Concept: A Shared-Sensing Satellite Network

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Abstract

This report explores the concept of a shared-sensing satellite network, emphasizing autonomous collaboration, efficient communication protocols, and the application of advanced discrete simulation techniques. The proposed framework has significant implications for satellite formation flying, orbital debris tracking, and collision avoidance strategies.

1 Introduction

The increasing complexity of satellite missions necessitates robust frameworks for autonomous collaboration. Current Earth-based radar systems are limited in tracking smaller debris and localized phenomena. This report proposes a novel framework for a shared-sensing satellite network, where satellites autonomously detect, prioritize, and share critical information. Inspired by principles of Parallel and Distributed Event Simulation (PDES), this approach optimizes data exchange and decision-making processes.

2 Conceptual Framework

2.1 Localized Sensing Advantage

Satellites equipped with advanced sensors can detect small debris and faint objects beyond the reach of Earth-based systems. By leveraging their unique perspectives, these satellites form a distributed sensing network.

2.2 Targeted Information Sharing

Unlike traditional broadcast systems, the proposed network employs selective communication protocols. Satellites prioritize sharing critical information, reducing redundant data transmissions and conserving bandwidth.

2.3 Key Components

1. **Obstacle Discovery and Sharing**: Satellites detect objects within their local sensing range and decide on data dissemination based on relevance.

2. **Selective Communication Protocols**: A hierarchical or need-to-know communication structure ensures efficient data exchange.

3. **Latency vs. Bandwidth Optimization**: Critical messages (e.g., collision warnings) are transmitted with low latency, while data-heavy tasks are shared selectively.

3 Simulation Challenges and PDES Integration

The proposed framework draws heavily from PDES principles to simulate distributed satellite networks:

- **Optimistic Synchronization**: Satellites independently simulate future states and reconcile discrepancies through shared data.
- **Spatial Partitioning**: The orbital domain is divided into regions managed by local satellite nodes, minimizing global communication overhead.
- **Causal Messaging**: Communication follows logical event chains to ensure relevance and minimize redundancy.

4 Practical Implications

4.1 Collision Avoidance

Real-time shared sensing enables satellites to proactively adjust their orbits, reducing collision risks.

4.2 Debris Tracking

A unified satellite network enhances our ability to track and predict the paths of orbital debris.

4.3 Autonomous Cooperation

Satellites operating autonomously reduce the burden on ground-based operators, improving mission efficiency.

5 The Achates Obstacle Course

To validate the proposed framework, we introduce the "Achates Obstacle Course," a simulated environment for satellite formations:

- **Scenario Setup**: Satellites navigate through a debris field, sharing localized data to maintain formation.
- **Objectives**: Test distributed awareness and decision-making algorithms.
- **Outcomes**: Identify communication bottlenecks and optimize decision latencies.

Appendix

Conference Details: ACM SIGSIM PADS 2025

The *39th ACM SIGSIM Conference on Principles of Advanced Discrete Simulation (PADS 2025)* will take place from June 23-26, 2025, at the Drury Plaza Hotel in Santa Fe, New Mexico. For more details, visit https://sigsim.acm.org/conf/pads/2025/.

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