Galileo's timekeeping infrastructure: where do we go with the external time service provider?

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***Abstract*— This paper will summarize the Galileo timekeeping infrastructure. The purpose of such infrastructure is to:**

- **generate a stable time scale (Galileo System Time, GST) to fulfil the needs of the core services (i.e. Open Service, Safety-of-Life Service etc.)**
- **provide UTC parameters for broadcast**
- **determine the GPS to Galileo time offset (GGTO) in order to facilitate the user's interoperability.**

A description of the different time related actors and their corresponding roles within and outside the Galileo core infrastructure was given in [1]. The main elements are the Precise Timing Facility (PTF) being part of the Galileo Ground Mission Segment (GMS), the external Time Service Provider (TSP) and the external GPS system for the provision of GPS to Galileo Time Offset. The core function of the PTF is to generate GST, including a physical realization, GST Master Clock (GST(MC)), for metrological purposes and for providing timing reference signals to all elements within the Galileo system. The main task of the TSP is to provide the GST to UTC mod 1 sec steering corrections, and the offset between GST and UTC as required for the provision of the UTC time dissemination service.

In this paper we will emphasize the evolution of the Time Service Provider prototype Facility (GTSPF) currently under development towards a permanent Time Service Provider facility and entity for the fully operational system.

This opens up many questions in the technical, legal, institutional, and marketing areas:

- **How can the TSP - once in operation - improve its products?**
- **How do we see the cooperation of the National Metrology Institutes in the future and how do they contribute to the success of the Time Service Provider products?**
- **Having the operational Galileo system as one important customer of the TSP (which stipulated its development) are there other potential customers?**
- **Is there an interest for a certified time service?**
- **Is there a requirement to establish an EU legal time and can the TSP contribute to that?**

This paper aims at stimulating discussion among interested parties; it cannot at this stage provide conclusions and solutions.

I. INTRODUCTION

The Galileo TSP prototype facility is being developed for Galileo In Orbit Validation (IOV) by the Fidelity consortium [2], under the supervision of the European GNSS Supervisory Authority (GSA). At Galileo Full Operational Capability (FOC) a permanent TSP will replace Fidelity. The TSP will operate the Galileo Time Service Facility (GTSF) to provide a

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time service to Galileo during its initial 20 year operational lifecycle. It is anticipated that the TSP will put into place binding Service Level Agreements (SLAs) with external entities that it relies on for data, specifically certain UTC(k) laboratories known as "core" laboratories. It is also anticipated that TSP will maintain non-binding relationships with other UTC(k) laboratories ("associate" laboratories).

There are four core UTC(k) laboratories in the Fidelity consortium: INRiM, LNE-SYRTE, NPL and PTB. As part of their Fidelity consortium activities they will provide data to the prototype GTSF for IOV.

II. Mission of the TSP at Galileo Full Operational Capability

The mission of the time service provider at FOC is to supply the required time services to Galileo, principally the steering corrections needed to steer Galileo System Time to UTC mod 1 sec. The GTSF will be fully automated in normal operation (Fig. 1). This facility will automatically receive measured time transfer and clock data from the Galileo PTF's and supporting UTC(k) laboratories on a daily basis. It will automatically combine this information with other data received from the BIPM and compute the steering parameters and associated results. These data will then be sent automatically to the GMS, also on a daily basis.

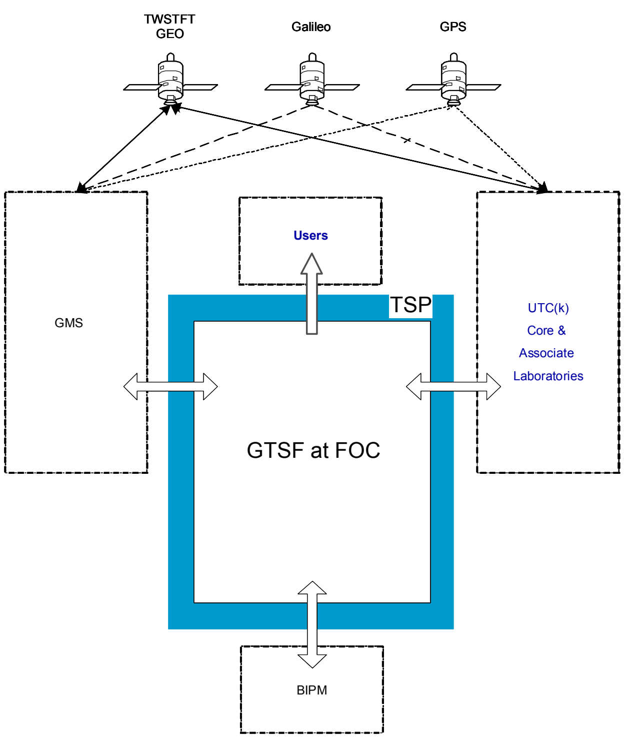

Figure 1. Context of the TSP & GTSF at FOC

The GTSF will interface with the following entities shown in Fig. 1:

a-) The Galileo GMS provides the GTSF with PTF clock and time-transfer data (measured using TWSTFT with GPS and Galileo CV as a backup) on a daily basis, together with the steers actually applied to GST(MC) together with any individual PTF physical clock steers. The GTSF provides the GMS with the GST(MC) steering parameters, the GST(MC) time offset from UTC, the number of UTC-TAI leap seconds, notification of any detected anomalies in the PTF clock or time transfer data and the TWSTFT schedule. The GTSF also supplies the GMS with information on the quality of GST broadcast in the Galileo SIS (GST(User)), on the basis of measurements from a Galileo timing receiver hosted in one of the UTC(k) laboratories.

b-) The UTC(k) laboratories provide the GTSF with individual clock data referenced to UTC(k) and time-transfer data (measured using TWSTFT or GPS or Galileo CV) on a daily basis. The GTSF communicates link parameters to individual UTC(k) laboratories together with notification of any detected anomalies in their clock or time transfer data. One of the UTC(k) laboratories also supplies the GTSF with measurements of GST(User)-UTC(k), obtained from a Galileo timing receiver.

c-) The GTSF obtains the Circular T from the BIPM on a monthly basis, which, among other information, contains the offset between TAI and UTC. It is proposed that the GTSF provide the BIPM with the GMS PTF clock and time-transfer data, to contribute to the calculation of UTC, and in view of the possible inclusion of the time difference UTC – GST(MC) in the Circular T (see section V. below).

d-) The GTSF also provides a secure web site including performance reports on GST to UTC steering for users (eg, ESA, GSA etc).

The data flows comprising the various time transfers between the GMS PTF and the UTC(k) timing laboratories are also included in Fig. 1. These represent the TWSTFT, Galileo CV and GPS CV data flows respectively.

The GTSF will process data provided by Galileo, UTC(k) laboratories and the BIPM. The GTSF will continue to supply data to Galileo, and the TSP will continue to maintain relations with the wider UTC community and with timing users.

III. Proposed Institutional Model for the TSP

The institutional model proposed by Fidelity for the TSP is shown in Fig. 2:

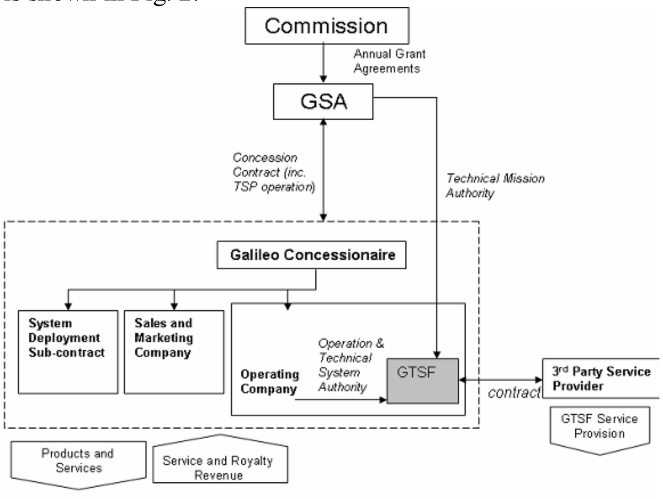

Figure 2. Proposed Institutional Model for the TSP

The main benefits of this proposed institutional model are summarised as:

a-) This option is likely to be compatible with the anticipated relationship between the GSA and the concession for the Galileo system and will therefore be likely to reduce complexity and cost.

b-) By selecting one entity to operate both the Galileo system and the GTSF there is likely to be a reduction in risk (to Galileo), assurance of continuity and the opportunity for operational efficiency through economies of scale.

The GSA will maintain control of the GTSF performance. This allows future performance or mission enhancement to be potentially realized and coordinated by the GSA.

IV. Institutional Relationships

It is proposed that the GTSF be operated by the Galileo Operating Company (GOC) with mission authority retained by the GSA. A TSP entity is required to establish institutional relationships in order for the GTSF to receive the required services, and for the TSP to perform its mission. In this proposal the TSP role will be performed by the GOC, i.e. the TSP is an integrated part of the operating company. The TSP will need to form relationships with the core and associate UTC(k) laboratories, the BIPM and users. The immediate applicable users would be ESA/GSA but this could expand to other timing users and those within the metrological community.

In addition, the relationship between the GSA and the concessionaire will need to be extended to include aspects applicable to the GTSF.

V. TSP in the Time Metrology Community

The above paragraph has identified the institutional relationships which the TSP will need to form or maintain. Through these relationships the TSP also becomes an active member of the time metrology community. There are specific issues associated with the future role of the TSP within this community and how potential benefits can be realized. These are outlined in the following section.

The general role of the TSP in the international time metrology structure is straightforward and presented in Fig. 3. The approach is to ensure that it strengthens and preserves the current (prior to the TSP) institutional structure:

a-) At one level, the TSP preserves the current institutional structure because its internal timescale does not participate in the Circular T and its links to the institutional structure are controlled through the involvement of European UTC(k) laboratories.

b-) At a second level, the TSP will strengthen the current process by acting as a liaison point with Galileo.

c-) The objective is for Galileo to participate in the Circular T by the provision of PTF clock and comparison data through the GTSF, thereby enhancing the Circular T and forming a role for Galileo in the timing community. In this case, it will be technically possible for GST to appear in the Circular T in two distinct ways: by the publication of UTC-GST(User), obtained from measurements by a Galileo timing receiver, analogously to the current procedure for GPS time and GLONASS time ; or by treating GST(MC) as the pivot timescale for PTF clock and comparison data, in the manner of a UTC(k). Of course the GMS does not have the same status as the entities currently providing UTC(k) timescales.

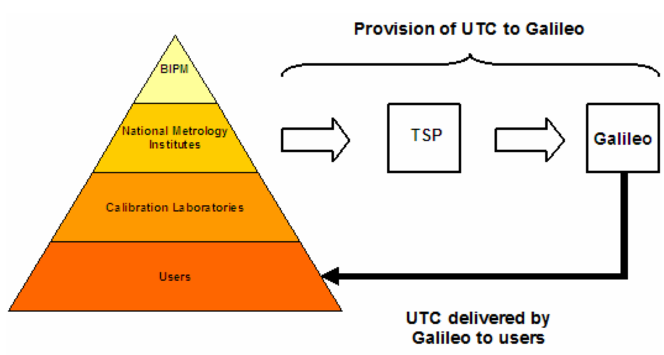

Figure 3. TSP and the International Time Metrology Structure

The TSP is proposed to be in charge of the task of promoting GST in the international time community, allowing users to obtain all useful information for the traceability of GST to UTC. This would ensure the "visibility" of the Galileo reference in the time and frequency community.

VI. GST Monitoring

The TSP, employing the GTSF, will have daily access to UTC(k)-GST(User) measurements from a Galileo timing receiver hosted in a UTC(k) laboratory. This will allow it to compute GST-GST(User) on a daily basis, providing an end-to-end test of time dissemination by Galileo, independent of monitoring by GMS itself.

Either the TSP or the concerned UTC(k) laboratory will provide the UTC(k)-GST(User) measurements to the BIPM on a monthly basis, which will allow the possibility of UTC-GST(User) appearing in the Circular T.

VII. Operational Structure

The TSP concept of operations at FOC has been described above. These operations reveal issues of satellite transponder time and ground infrastructure (including Time Transfer Equipment) at FOC which require consideration. For satellite transponder time, issues of payment, guarantees and communities served need to be agreed between the concessionaire, GSA, the satellite operating agency (Intelsat General Corporation up to 2011) and the laboratories participating in TWSTFT activities in Europe and North America. The process for the organization of the time transfer links needs to be continued through the CCTF working group on TWSTFT. The installation, operation and maintenance of Time Transfer Equipment (TTE) at UTC(k) labs collaborating with the TSP is operationally critical to the GTSF.

The TTE is external to the TSP and resides at UTC(k) laboratories. However, the TSP could perform functions relating to the installation, calibration and operation of this equipment as part of its operations. This is likely to (i) encourage UTC(k)s to support the TSP, (ii) promote QoS from UTC(k)s and (iii) facilitate early adoption of Galileo receivers. TTE also resides at the PTFs of the Galileo GMS and is similarly critical to the operation of the GTSF. The institutional option proposed sees the role of the TSP performed by the operating company. The operating company is anticipated to operate the GMS and would likely need to have responsibility for the TTE at the PTFs. Should this institutional option not be taken forward (ie TSP role not taken by the operating company) then it would appear appropriate that no additional tasks should be allocated to the TSP concerning the operation, maintenance or installation of TTE at the PTFs. This is based on the assumption that specific timing-oriented skills are provided by the GMS operations team.

Meanwhile, for the aspects of calibration, GTSF requirements need very accurate time transfers, thus very accurate calibration. Calibration needs to be performed for TTE at UTC(k) laboratories and PTFs. During FOC operations an annual calibration campaign of GPS / Galileo / TWSTFT will need to take place at the UTC(k) laboratories and the PTFs. TWSTFT and GPS CV calibration in Europe are presently managed by some UTC(k) laboratories and BIPM for the production of UTC [3], [4].

As part of its operational obligations, it is proposed that the TSP carry out the calibration of TTE at UTC(k) laboratories and at the PTFs. In addition it has been recommended by advisors to GSA that European organizations (GSA, ESA, European Space Agencies, EURAMET, NMIs,…) support the setting up of a European operational calibration centre in charge of calibrating time transfer equipment (TWSTFT stations, GPS/Galileo timing receivers).

VIII. Evolution of the Mission of the TSP

There is the potential to extend the role of the TSP after FOC from its primary requirement to support Galileo. This section identifies and assesses those potential options. The extensions to the TSP mission considered here are the following:

A. Future TSP Customers

The operational Galileo system will be the only customer of the TSP at FOC. After FOC is established, there is the potential to extend the role of the TSP to provide a service to other customers. The customer typology which the future TSP could serve is identified as:

1-) Timing information customers: which rely on time services and would see benefits from information on GTSF, UTC, TAI and GST parameters produced in the TSP products. These include TV and radio broadcasting companies, telecommunication network companies, electricity supply companies, private individuals, and scientific users amongst others who already use GNSS time references for a number of applications.

2-) System steering customers: which operate a system time that could be steered by the GTSF. At FOC the GTSF will provide steers to Galileo for the steering of Galileo System Time to UTC mod 1 sec. Through some additional coding and implementation of new interfaces the GTSF would be able to steer other system times to UTC. The following potential customers for the TSP are identified:

- Financial, business and government;

- eLoran (maritime), radio-frequency identification (RFID) and network based cell positioning systems;

- electricity / telecommunication companies, etc…

The change in the service delivery mechanisms that would likely need to be put into place in order to support these two customer types is shown in Fig. 4. The top half of the diagram details the GTSF data delivery at FOC; where GTSF data is delivered through the Galileo constellation and GTSF website to end users. The bottom half of the diagram suggests service provision to future customers through delivery of precise time data over communication networks or by direct steering of other systems.

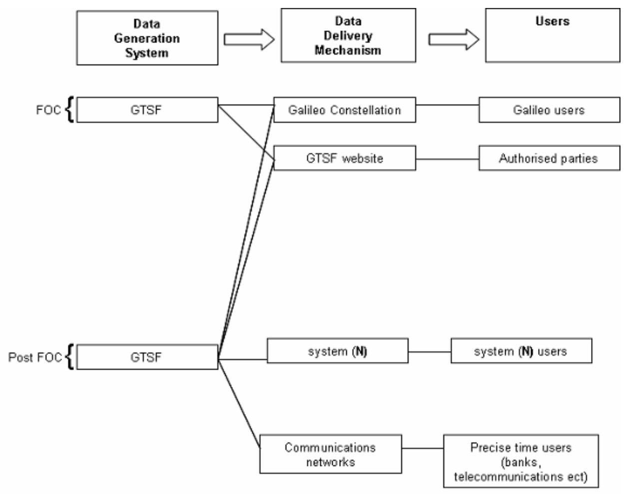

Figure 4. Post FOC TSP Potential Delivery Mechanism

B. Evolution of TSP Products

Once the GTSF has reached FOC operation, a process to continually assess the potential improvements of products to external entities in terms of robustness, quality and content is likely to be advantageous. The reliability and quality of the TSP products delivered to the GMS is dependent on the algorithms of the GTSF, data from the UTC(k) laboratories and data from GMS. The requirements on these algorithms and data put in place for FOC will enable the GTSF to meet the performance requirements of this data flow. Improvements in the quality and reliability of GTSF products could come from the following evolutions:

- Improvements in composite clock and steering algorithms of the GTSF;

- Increased number of UTC(k) laboratories, or other timing sources;

- Improvements of the participating clocks;

and so on.

C. UTC(k) Cooperation Evolution

At FOC the UTC(k) laboratories will be critical to the operation of the GTSF and the success of the TSP. SLAs are recommended to be put in place between "core" UTC(k) laboratories and the TSP in order to guarantee a data service. In addition, "associate" UTC(k) laboratories will be able to provide data on a voluntary basis. The more UTC(k) laboratories that contribute to the GTSF the greater the robustness and performance of the GTSF itself. It is therefore beneficial to take steps to encourage UTC(k) involvement. UTC(k) laboratories could also take an active role within the operations of the GTSF. UTC(k) laboratories with specific capabilities in TTE calibration could lead the calibration activities of the TSP through extended SLAs.

D. Time dissemination through Galileo and the role of the Time Service Provider

One of the services provided by Galileo will be the dissemination of UTC. It is interesting and important to consider to what extent this may permit Galileo to serve as a means of access to legal time, in European countries.

UTC is calculated by the Time Section of the BIPM, using clock and comparison data provided by NMIs and other time laboratories from around the world, and applying IERS decisions on leap seconds. Recommendations by many entities such as the ITU, the CIPM (or the CGPM) based on propositions by the CCTF, and the metrological coordination provided by the BIPM, mean that UTC constitutes the recognised basis for ensuring the worldwide consistency of time measurements.

Although not all countries have adapted their laws to explicitly identify UTC as the basis of legal time, it is the effective basis of legal time in many or all countries. NMIs and other entities realise real-time approximations to UTC, the UTC(k) timescales, which serve the needs of their metrology users and provide traceability to UTC through the Circular T. The Mutual Recognition Arrangement of the CIPM, with the time and frequency key comparison, reinforces the role of UTC and engages the participating NMIs to recognise each other's calibration and measurement certificates.

The differences and specificities of national time legislation in European countries lead to rare incongruities, such as the European directive on summer time [5], which is referenced to GMT in its English version and to UTC in its French and German versions. However, given the very strong coordination outlined above, it is not known to the authors if they lead to any concrete obstacles in the dissemination of legal time, which could motivate work on legislative harmonisation at the EU level. In the following, we assume that traceability to UTC is sufficient for legal time dissemination.

The provision of legal time through Galileo may be considered to depend on 3 elements:

- the Galileo reference timescale, taken here to mean GST(MC);
- the broadcasting of time information through the Galileo SIS;
- the user equipment.

GST(MC) will be steered to UTC (mod 1 s), which is in principle a good starting point for a time dissemination service. Further, the TSP will provide daily traceability of GST(MC) to the UTC(k) timescales of contributing laboratories, initially INRiM, LNE-SYRTE, NPL and PTB. Finally, as has already been discussed, it is proposed that GST appear in some form in the Circular T.

It will be necessary to validate the Galileo system as a means of diffusing this time reference. This may presumably be done by initial studies and by ongoing monitoring, as mentioned in section VI.

Note that the TSP in fact only provides steering parameters for synchronising the GST(MC) second boundaries with those of UTC. The date and time of day information provided by Galileo will be encoded in terms of Galileo week and second numbers, outside of the responsibility of the TSP. For time applications, as distinct from frequency, this information is of course crucial. It may be possible to extend the UTC(k)-GST(User) monitoring mentioned in section VI to include date and time of day. It may be desirable that more than one UTC(k) laboratory collect this information.

To complete the chain of traceability, user equipment would need to be validated, including decoding of the date and time of day, and calibrated. There will be much in common here with well-known measurement procedures for GPS and GLONASS equipment, although it may be necessary to develop calibration laboratory capabilities if user demand is high. An exception concerns the absolute calibration of GNSS receivers, which is not readily available in Europe, although work has been done by CNES [6].

These various elements may provide the basis for using Galileo as an accredited method of access to legal time. The Fidelity consortium wishes to go further by exploring the concept of a "certified" time service:

- would this be useful and which user domains might be interested?
- what would constitute a certified time service/how would it differ from the more usual accreditation processes?

Presumably one aspect of a certified service would be the capacity to authenticate the received SIS as a genuine Galileo signal. Another aspect may be liability for damages due to interruptions in the service. Fidelity welcomes any and all comment on this subject.

It is clear that the TSP will be in a strong position to contribute to the dissemination of time by Galileo, by the provision of data on the traceability of GST(MC) to the participating UTC(k) timescales, by the coordination of monitoring of Galileo SIS, and through the GNSS receiver calibration capacities it is developing.

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