26th IAA SYMPOSIUM ON SMALL SATELLITE MISSIONS (B4)
Interactive Presentations - 26th IAA SYMPOSIUM ON SMALL SATELLITE MISSIONS (IP)

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SIMULATING DISTRIBUTED SMALL SATELLITE NETWORKS: A MODEL-BASED TOOL TAILORED TO DECENTRALIZED RESOURCE-CONSTRAINED SYSTEMS

Abstract

Current societal and environmental needs have spurred the design of new Earth observing systems capable of providing global coverage and high-resolution imagery with shorter revisit times, and near-real-time data access. Large-scale, distributed satellite missions encompassing single-instrument satellites in multiple orbital planes are naturally suited to address these requirements. In parallel, the consolidation of the CubeSat era has fostered the value proposition of complex system-of-systems that hybridise small-satellite technologies with traditional space assets. Current large constellations of small-satellites, like Planet's Flock, have ushered in Distributed Satellite Systems (DSS) as feasible alternatives to implement new Earth Observation systems. Furthermore, many DSS concepts have suggested the deployment of heterogeneous satellite systems wherein spacecraft communicate through Inter-Satellite Links (ISL) to coordinate collective sampling, maintain flight formation, or offer in-orbit data services.

Two enabling technologies are critical for designing novel DSS: (1) ISL and inter-satellite networks (ISN); and (2) autonomous decision-making. Satellite-to-satellite communications and network protocols are critical features for collaborative and/or opportunistic coalitions like the ones envisioned by Federated Satellite Systems. On the other hand, the ability to operate these large-scale, potentially heterogeneous DSS in an autonomous manner is regarded as a critical enabler given their dynamic nature (i.e. incrementally deployed, evolvable, decentralised), and to deliver most of the promised system-level qualities (responsiveness, adaptability, resilience, robustness).

Up to now, the engineering efforts that tried to validate these operational characteristics (Inter-Satellite Networks and autonomous operations) have either relied upon generic mission analysis tools—unable to simulate packet-level performance—, or generic network simulators—which do not simulate space dynamics and subsystems out-of-the-box. This paper presents an integral model-based simulation framework that has been specifically tailored to DSS, and which aims at becoming a tool for the design of new ISN protocols and autonomous operational schemes. The software presented in this paper leverages the modelling paradigm and event-based simulation provided by the Network Simulator-3 (NS-3) and extends it with a customizable environment where researchers can model satellite subsystems and communications, on-board resources, and autonomous satellite behaviours. This software has been paired with space visualisation tools to provide a modular and flexible framework that allows the simulation of: (a) resource constraints in small satellite platforms; (b) heterogeneous constellations; (c) Machine-to-Machine (M2M)

interactions; (d) in-orbit data services; (e) the impact of communications upon resources; and (f) decentralised autonomous operations. This paper details the software architecture, user configurability and model-based environment, and show results of representative simulations that validate the platform.