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LUNAR COMMUNICATION RELAY ARCHITECTURE DESIGN VIA MULTIPERIOD FACILITY LOCATION PROBLEM

Abstract

A reliable data link between the Earth and the Moon is primordial to support the upcoming, larger-scale crewed and robotic exploration of the lunar surface. The LunaNet concept, proposed by NASA, is planned as a flexible and extensible communications architecture for the Moon, connecting cislunar segments and the Earth. In anticipation of addressing needs for designing LunaNet Service Provider (LNSP) architectures, this work considers the design of lunar communication relay architectures that can adapt to evolving demands over time. The design optimisation is formulated as a novel adaptation of the multiperiod facility location problem (MFLP). The facility location problem (FLP) is a classic subject in the Operations Research community that has been studied and successfully applied to a wide range of terrestrial logistics applications, ranging from emergency services, telecommunications, healthcare, waste disposal management, and disaster response. For space-based applications, the FLP has previously been used for design problems in on-orbit servicing and asteroid mining. The FLP may be considered both in terms of continuous or discrete optimization problem. In the case of the latter, the FLP becomes a binary linear programming (BLP) problem, which can be solved efficiently through commercial LP solvers such as Gurobi and CPLEX. In this work, the BLP realization is adopted. The multiperiod facility location problem (MFLP) is an extension of the FLP that captures the time-varying demands of clients, such as shipment decisions, where there is seasonal shift in demand. In the context of lunar communication relay architecture, we consider increasing demands both in terms of uplink and downlink bandwidth as well as coverage. The initial phase involves limited bandwidth relay for limited spots on the lunar south pole, while this region is progressively increased to also include limited demands in equatorial regions on the far-side. This work considers the relay architecture to operate in the radio frequency (RF) band according to the LunaNet specification. Specifically, a relay system with 23 GHz for uplink and 27 GHz for downlink, with a data rate of 1 Gbps is considered. The MFLP formulation allows for the cost-optimal design of an evolving architecture that can adapt to multiple phases of demands, through the use of the optimal number of spacecraft deployed at optimal orbits at optimal times.