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Author: Dr. Maksim Shirobokov
Keldysh Institute of Applied Mathematics, RAS, Russian Federation, shirobokov@keldysh.ru

Prof. Mikhail Ovchinnikov
Keldysh Institute of Applied Mathematics, RAS, Russian Federation, ovchinni@keldysh.ru
Dr. Sergey Trofimov
Keldysh Institute of Applied Mathematics, RAS, Russian Federation, sertrofimov@yandex.ru

LUNAR FROZEN ORBITS FOR SMALL SATELLITE COMMUNICATION/NAVIGATION CONSTELLATIONS

Abstract

Satellite constellations have been serving for communication and navigation purposes for many years. Since 1960s, the overwhelming majority of orbital dynamics studies on the constellation design and optimization have been devoted to the Earth coverage problem. To ensure the global coverage, a symmetrical orbital configuration is usually considered, with several orbital planes equally distributed around the globe.

The recent strategies of the Moon exploration developed by the world's leading space agencies stimulate building the communication and navigation infrastructure in the near-lunar space. Contrary to Earth-orbiting constellations, lunar distributed satellite systems require a much higher deployment and maintenance cost. Moreover, the orbital dynamics environment is known to be much more complex, which prevents using most of the existing constellation theories based on Keplerian orbits or J2-perturbed orbits. To minimize the number of satellites in a constellation, medium or high lunar orbits are of primary interest. In this case, the major perturbation is due to the Earth gravity. It makes near-polar orbits unstable. Therefore, Ely and Lieb resorted to mid-inclined (40 deg) frozen orbits with the mean values of the eccentricity and the argument of periapsis both almost constant over a long time period. Six satellites in two orbital planes are proved to be sufficient for the global lunar coverage. An option of building a constellation in the lunar L1/L2 region is thoroughly studied by many researchers as well.

The orbital stability is even more important for a small satellites constellation. Such a constellation must be placed in low to medium lunar orbits due to antenna size/power limitations. On the one hand, this ensures low latency and eases the establishment of inter-satellite links. On the other hand, to avoid prohibitively high station-keeping costs, a designer has to solve the problem of how to select proper frozen orbits (note that lunar harmonics also come to play) for tens of satellites in the constellation. In this paper, we investigate low and medium frozen orbits of different altitude and inclination from the viewpoint of stability, lunar surface coverage, visibility of the Earth and some libration point orbits, revisit time for specified sites on the lunar surface, etc. To the best of the authors' knowledge, this research is the first attempt to systematically explore the potential of low- to mid-altitude frozen orbits for arranging a small satellite lunar constellation. Examples of leveraging the developed catalog of orbits in the design of communication/navigation satellite systems are given.