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TIME SYNCHRONIZATION STRATEGIES FOR A LUNAR RADIO NAVIGATION SYSTEM

Abstract

ESA's Moonlight initiative foresees the development of a Lunar Radio Navigation Service (LRNS) to support forthcoming institutional and private exploration missions. The architectural solution proposed by the ATLAS consortium[1] envisages a four-satellite constellation tracked in two-way coherent mode by a network of small dish antennas operating in K-band, exploiting the concept of multiple spacecraft per aperture (MSPA). This configuration enables a complete decoupling of the orbit determination and clock synchronization across the constellation. This study focusses on the latter, answering the question "*What is the optimal time synchronization strategy for maintaining the LRNS timescale?*" through extensive numerical simulations addressing the complex interplay of three factors:

- Ground-to-space time transfer (TT) accuracy. Two techniques are being investigated, differing in the combination of the exchanged radio signals and in the processing of the observables. *Asynchronous* two-way satellite time and frequency transfer (TWSTFT)[2], cancelling out systematic influences at the cost of tracking data interruption, and the *synchronous* mode, relying on precise spacecraft range information based on the two-way regenerative ranging measurement.
- Desynchronization between ground tracking stations. MSPA effectively mitigates this threat by enabling simultaneous TT with all constellation nodes, maintaining the consistency of the internal timescale. For reasons of system interoperability, strategies to align the internal timescale to TAI/UTC indirectly via GNSS are explored, as well as receivers exploiting TWSTFT for direct links to UTC(k).
- Onboard clock selection, a delicate balance between inherent stability, SWaP-C (Size, Weight, Power Cost) and technology readiness level.

The evaluation metric is the clock contribution to the System-in-Space Error (SISE). This is a key performance parameter of the LRNS expressing the instantaneous difference between the time prediction as broadcasted by the navigation message and the true satellite time. Preliminary results suggest the usage

[1]Iess et al. "High Performance Orbit Determination and Time Synchronization for Lunar Radio Navigation Systems." ION GNSS+ 2023

[2]Hanson "Fundamentals of two-way time transfers by satellite." Proceedings of the 43rd Annual Symposium on Frequency Control. IEEE, 1989

of a Rubidium Atomic Frequency Standard (RAFS) with a strategic sequence alternating (a)synchronous TTs, limiting the desynchronization induced by the ageing of the navigation message to 10ns (∼3m) in nominal operations. Finally, relativistic effects are investigated and shown to be treatable as deterministic.