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MULTIDISCIPLINARY DESIGN OPTIMIZATION OF EDGE COMPUTING IN SPACE FOR ADVANCED SATELLITE MISSIONS

Abstract

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Satellite system design is a problem of several highly constrained and inter-dependent budgets. As satellite missions heighten in complexity, there is a need for spacecraft equipped with greater intelligence and autonomy. This calls for onboard, real-time decision-making abilities on weight- and power-constrained processors, one of the most challenging of all "edge computing" problems. Autonomy in satellites is a function of advancement in satellite technology, artificial intelligence, and computing hardware. For example, the trend towards larger distributed constellations of satellites calls for orbital "edge sensing" and "edge communication" capabilities to overcome the limiting nature of traditional bent pipe communication architectures. Consider another example, in the case of Earth Observation Satellite Systems (EOSS), satellites must manage the several terabytes of data collected daily requiring massive amounts of visual and sensor data to be inferenced and managed using an onboard processor. This is necessary to overcome the network bottleneck that occurs when sensor data rate exceeds bandwidth. The Starlink constellation of satellites employs edge computing for automated conjunction warning and collision avoidance maneuvers to keep constellation satellites safe from space debris and other non-cooperative targets. By endowing spacecraft with processing capacity, data may be processed directly in orbit either on-site or by another satellite of the constellation. Achieving this level of autonomy necessitates the processing of vast amounts of visual and sensor data in real time, all within the constraints of onboard processors, data storage, power and energy sources, and thermal management. Greatly complicating the problem of edge computing in space is the constraint that all the in-situ computing generates in-situ heat. Even on Earth, large computing facilities are intentionally located near water bodies for cooling the vast amounts of heat generated. In space, the thermal problem is far more challenging because the only mode of heat dissipation is radiation (recall the Stefan-Boltzmann law). Radiators take up valuable mass, and water bodies are not quite conveniently located. In this paper we perform a multidisciplinary design optimization(MDO) analysis of the tradeoffs that occur when onboard computing capacity of advanced mission satellites is heightened, and apply the framework to three satellite classes where edge computing is necessary. Each satellite class presents a unique challenge: data and bandwidth efficiency for an Earth Observation Satellite(EOS), autonomous navigation for an Active Debris Removal (ADR) satellite,

bandwidth and communication constraints for a Mars Orbiter Mission (MOM), and energy and thermal constraints for all.