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A STOCHASTIC CONSTELLATION REPLENISHMENT PLANNER FOR GALILEO SECOND GENERATION

Abstract

Constellation replenishment will determine whether a planned constellation can deliver its objectives within budget over the long term. The key measure is service availability: the fraction of time when there are sufficient functioning satellites in the correct constellation slots. An efficient replenishment strategy means minimising the number of replacement satellites and launches required. In the frame of ESA's European GNSS Evolution Programme for the Galileo 2nd Generation, Deimos Space developed a stochastic simulator with the objective of computing and trading off different constellation replenishment plans.

Replenishment strategy candidates were designed, and characterised in terms of launchers, spacecraft types, launch scenarios and transfer to the final slot in the constellation. A comprehensive trade-off definition has been performed, and the most promising subset of candidates selected for further analysis using the Replenishment Planner. Different methods were used to characterise candidate strategies, from bibliography research to low-thrust transfer optimization using an improved Edelbaum method which takes into account Earth eclipses.

The Replenishment Planner was then designed and implemented. A stochastic approach is used to calculate the probability of having a certain number of satellites in each constellation plane. The Replenishment Planner maintains the service availability above a user defined threshold by means of different launch strategies, using the selected strategy candidates as "building blocks". The simulator has the flexibility to consider a wide set of inputs, conditions and constraints:

- Satellites types, e.g. current Galileo satellites, and future new designs or user defined satellites.
- Launch strategies can include triggering corrective launches to replace failed satellites, preventive launches to anticipate the decrease of the service availability, preventive launches to avoid the loss of spare satellite capability, or a combination of the previous.
- Transfer strategies including direct injection, electric thrust transfer, and staggered separation to inject satellites into different orbital planes at different altitudes.

- Satellite and launcher reliability.
- Policies on maintaining spare capacity and satellite decommissioning.
- Minimum intervals between launches and time required to procure a launch.

Simulations covering 100 years have been run, considering the decay of the current satellites and their replacement, using different launchers, computing relocation of spare satellites and considering temporary outages. Study cases have been run to validate the novel approach implemented in the Constellation Replenishment Planner, yielding promising results.

The approach is not limited to GNSS, but applicable to any constellation, and we discuss extension to Earth Observation and communications megaconstellations.