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AN ANALYTICAL LOW-THRUST CONTROL STRATEGY FOR LARGE CONSTELLATION DEPLOYMENT

Abstract

Over the past years, the international interest in large constellations, which are aiming to provide global telecommunications services with low-latency, is increasingly growing. The build-up of a large constellation would require staged deployments for multiple times. A feasible staged deployment method is to launch multiple satellites into a single injection orbit and then separate the orbital planes of satellites to the desired Right Ascension of the Ascending Nodes (RAANs) by exploiting the J2 effects. Using this method, this paper presents an analytical low-thrust control strategy for large constellation deployment, by finding analytical solutions for orbital elements and designing the switch sequence of low-thrust engine for every satellite. Compared with the previous works using numerical optimisation techniques, the proposed strategy needs little computational efforts, and thus it is applicable for large constellations composed of hundreds to thousands of satellites.

The deployment is decoupled into two steps, for the purpose of obtaining analytical solutions for orbital elements. The first step is to increase the semi-major axis with an in-plane tangential thrust, during which the inclination remains constant. The second step is to change the inclination and RAAN with an out-of-plane yaw thrust, during which the semi-major axis remains constant. In the second step, a weighting parameter, which indicates the location to switch the direction of yaw thrust in every revolution, is introduced to adjust the time rates of change of the inclination and RAAN. Note that during these two steps, the J2 effects will cause a drift in RAAN and latitude. Under the assumption of near-circular orbits, an orbital averaging technique is employed to eliminate the periodic motions related to the latitude, and then two sets of analytical solutions for orbital elements corresponding to tangential and yaw thrust are derived. To generate different RAAN and latitude drift rates among the satellites, the instantaneous orbital elements of satellites are required to be different from each other; this is addressed by designing the switch sequences of low-thrust engine for all satellites. Based on the analytical solutions, the switch sequence of low-thrust engine is determined for each satellite, by solving a coupled control equation which makes the desired RAAN and latitude satisfied at the end of the deployment. Finally, a trade-off analysis is conducted between the change in velocity and time of deployment, through which the feasible solutions, i.e. switch sequences of low-thrust engine and weighting parameter, for a given mission can be found.