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Collaborative Autonomy for Space Situational Awareness

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ABSTRACT

Tracking satellites is an important component of space situational awareness (SSA). However, current ground-based tracking approaches rely on **centralized** detection and require **hours** to accurately estimate an orbit. A constellation of low-cost, **autonomous** cube satellites could provide a **fast** and robustly **decentralized** architecture for SSA. We propose **distributed particles filters** as a method to iteratively refine orbit estimates with **low communication** bandwidth. We demonstrate the feasibility of this approach by implementing our algorithm in **simulation**. This simulator can also be used to evaluate the parameter space for future satellite constellation design, as well as test the system's robustness to failures.

PROBLEM

GOAL
Fast, robust, distributed orbit determination of multiple targets

CHALLENGES
- Imperfect knowledge (e.g., noisy sensing, faulty clocks)
- Limited communication (low bandwidth, occlusion)

SYSTEM
Targets: Satellites in geosynchronous orbit
Observers: Multiple cube satellites with sensors in low-earth orbit
Hub: Ground-based center for coordination and communication
Communication:
CubeSat ↔ CubeSat: Line-of-sight light beaconing, low bandwidth
Hub ↔ CubeSat: Overhead satellites, higher bandwidth

ALGORITHM

1. OBSERVATION
- Take 10–30 s bserviations of target
- Estimate streak endpoints with Monte Carlo sampling
- Convert to cartesian endpoint positions (using sampled range)

2. PRELIMINARY ORBIT DETERMINATION
- Compute Keplerian orbit parameters (6) for each endpoint pair

3. PARTICLE FILTER
- Incorporate all orbit estimates into 6D particle filter for target
- Resample particles for uniform weight

4. BROADCAST
- Broadcast particles to any other sats within range (~1 particle/s)
- Send most informative particles

5. RECEIVE AND INCORPORATE
Incorporate particles from other observers into orbit estimate

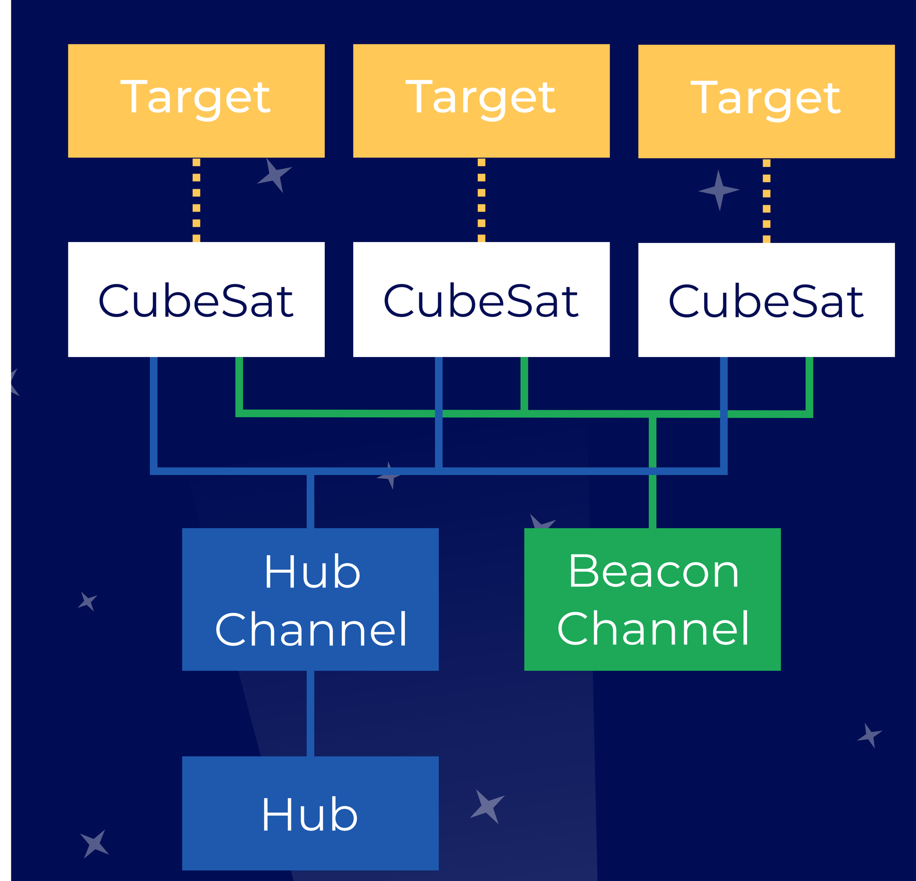
TARGET SELECTION
- Observers individually select target to observe from common set
- Observe unoccluded target with least certain orbit estimate

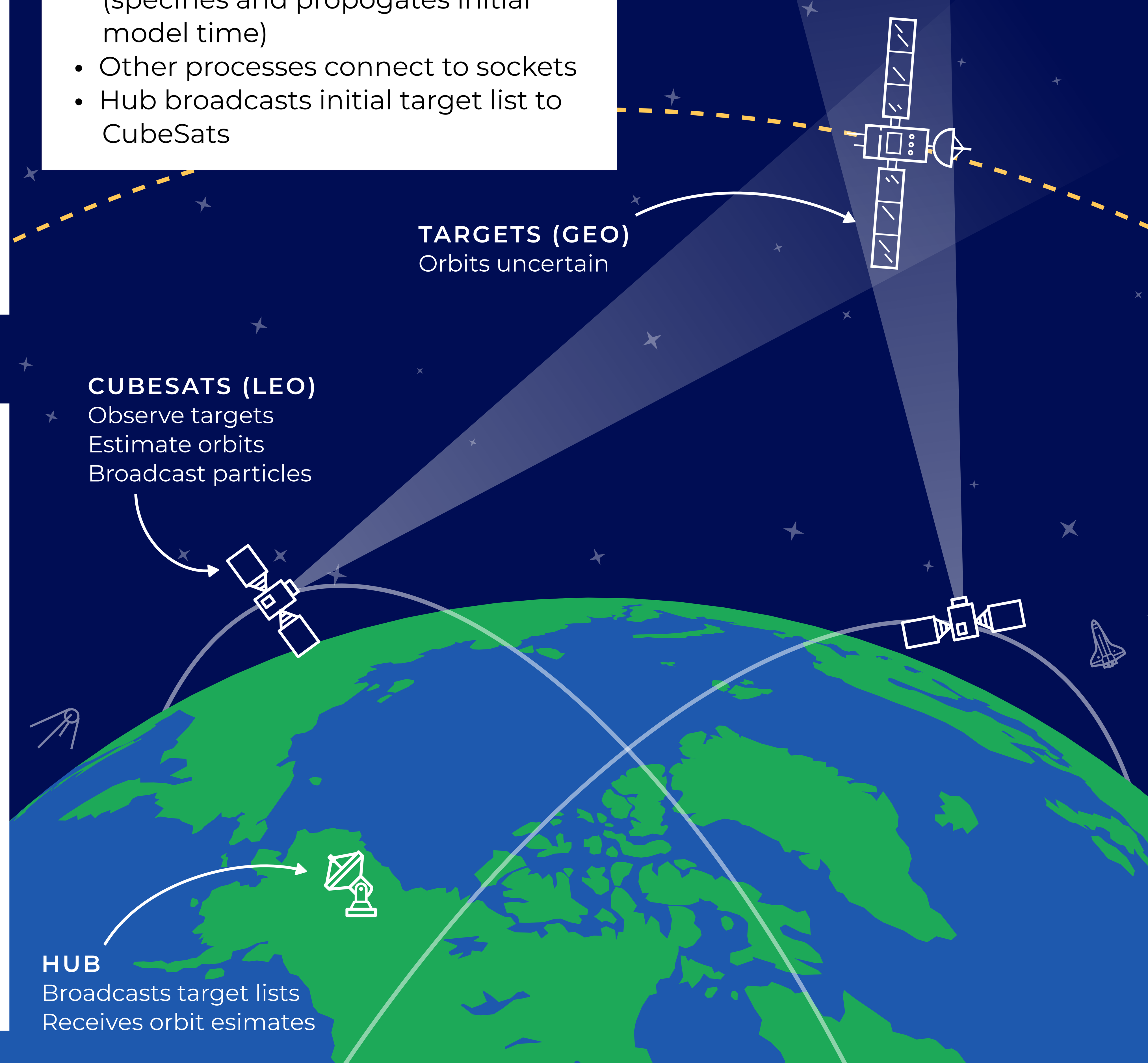
SIMULATOR

SYSTEM ARCHICTURE
- Separate modules to represent each CubeSat, communication channel, and hub
- Shared custom wire protocol with bandwidth and latency constraints
- Targets represented within

IMPLEMENTATION
- Modules are multi-threaded Python processes
- TCP/IP communication over sockets
- TLEs specify ground truth orbits
- Scaled real-time clocks (implicit synchronization, allows drift and communication latency)

USAGE
- Launch hub channel process (specifies and propogates initial model time)
- Other processes connect to sockets
- Hub broadcasts initial target list to CubeSats



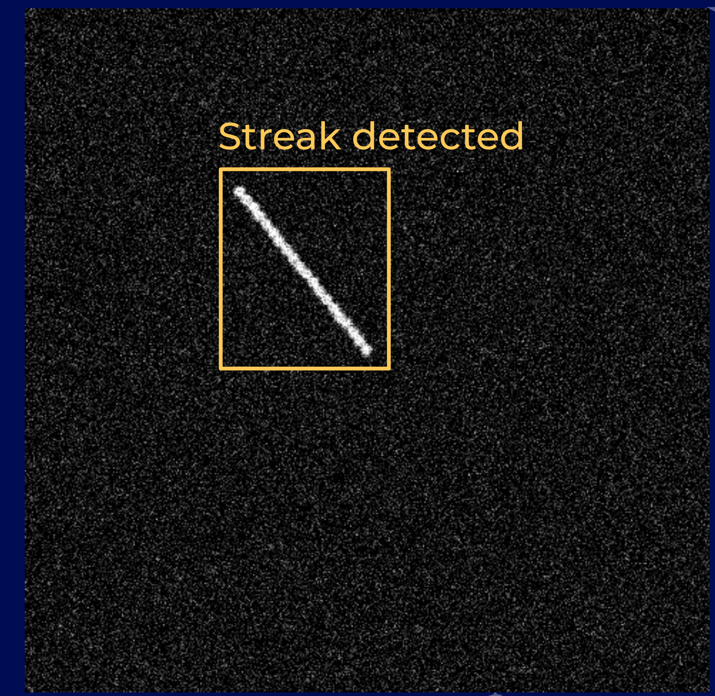


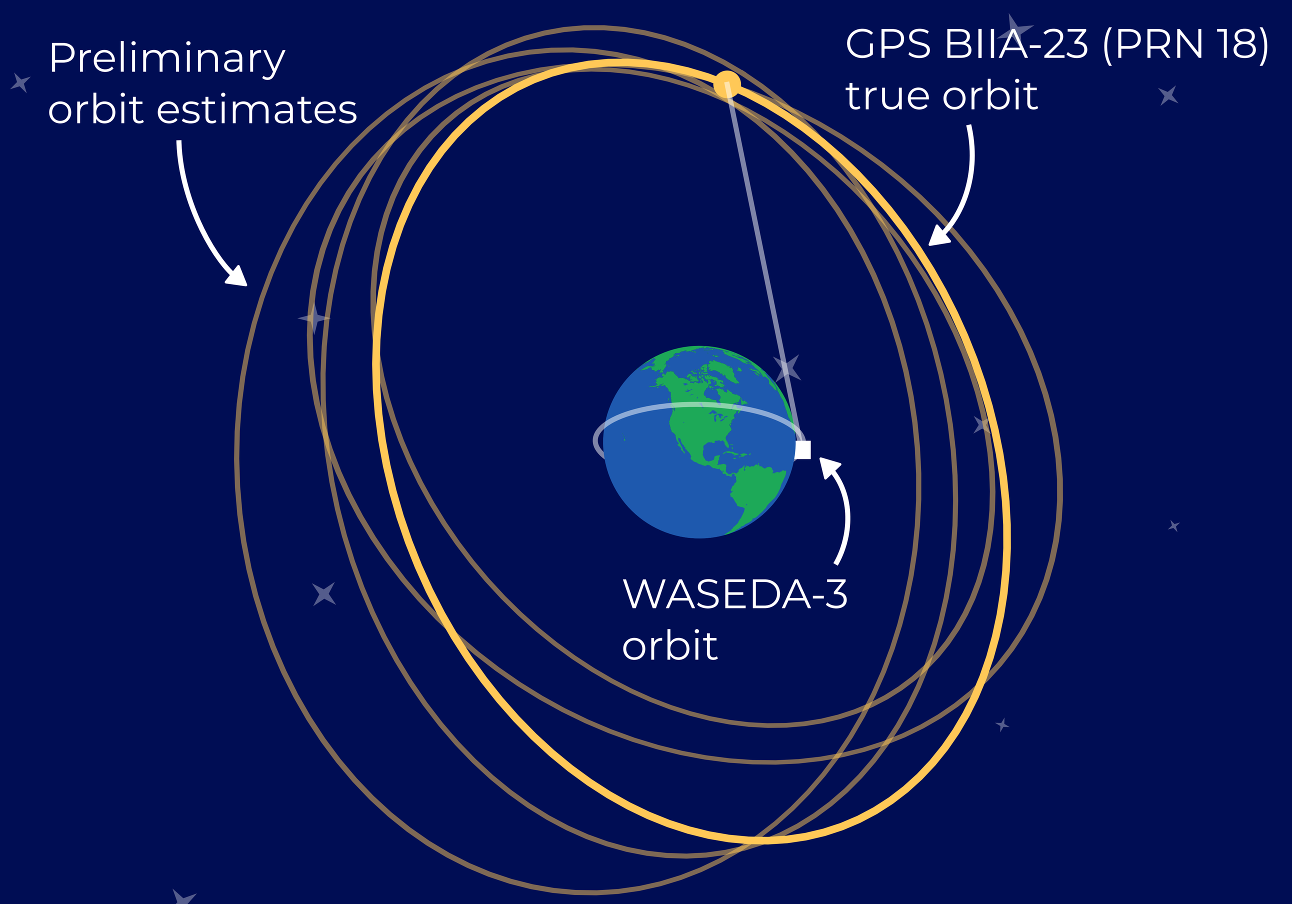
PROGRESS & RESULTS

Observer: WASEDA-3
Target: GPS BIIA-23 (PRN 18)
Time: 2018-07-11 3:11:01 UTC

1. 10 s exposure from CubeSat
2. Streak detection
3. Preliminary orbit estimation

In progress: Integration of orbit determination and particle filter into simulator.





DISCUSSION & FUTURE WORK

CONCLUSION
- Algorithm can successfully estimate GEO orbits from LEO
- Distributed simulator allows for integrated testing of orbit determination and system design

SYSTEM EVALUATION/UTILIZATION
- Monte Carlo simulations to optimize system parameters (e.g. number and orbit of CubeSats, sensor design)
- Test system robustness to Byzantine failures

EXTENSIONS
- Frame tradeoffs in bits of information for optimization: e.g., choice of what to communication, where to observe
- Improved target selection: Determine heuristics ahead of time for optimal selection without online Bayesian forward modeling

REFERENCES
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