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INITIAL FORMULATION OF A TIME VARYING DYNAMIC GRAPH DECENTRALIZED OPTIMIZATION FRAMEWORK FOR SCALED SATELLITE NETWORK INFRASTRUCTURE OPERATIONS

Abstract

The optimization of satellite network infrastructure plays a critical role in ensuring effective data transmission, communication, and resource allocation in space. As the number of satellites and complexity of in-space operations continue to increase, traditional centralized optimization methods are poised to become a limiting constraint to overall network performance, leading to the exploration of decentralized optimization techniques.

The goal of this paper is to illustrate the initial formulation of a time varying dynamic graph framework for decentralized optimization of scaled satellite networks. Key research questions addressed in our work are the performance characterization of dynamic space networks as well as the quantification and comparison of asymptotic performance limitations of centralized and decentralized optimization algorithms for managing satellite operations. The goal of our research is to estimate threshold numbers by which decentralized operations become necessary or provide substantial advantage compared to traditional centralized satellite operations.

Decentralized optimization involves distributing the optimization process across multiple nodes in the network, allowing each node to make decisions based on its own data, constraints, and partial knowledge of the other nodes. Under certain operational assumptions on network topology and knowledge uncertainty, that are explored in this paper, decentralized approaches offer superior performance over traditional centralized management of satellite network operations, including improved reliability, data latency, scalability, and robustness.

The paper will present our initial results in exploring the benefits and drawbacks of decentralized optimization for satellite networks. It identifies the conditions to determine the envelope of operational advantage of decentralized operations over centralized satellite network management. We demonstrate our approach on a toy problem, and illustrate its application on an Earth Observation use case, building the case for the use of decentralized optimization in dynamic resource instantiation in virtual satellite missions. Our work aims at identifying fundamental conditions and operational criteria for designing future decentralized satellite networks in support of the growth of the satellite population in orbit, as well as more sustainable use of limited in-space resources such as orbit allocations and radiofrequency spectrum use.