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LUNAR CONSTELLATION DEPLOYMENT TECHNIQUES LEVERAGING NATURAL PERTURBATIONS

Abstract

The recent surge in lunar exploration has not only underscored the Moon as a pivotal stepping stone for Mars missions but also as a significant target for scientific research, technological advancements, and emerging market opportunities. This has led to a multitude of diverse lunar missions being planned and executed, potentially leading to a crowded lunar environment in the near future.

This situation necessitates the establishment of space infrastructures to provide recurrent services such as data relays, communication links, and navigation in the cislunar environment, thereby simplifying and enhancing the implementation and operation of individual missions.

In recent years, numerous studies have been conducted by various agencies for a sustainable, long-term infrastructure for lunar communication and navigation. In particular, the use of elliptical lunar frozen orbits (ELFO) is a common denominator of several studies, combining the benefit of orbital stability, visibility of the surface and of the Earth, and dilution-of-precision (DOP) figures of merit. In this context, this paper analyses and critically discusses alternatives for such constellation deployments within the lunar environment. The study delves into the analysis of natural perturbations effects and their possible exploitation, with a focus of the aforementioned ELFOs.

The study first analyses different strategies to maximise lunar coverage and enable communications and navigation, trading off the number of satellites and orbital planes against the transfer and deployment cost. It further explores the impact of these factors on communication and navigation performances. Then, a particular focus is given to the exploitation of natural perturbations, particularly the Earth's gravitational pull, to aid in the constellation deployment and achieve low-propellant solutions, which ease the spacecraft design and enable cost-reducing opportunities. Specifically, a plane separation strategy is proposed, drastically reducing the plane change Delta-V, giving an added value to those constellations which require large plane separation to achieve high DOP values.

Finally, a comprehensive understanding of the challenges and opportunities in deploying lunar constellations are provided, offering valuable insights for future lunar missions.