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A novel design for the navigation system and proposal to unify the timing and the positioning system using GIOVE Follow-on

D. Svehla (1)

Technische Universität München, Institute of Astronomical and Physical Geodesy, Munich, Germany (Email: svehla@bv.tum.de)

Firstly, we present a novel design of the global navigation system based on two-way links and master clock(s) in the GEO orbit. The idea is to place at least one or several master clocks in the GEO orbit and to use two-way links to transfer their stable frequency to the navigation satellites in the MEO orbit equipped with simple ultra-stable oscillators (USO). The advantage of the two-way links is the cancellation of the first order Doppler effect and therefore allowing for the real-time frequency dissemination. With this concept, the use of H-masers and Cs- or Rb-clocks in the GNSS satellites can be reduced to the USO of higher quality. In order to introduce redundancy in such a system, at least two or three master clocks would be required in the GEO orbit. However, considering geometry and the USO performance, only one GEO satellite is sufficient to have an operational frequency dissemination system. In addition, to steer the frequency of the several GEO satellites equipped with USO clocks using master clocks on the ground is an alternative and will be discussed here as well. Compared to pseudo-range and carrier-phase observables from the GPS or GALILEO system, two-way links provide range in the real-time that does not require estimation of the clock/ambiguity parameters in the orbit determination. This is the reason why simulations show that based on the two-way range the orbits of the GEO and MEO satellites can be determined with an accuracy of several centimeters in real-time. The concept of such a navigation system based on the dual constellation between "fast moving" GNSS satellites in the MEO and "stable" GEO satellites enables very accurate real-time orbit and frequency dissemination in addition to considerably reducing the need

for dense real-time network on the ground. Such a navigation system can be extended to other orbit altitudes between LEO and GEO, e.g satellites like ASTRA and IRIDIUM. However, the use of a LEO orbit in such a navigation system considerably limits the tracking time for a ground station to only a few minutes. Using simulated data we show all the advantages of the navigation system based on master clocks and two-way links in space. The first optical clock reached stability down to one part in 10^{-17} over a few hours of averaging and the first cesium clock for space have been under development for the ACES mission on board the Space Station with the stability of 10^{-16}. The microwave two-way link developed for the ACES mission follows these orders of stability. In the second part we show the benefits if only one GALILEO satellite is equipped with the two-way link, like the one developed for the ACES mission. The two-way link on only one GALILEO satellite will allow, for the first time, unification of the timing and positioning system and calibration of the entire GALILEO constellation. Currently, there is no operational system available to compare the best ground optical clocks that have already demonstrated an accuracy of few parts in 10^{-17}. In the very near future, there will be a gap in performance between the TAI clocks and the satellite based time/frequency comparison systems. The two way link developed for the ACES mission allows frequency comparison down to 10^{-17} and this is almost two orders of magnitude better compared to the best TWSTFT, or one-way systems like GPS and GALILEO. With the two-way link on only one satellite, like GIOVE follow-on, GALILEO will serve in establishing the reference frame for time (TAI), and open doors for operational relativistic geodesy. One part in 10^{-17} of the clock frequency corresponds to about 10 cm in the variation of the gravitational potential in terms of the geoid heights. Therefore, already now it is feasible to measure "physical heights" using terrestrial clocks, but there is no satellite system available to compare frequencies of the terrestrial clocks with sufficient accuracy. In this way, GALILEO will unify geometrical and gravitational positioning (potential). On the other hand, the GALILEO orbit is high enough that the two-way MW-downlink signal can be tracked by VLBI antenna (S/Ku band). This opens new possibilities in combining the GNSS based reference frame and, at the moment, fully independent VLBI inertial reference frame based on quasars. Compared to the two-way link, with the one-way systems like GPS and GALILEO it is impossible, in the absolute sense, to separate the receiver/satellite clock, the phase ambiguity, the ionosphere/troposphere delay and the differential code biases (DCBs). This will be the case even if three or four GALILEO frequencies are available and two-way links is only alternative. Therefore, two-way links on only one GALILEO satellite in combination with the one-way GALILEO signal will play a major role in the calibration of the GALILEO measurements and ambiguity resolution.