.com/

[2] Vilzmann, J., Kirchner, M., Schäfer, C. (2007): BayNavTech - Performance Assessment Facility for GNSS. Proceedings of ION GNSS 2007, 25-28 September 2007, Fort Worth, Texas, USA.

[3] ESA GIOVE homepage http://www.giove.esa.int/

[4] IGS Clock Products Working Group, https://goby.nrl.navy.mil/IGStime/

[5] International GNSS Service, igscb.jpl.nasa.gov

[6] Kirchner, M., Vilzmann, J. (2008): Assessment of Galileo Data with BayNavTech Performance Assessment Facility. Proceedings of ION GNSS 2008, 16-19 September 2008, Savannah, Georgia, USA.

[7] Mozo García, A., Píriz, R., Fernández, V., Navarro-Reyes, D., González, F., Hahn, J. (2008): GIOVE Orbit and Clock Determination and Prediction: Experimentation Results. European Navigation Conference 22-25 April 2008 Toulouse.

[8] Waller, P., Gonzalez, F., Hahn, J., Binda, S., Piriz, R., Hidalgo, I., Tobias, G., Sesia, I., Tavella, P., Cerretto, G. (2008): In-Orbit Performance Assessment of GIOVE Clocks. Precise Time and Time Interval Meeting 1-4 December 2008, Reston Virginia.

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