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INTEGRATED APPROACH TO OPTIMIZING SPACECRAFT VEHICLES AND OPERATIONS

Abstract

Current small satellite developers face the challenges of complex communication systems, the restrictions of on-board satellite power and data constraints, and competition for ground station resources. Our vision is to support multiple satellites performing science missions in concert, collecting data, communicating, and downlinking; enabling scientists to perform missions that have conventionally been impossible. For example, consider the proposed Armada science mission, consisting of 48 CubeSats. The spacecraft will exploit the Earth's oblateness effects to distribute and achieve global coverage and collect multi-point, in-situ atmospheric measurements. The Armada spacecraft have articulated solar panels, active attitude control, variable rate radios, opportunistic (uncertain) science collection and downlink opportunities, and compete for ground resources. The Armada subsystems and operations are tightly coupled, and therefore vehicle design and operational strategies are extremely difficult.

This paper presents analytic subsystem models for both the spacecraft and ground station. We include mathematical descriptions of the spacecraft subsystems, including attitude dynamics, attitude determination and control, power, communication, and mission requirements and constraints. Ground stations are modeled such that realistic link budgets and communication capacity can be analyzed. We consider dynamic federated ground station networks that are composed of geographically diverse stations that provide satellite connectivity.

The inherent interdependence of the vehicle subsystems results in significant complexity in the vehicle design and operational scheduling. Conventional approaches have independently designed the vehicle and operations at different stages of mission design, however we propose a formulation which integrates these two highly interconnected problems and solves them simultaneously. We formulate the optimization problem to maximize science return across the constellation of spacecraft and available ground stations. We include critical vehicle parameters such as the solar panel size and battery size as decision variables, which are often chosen early in the mission and can have important consequences in operational limitations. Scheduling decision variables include how and when to perform science operations and communicate with ground stations (including data transfer rates linked to the power and pointing constraints). Realistic constraints on mass, size, volume, cost, efficiency, availability of ground networks, and mission requirements are also included in the formulation, and relaxed appropriately to reduce problem complexity and solve time.

We present optimal vehicle designs and schedules for representative existing and proposed satellite missions and ground networks. The models and tools we develop provide a solution to inefficient and disjointed design strategies and enable rapid end-to-end mission design for the next generation of spacecraft constellations.