

## CONCEPT FOR A GEODETIC AND TIME REFERENCE IN SPACE (GETRIS)

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### **Abstract:**

Data transfer as well as time transfer and ranging in space are carried out by free propagating modulated electromagnetic signals. In principle all three tasks can be done with the same link equipment and the same signal. To make use of this synergy a common concept for all three applications has to be developed together with adapted instruments. In this talk we introduce such a common concept and discuss the areas of application and benefits for geodesy. We show how satellite laser ranging stations are integrated in this concept and which chances emerge from such a concept. The discussed benefits range from access to extended tropospheric monitoring at the tracking stations to having access to precise timing information. This will be a step forward for stations to reach the demands for future GGOS applications. For interplanetary applications GETRIS can provide a geostationary base station for ranging, data transfer and time synchronization, avoiding the problems of a turbulent atmosphere.

### **Introduction:**

Since some years new applications for SLR are discussed at previous ILRS workshops. Apart from space debris tracking (Green et al. 2002) the synergy between SLR and data transfer (Kirchner et al. 2011) and SLR and time transfer (Fridelance et al. 1997) are discussed in many aspects. In this paper we want to introduce a concept for a geodetic and time reference in space, called GETRIS (Schäfer et al. 2013), exploiting of the synergy between all three aspects of using an electromagnetic signal in space, namely data transfer, ranging and time synchronization. Starting point for a combination are the individual ESA concepts for the near future in the fields of positioning systems, data transfer and timing.

ESA's positioning system is Galileo, a constellation with eventually 27 satellites on three orbital planes inclined by 56°. Allowing orbit determination of low-orbiting satellites with the same precision as with the GPS constellation of 1.5 mm (Jäggi et al. 2009, Jäggi et al. 2012). A discussed future evolution will be the establishment of two-way intersatellite links between the spacecrafts to synchronize the space clocks, transfer system relevant data and perform ranging. The result will be a rigid constellation with a common clock (Amarillo and Gerner 2007) and realtime integrity information (Rodriguez-Pérez et al. 2011).

ESA's answer to rising data volume on scientific low-orbiting (LEO) missions is the European Data Relais System (EDRS). Up to three geostationary satellites (GEO) will collect the data of LEO missions using an optical coherent bi-directional link and transferring data to ground with either optical or microwave signals. The optical GEO-LEO link has a data rate of 1.8 Gbits/s.

Although optical clocks do not work continuously on ground the discussion where to locate them if they will become operational is already ongoing. The geopotential on the Earth surface is not known well enough. A stable orbit is therefore discussed as a solution (Schiller et al. 2007).

**Concept:**

The GETRIS concept is based on the Galileo system with two-way inter-satellite links. “Geostationary Galileo satellites” will be integrated into the system to carry the high precision master clocks, if available, or allowing a permanent link to ground. Due to the inter-satellite links we expect high precision orbits and synchronized clocks for the whole constellation. For LEO precise orbit determination (POD), time synchronization and data transfer, as well as gravity field determination (Schäfer et al. 2013) a bi-directional high-low link is proposed (for POD, simulations show, that even two simultaneous links are necessary). A bi-directional ground link will allow data up- and down-link and gives access to precise timing and ranging information. This ground link is highly insensitive to troposphere and atmosphere for the purpose of time synchronization. For validation and calibration of the satellite link an ELT (European Laser Timing) payload should be integrated at one spacecraft (Schreiber et al. 2009). One-way laser ranging will become possible, using synchronized clocks. Possible extensions can be the completion of an “GGOS station in space” (co-location of all space techniques on one satellite, comparable to the GRASP mission (Bar-Sever et al. 2009)) by adding a VLBI beacon or a further link to the moon, to the Lagrange point or even to interplanetary missions.

**Possible Techniques:**

Various techniques are used for the three different tasks of ranging, data and time transfer. All of them are space qualified, but some have to be modified to extend their capability to all three tasks simultaneously. One possible candidate in the microwave frequency regime would be the MWL (microwave link) of the Atomic Clock Ensemble in Space (ACES) (Salomon et al. 2007). Designed for time and frequency transfer, this technique uses phase modulated signals in the Ku-Band with chip rates of 100 MHz. The data transfer link of EDRS is phase modulated, too, but the carrier frequency is in the optical frequency range. The higher modulation frequency of 1.8 GHz of the laser communication terminals (LCT) allows a higher bit rate, and higher time transfer and ranging precision. Outside the troposphere an optical pulsed method with pulse position modulation (PPM) (Kirchner et al. 2011) may also be possible, but this method would need some more investigations.

Even though the GETRIS concept is not elaborated enough to define a link method, there are two cases where a preferred frequency exists. The preferred concept is based on bi-directional coherent links, outside the atmosphere in the optical regime and in the microwave regime, i.e. Ka-band or higher, for ground links, which eventually could be replaced by space-ground optical links, once they become available. In the later discussion of application fields, the ground link is always a microwave link, allowing time synchronization and ranging at any time, and the high-low link is an optical link, virtually free of ionospheric effects, as seen for example in GPS tracking at the magnetic equator or the poles (van den IJssel et al. 2011).

**Fields of application:**

Depending on the expansion stage of the GETRIS concept, different applications can profit from a two-way link. If only one high-low link per LEO exists to two GEOs or three Galileos a continuous tracking of the LEO is possible allowing for gravity field determination (Schlie et al. 2014, Reußner 2013). Low-Earth orbiters carrying DORIS receivers will benefit from a continuous synchronisation of their clock to a common Galileo time (inter-satellite links assumed). Also realtime navigation will benefit, as time synchronization to common time scale will turn one-way pseudoranges into biased ranges which can be evaluated immediately with high precision. Multi-

static InSAR missions can synchronize their clocks, and Galileo-reflectometry will also profit from biased ranges.

Two links per LEO satellite will allow precise orbit determination in the millimeter accuracy range. And a constellation of ground links together with an inter-satellite link can make a “pseudo common view” constellation for intercontinental time transfer or relativistic geodesy.

At least a geostationary base station for interplanetary data transfer, time synchronization and ranging can be established having a GEO satellite with synchronized clock in a well known orbit exploiting inter-satellite links. Such a base station will have the advantage of establishing interplanetary links without tropospheric signal damping and further spreading of the beam together with beam wander and irradiance fluctuations caused by a turbulent atmosphere.

### **Benefit of SLR stations:**

The GETRIS concept is independent of the location of a precise clock defining a time scale. If the precise clock is on ground, GETRIS is able to bring the clock information into space and vice versa if the clock is in space. The combination of a two-way link at an SLR station will give the opportunity for stations having access to precise time on ground to transfer time with very high precision via a microwave link and to compare the time scale in space and on ground with high accuracy. Additionally the MWL can be calibrated and validated by the laser link. As the clocks are getting better and better there will be the possibility of monitoring the geopotential at the station by relativistic geodesy.

DORIS will already benefit from GETRIS very much by monitoring the space clocks. A DORIS beacon co-located on ground with a two-way MWL will lead to synchronized clocks in space and ground allowing analysis of the phase. Co-located SLR can add the ranging information and will complete the information for LEO orbit determination.

The co-location of different “ranging” techniques at different wavelength at one station with known clock bears the opportunity to monitor the troposphere at the station. Having a GGOS station in space (compare to GRASP (Bar-Sever et al. 2009) and on ground co-locates three or four systems at two points. By comparing their “range” measurements, not only systematic errors in each technique can be evaluated, but also the different influences of the troposphere on the different wavelength of the electromagnetic signals will lead to a separation of atmospheric effects in distinct directions. Additionally the troposphere can be scanned in many directions by one-way Galileo tracking: With synchronized clocks the GNSS pseudo-ranges convert to biased ranges and after bias elimination the troposphere is the biggest remaining error contribution. New installations like SKA could benefit from improved knowledge of the tropospheric delay.

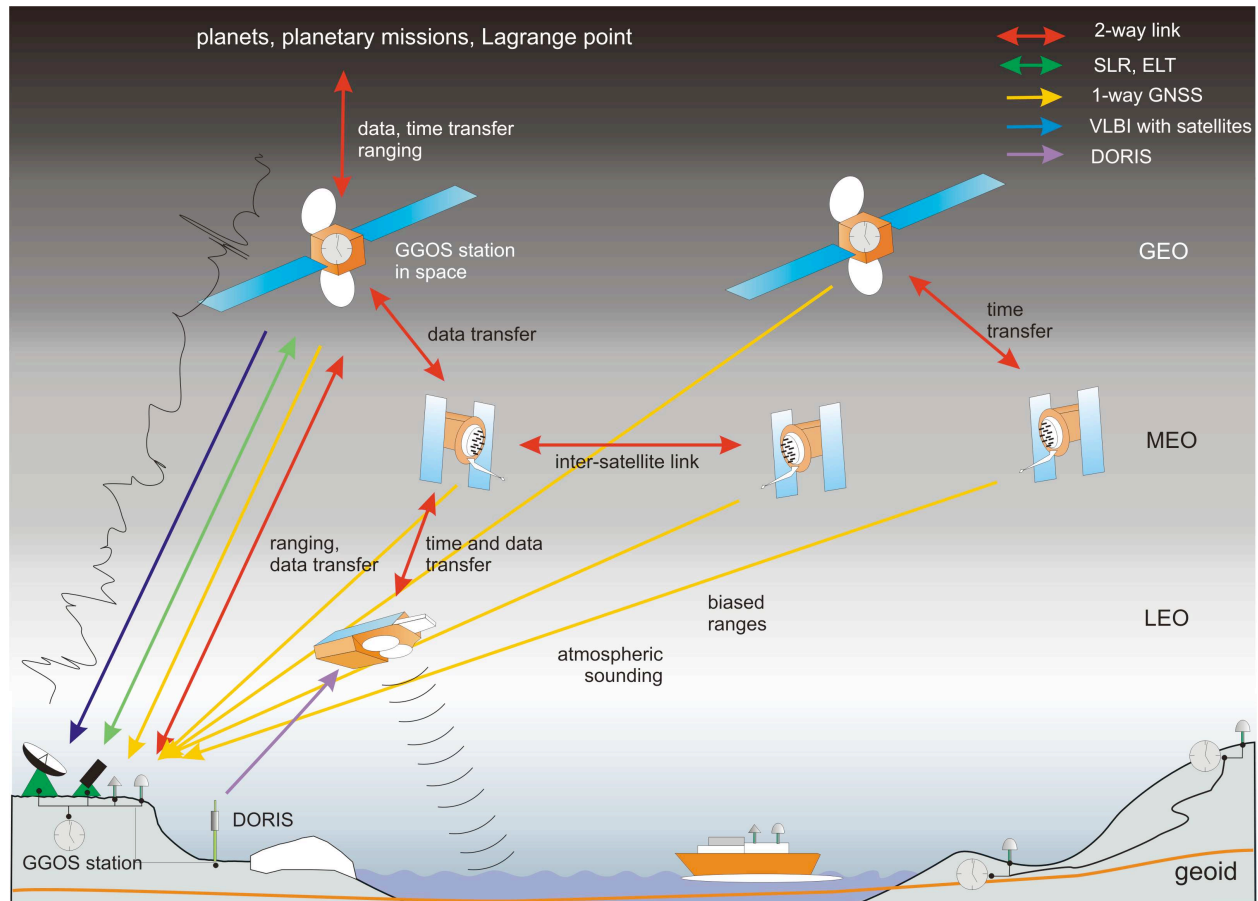
A further aspect may come from the data transfer side: The co-located SLR/MWL stations can take over parts of data up/down link function for ESA, reducing the need for own capabilities. At least in the sense of an early warning scenario this would fit into the vision of GGOS.

The benefits are summarized in fig. 2.

### **Conclusion:**

Using the synergy between the three tasks related to the propagation of electromagnetic signals in space, namely ranging, time synchronization and data transfer, bears the opportunity to establish a geodetic and time reference in space. A broad range of applications can be pointed out on the scientific user side and is listed in this paper. Looking for a “win-win” situation between science and commercial interests, GGOS and ILRS should think about the following offer to ESA:

“With a system like GETRIS a **validated monitoring of Galileo clocks in precision and accuracy and precise orbits** of Galileo satellites from stations with a **well observed troposphere** can be provided. The contribution of individual SLR stations for **data up/down link of early warning messages** or even **scientific data** can be discussed.”



**Figure 1:** Application fields for GETRIS at a GGOS station and as a base station for inter-planetary ranging, time synchronization and data transfer.

**Acknowledgement:** The work was funded by the European Space Agency (ESA) under contract 4000103328/2011/NL/WE. The view in this paper can in no way be taken to reflect the official opinion of the European Space Agency.

## References

- Amarillo, F., Gerner, J.L.: Inter-satellite ranging and inter-satellite communication link for enhancing satellite broadcast navigation data. First Colloquium on Scientific and Fundamental Aspects of the Galileo Programme, 2007.
- Bar-Sever, Y., Haines, B., Bertiger, W., Desai, S., Wu, S.: Geodetic Reference Antenna in SPace (GRASP) A mission to enhance space-based geodesy, in COSPAR Colloquium: Scientific and Fundamental Aspects of the Galileo Program, Padua, Italy, 2009.
- Fridelance, P., Samain, E., Veillet, C.: T2L2 – Time Transfer by Laser Link: a new optical time transfer generation, *Exp. Astron.* 7, 191 – 207, 1997.

- Green, B., Gao, Y., Moore, C., Wang, Y., Boiko, A., Ritchie, J., Sang, J., Cotter, J.: Laser Tracking of Space Debris, Proceedings of the 13<sup>th</sup> Laser Ranging Workshop, Washington, 2002.
- van den IJssel, J., Visser, P., Meyer, U., Bock, H., Jäggi, A.: GOCE SSTI L2 tracking losses and their impact on POD performance, Proceedings of the 4th International GOCE User Workshop, Munich, Germany, 2011.
- Jäggi, A.; Dach, R.; Montenbruck, O.; Hugentobler, U.; Bock, H.; Beutler, G.; (2009): Phase center modelling for LEO GPS receiver antennas and its impact on precise orbit determination, J. Geod. 83: 1145 – 1162.
- Jäggi, A.; und Montenbruck, O.; Moon, Y.; Wermuth, M.; König, R.; Michalak, G.; Bock, H.; Bodenmann, D.; (2012): Inter-agency comparison of TanDEM-X baseline solutions. Advances in Space Research, 50, 260-271.
- Kirchner, G., Koidl, f., Kucharski, D., Steinegger, W., Leitgeb, E.: Using Pulse Position Modulation in SLR stations to transmit data to satellites, Proceedings of the 11th international Conference on Telecommunications, 2011.
- Reußner, E.; (2013). Konzept einer zukünftigen Schwerefeldmission: GNSS-LEO-Tracking. Bachelor's Thesis, TU München, [http://www.iapg.bv.tum.de/Bachelorarbeit\\_Reussner\\_2013/](http://www.iapg.bv.tum.de/Bachelorarbeit_Reussner_2013/)
- Rodriguez-Pérez, I., Garcia-Serrano, C., Catalan, C.C., Garcia, A.M., Tavella, P., Galleani, L., Amarillo, F.: Inter-satellite links for satellite autonomous integrity monitoring, Adv. Space Res. 47, 197-212, 2011.
- Salomon, C., Cacciapuoti, L., Dimarcq, N.: Atomic Clock Ensemble in Space: an update, Int. J. Modern Phys. D, 16, 2511-2523, 2007.
- Schäfer, W.; Flechtner, F.; Nothnagel, A.; Bauch, A.; Hugentobler, U.: Geodetic Time Reference in Space (GETRIS). ESA Study AO/1-6311/2010/F/WE Final Report GETRIS-TIM-FR-0001, 2013.
- Schiller, S., Görlitz, A., Nevsky, A., Koelemeij, J.C.J., Wicht, A., Gill, P., Klein, H.a., Margolis, H.S., Miletì, G., Sterr, U., Riehle, F., Peik, E., Tamm, Chr., Ertmer, W., Rasel, E., Klein, V., Salomon, C., Tino, G.M., Lemonde, P., Holzwarth, R., Hänsch, T.W.: Optical Clocks in Space, Nuc. Phys. B (Proc. Suppl.) 166, 300-302, 2007.
- Schlie, J.; Murböck, M.; Pail, R.: Feasibility Study of a Future Satellite Gravity Mission using GEO-LEO Line-of-Sight Observations. In: Willis P. et al. (eds.): International Association of Geodesy (IAG) Symposia, Gravity, Geoid and Height Systems, 2014.
- Schreiber, U.; Procházka, I.; Lauber, P.; Hugentobler, U.; Schäfer, W.; Cacciapuoti, L.; Nasca, R.: The European Laser Timing (ELT) experiment on-board ACES; Proceedings of the 23rd European Frequency and Time Forum (EFTF 2009), 594-599, 2009.