IAF ASTRODYNAMICS SYMPOSIUM (C1)
Mission Design, Operations & Optimization (1) (6)

Author: Dr. Max Bannach
European Space Agency (ESA), The Netherlands

Mr. Giacomo Acciarini
European Space Agency (ESA), The Netherlands
Dr. Dario Izzo
European Space Agency (ESA), The Netherlands

ON THE KEPLERIAN TSP AND VRP: BENCHMARK SETS AND ENCODING TECHNIQUES

Abstract

The Keplerian Traveling Salesperson problem (TSP) represents a special case of the conventional TSP, where the "cities" correspond to objects on Keplerian orbits. In this scenario, the salesperson is akin to a "spacecraft" or "ship," tasked with achieving rendezvous (matching position and velocity) with each orbital object while minimizing the required ΔV imparted by the onboard propulsion system, and possibly subject to other operational constraints, for example in the form of limits to the time of flight. Compared to the classical version of the TSP, which is an object of intensive research in computer science, the Keplerian TSP introduces novel elements of complexity. Node dynamics arises due to the non-linear movement of orbital objects over time, coupled with corresponding variations in the metric, specifically the cost associated with each orbital transfer. The Keplerian Vehicle Routing Problem (VRP) extends this concept further by involving multiple spacecraft that cover the designated targets collaboratively. The Keplerian TSP and VRP have surfaced in the past decade as compelling advanced trajectory optimization scenarios, notably featured in the Global Trajectory Optimization Competition series. These problems have been instrumental in automatically designing multi-rendezvous trajectories in the asteroid belt, effectively addressing challenges such as the asteroid selection problem. They also found applications in planning active debris removal missions and devising strategies for future asteroid mining endeavors. It is now widely acknowledged that tackling these complex problems, at a preliminary mission analysis level, within the framework of Keplerian TSP offers significant advantages over alternative approaches.

In this work, we establish and make available to the scientific community new benchmark sets of various difficulties for Keplerian TSP and VRP using asteroids from the main belt, Earth satellites from the Space Track catalog and subject also to the J_2 perturbation, and various data sets from the Global Trajectory Optimisation Competitions. We then present different encodings of these problems into well-known combinatorial optimization tasks including ILP and MaxSAT. Our primary emphasis is on addressing the intricate process of *unrolling time*, a pivotal step in translating dynamic problems like the Keplerian TSP into discrete optimization tasks. We investigate diverse methodologies for dynamically and automatically generating suitable time grids to surmount this challenge effectively in the context of spacecraft trajectories. We conclude our studies with an experimental evaluation of the various encodings using our new benchmark set and various ILP and MaxSAT solvers.