Prospective Performance Budget of the T2L2 Experiment

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***Abstract*— The Time Transfer by Laser Link (T2L2) experiment [1], [2], under development at OCA (Observatoire de la Côte d'Azur) and CNES (Centre National d'Études Spatiales), France, will be launched in 2008 on the altimetric satellite Jason 2. The experiment principle is issued from laser telemetry, i.e. the timing of transmitted and reflected laser pulses. This paper is a prospective study of the T2L2 performance budget lead on simulations of the stations network geometry, the orbit parameters and the instrumental error budget.**

I. Introduction

The optical time transfer principle is based on the timing of laser pulses transmitted between ground stations and a space equipment. The high interest of the experiment was shown by the selection of the T2L2 instrument as a passenger on the French-American altimetry-dedicated mission Jason 2 scheduled for launch in mid-2008. T2L2 will permit to synchronize remote ground clocks and compare their frequency stabilities with a performance never reached before. It will allow to perform a synchronization of a ground and space clock and also to measure the stability of remote ground clocks over continental distances, itself having a time stability in the range of 10 ps over one day.

We will develop three possibilities of experiments that could be implemented and extract the favourable configurations, the corresponding dead time between orbit passes, the expected precision and accuracy. We study possible improvements of the time transfer by generating a corrected DORIS time scale monitored with the measurements given by each of the tracking stations along the passes. This will finally give a fine estimation of the precision we may obtain from the T2L2 experiment and indications about the observational approach that has to be implemented.

II. Context

T2L2 is developed at the Observatoire de la Côte d'Azur (OCA) with the technical and financial support of CNES. The instrument will be launched in mid-2008 on the altimetric satellite Jason 2. The operation principle is issued from laser telemetry: a laser station on the ground emits short light pulses towards the satellite. The laser pulse is detected onboard and a part is reflected towards the ground telescope with a corner cube reflector. Three datations are performed for each pulse:

- t_{Start} is the date of pulse emission from the ground terminal (in ground clock time scale)
- t_{Board} is the date of pulse detection onboard the satellite (in space clock time scale)
- t_{Return} is the date of reflected pulse detection at the ground terminal (in ground clock time scale)

The comparison of ground and space clock time scales relies on the knowledge of the ensemble of date triplets t_{Start}, t_{Board}, t_{Return} corresponding to a large number of detected laser pulses.

$$\chi_A = \frac{t_{Start} + t_{Return}}{2} - t_{Board} + \tau_{Rel} + \tau_{Atm} + \tau_{Geom}$$

III. Comparison between ultra-stable atomic clocks

The availability of transportable cold-atoms clocks in Europe, such as the mobile atomic fountain developed at LNE-SYRTE, could lead to an experiment consisting in synchronizing two cold-atoms clocks over 1,000 km. On the first hand, such a transportable clock could be installed at OCA near the MeO laser station, on the other hand, the French Transportable Laser Ranging System (FTLRS) developed at OCA and dedicated to participate to such specific missions would be able to play the role of the local laser station at SYRTE, Paris.

The prospective performances of T2L2 in this kind of configuration represent an important improvement. The ultimate stability will be better than 10 ps over one day and will thus allow an improvement of one to two orders of magnitude with respect to the performances of existing time transfer systems, like GPS or Two-Way Satellite Time and Frequency Transfer (TWSTFT). In term of accuracy, the uncertainty is dominated by our capability to calibrate the equipments and to monitor their drifts. Calibration accuracy is difficult to evaluate precisely, but a fine analysis of the ground and space equipment should lead under the 100 ps level. This order of performance represents an enhancement of one magnitude in accuracy as compared to the existing links which are at the nanosecond level. As a result, it will allow the calibration of these radiofrequency systems, and comparisons of cold atoms clocks at a level never reached before. This contribution will

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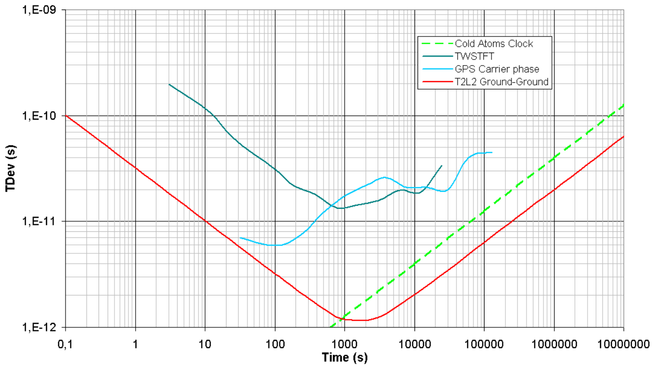

Fig. 1. Microwave links and cold atoms stabilities compared with T2L2

surely be profitable for the atomic time scales generation. We must notice that a second transportable laser station could allow to extend this configuration to any time-frequency lab in the world, for calibration purpose of the existing microwave links.

The prospective time stability of the T2L2 experiment in a common-view mode can be compared with the microwave time transfer techniques and the cold-atoms clocks as shown on Fig.1.

IV. Transatlantic time transfer

The orbit parameters of Jason 2 (Table I) and the 110 degrees field of view of the detectors allow common-view experiments between stations separated by a distance up to 6,500 km. Beyond this limit, we can still proceed experiments, but in a non-common view mode, for example between the US and France. Greenbelt and Grasse laser stations are separated by a distance of 6,700 km (Fig.2). In a repetitivity period of about ten days, the satellite covers a 315 km-width grid at the earth's surface. The mean duration of a pass for a ground station is about 14 minutes of visibility over five degrees elevation, with four to five consecutive passes every day separated by two hours.

TABLE I
Jason 2 orbit parameters

Parameter	Value
Semi-mayor axis	7714.4278 km
Inclination	66.039°
Altitude	1,336 km
Nodal period	112'42"
Repetitive period	9.9156 days
Passes per cycle	254

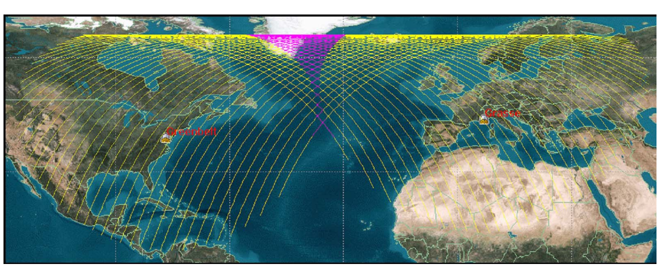

Fig. 2. Satellite visibility (> 5° elev.) over Grasse/Greenbelt (yellow), non-visibility (purple) [STK Software]

Into a period of ten days, out of the 75 visible passes over each of the Grasse and Greenbelt stations, 45 are giving favorable configurations for experimentating T2L2. The satellite starts being visible from the Grasse laser station only two minutes after leaving the Greenbelt's field of view. This short dead time between the two observations minimizes the limitation imposed by the onboard clock's drifts at less than 30 ps (Fig.4).

V. Transcontinental time transfer

The experiment can be extended in a longer baseline, for example between France and China, with a distance of 9,300 km between the Grasse and Shanghai laser stations (Fig.3). Over a period of ten days, the number of favorable configurations to transfer time with a minimum dead time is 29, with a typical distribution of three consecutives passes every day separated by two hours. The mean duration of non-visibility is ten minutes, leading to an important uncertainty of 300 ps carried by the onboard USO (Fig.4). This level of precision degrades the interest of using the laser link for transferring time, microwave links being more easy to implement. The Maidanak laser station in Uzbekistan is located at a strategic

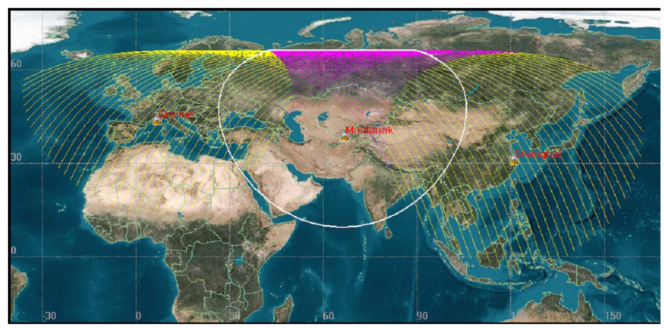

Fig. 3. Satellite visibility (> 5° elev.) over Grasse/Shanghai (yellow), non-visibility (purple), visibility over Maidanak (white) [STK Software]

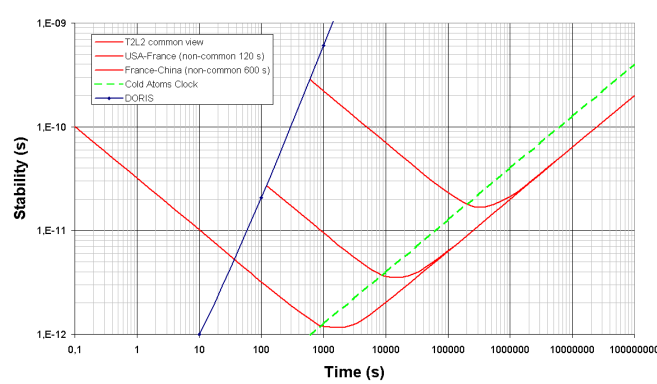

Fig. 4. T2L2 stability in a common-view mode and for transatlantic and transcontinental configurations

position for this kind of French-Chinese experiment. In fact, Maidanak could be used as a relay between Grasse and Shanghai by tracking the satellite to measure the oscillator's drifts during the non-visibility period and generate a DORIS corrected time along the passes.
The presence of intermediary laser stations distributed at the Earth's surface and tracking Jason 2 would permit a high improvement of the very long baseline time transfers by multiplying the possibilities and the range of operation.

VI. Conclusion and openings

The Jason 2 satellite is scheduled for launch in June 2008. The T2L2 instrument onboard will allow to process clock comparisons at the picosecond level between stations, from simultaneous to few minutes non-common view configurations. In this latter case, the DORIS USO will be the limitative factor in term of precision, confirming the high interest of a wide participation of laser stations to follow the onboard drifts and correct them. The laser ranging stations and laboratories interested in participating to the T2L2 experiment are represented on Fig.5. The optical time transfer

Fig. 5. T2L2 participation

technique still has possibilities to provide better results. The metrological performances could reasonably be improved by one magnitude with few minor modifications operated on the current instrument:

- By replacing the nine corner cube pyramid target with a single retroreflector ensuring both the reflexion and detection functions to avoid geometrical uncertainties and complexes target signatures. Such a target has been developed and tested at OCA.
- By shooting at a higher cadency to shift the peak of stability before the current 1000 s integration time needed to reach this level of precision.
- By increasing the level of energy in the laser pulses to improve S/N ratio.
- By implementing photodetectors with an enlarged collection surface.
- By taking advantage of the latest improvements done in the photodetectors technology or by replacing them with MCP.
- By embarking the T2L2 instrument on a satellite orbiting at a higher altitude, to extend the duration of the passes and benefit to more important common view configurations, and/or with an atomic clock onboard. In such a way, it could be a very valuable opportunity to embark a T2L2 instrument onboard a space vehicle from the Galileo constellation.

References

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