SPRINT

Scheduling Planning Routing Intersatellite Network Tool

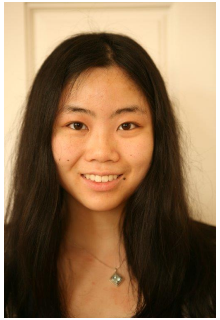
PI: Dr. Kerri Cahoy

NASA Partners: Dr. Jeremy Frank (ARC), Gary Crum (GSFC)

Student Contributors: Mary D., Juliana C.

The Team

Mary Dahl
First year graduate student
marydahl@mit.edu



Juliana Chew
Undergraduate (Junior)
jlchew@mit.edu

- Dr. Kerri Cahoy
  - PI
- Joe Kusters
  - Graduate student
- NASA Partners:
  - Dr. Jeremy Frank (ARC)
  - Gary Crum (GSFC)

Previous team members: Kit Kennedy (creator of the project), Bobby Holden, Warren Grunwald

A. Kitrell Kennedy, "Planning and scheduling for earth-observing small satellite constellations", Massachusetts Institute of Technology, 2018.

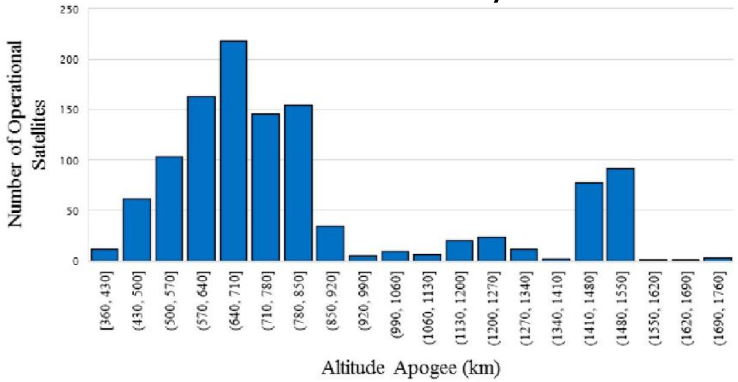
B. Holden, II., "Onboard distributed replanning for crosslinked small satellite constellations", Massachusetts Institute of Technology, 2019.

W. Grunwald, "Decentralized On-board Planning and Scheduling for Crosslink-enabled Earth-observing Constellations", Massachusetts Institute of Technology, 2019.

Affordability Brings New Problems

- With the advent of smallsat technology and rideshares, space is filling with satellites
- Constellations continue to grow

Satellites in Orbit by Altitude



[1]

[2]

Constellation	Orbcomm	Planet Flock/Dove	Iridium NEXT	SpaceX Starlink	OneWeb
Year First Launched	1991	2013	2017	2018	2019
Satellites (On orbit / Planned)	31	200	75	1385 / 41493	146 / 716

How do we manage the operation of such large constellations?

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Satellites for Disaster Relief

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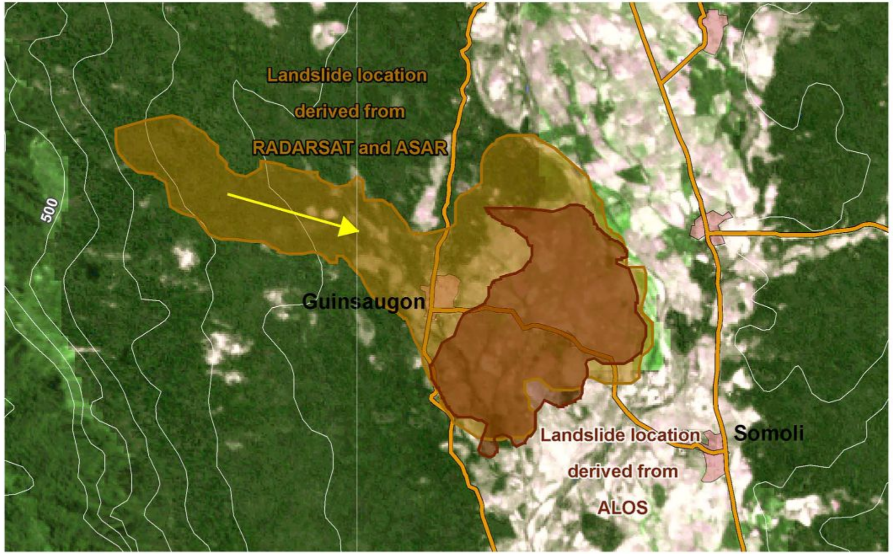
- Earth observing satellites can provide key updates during ongoing natural disasters
- Even if satellites are in orbit over affected areas, if their mission is not to image them, it can be difficult to get commands up and data back down in time.



How can we ensure the most information we can reaches the ground as quickly as it can?

We need a framework to plan how to get data down fast AND be able to change plans on the fly.

SPRINT: Planning and Replanning

- SPRINT is able to replan on the fly to ensure no images are missed out on
- Automate operations for resource-constrained Earth-observing constellations with hundreds of smallsats
- Urgent data routing cleanly handled using crosslinks
- Applicable for future distributed and swarm missions

[4]

Metric	Threshold	Goal
Latency	≤ 1 hour	≤ ¼ hour
AoL	≤ 1 hour	≤ ½ hour
Time for plan	≤ 1.5 hour	≤ 1 hour

Planning and scheduling metrics

SPRINT: Technology Summary

- **Global** planner for high level optimization
- **Local** planner for real time replanning
- Protocol for distribution of plan changes across constellation

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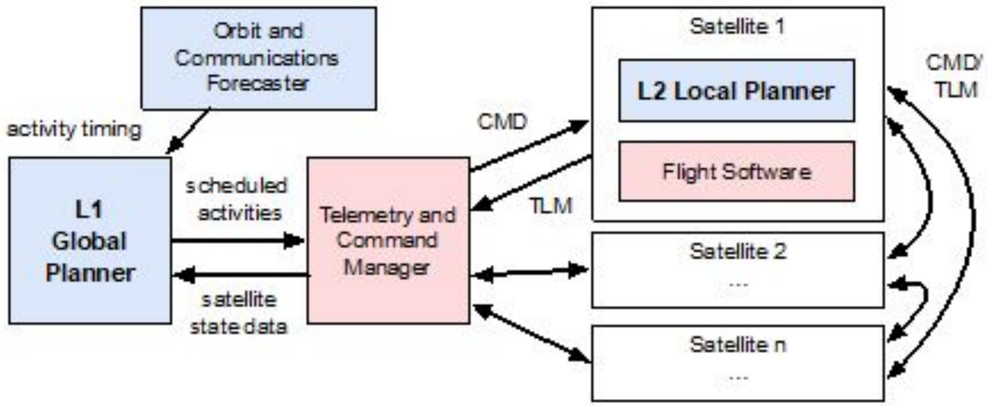

Open source release available:
https://github.com/MIT-STARLab/SPRINT

Software Architecture Overview

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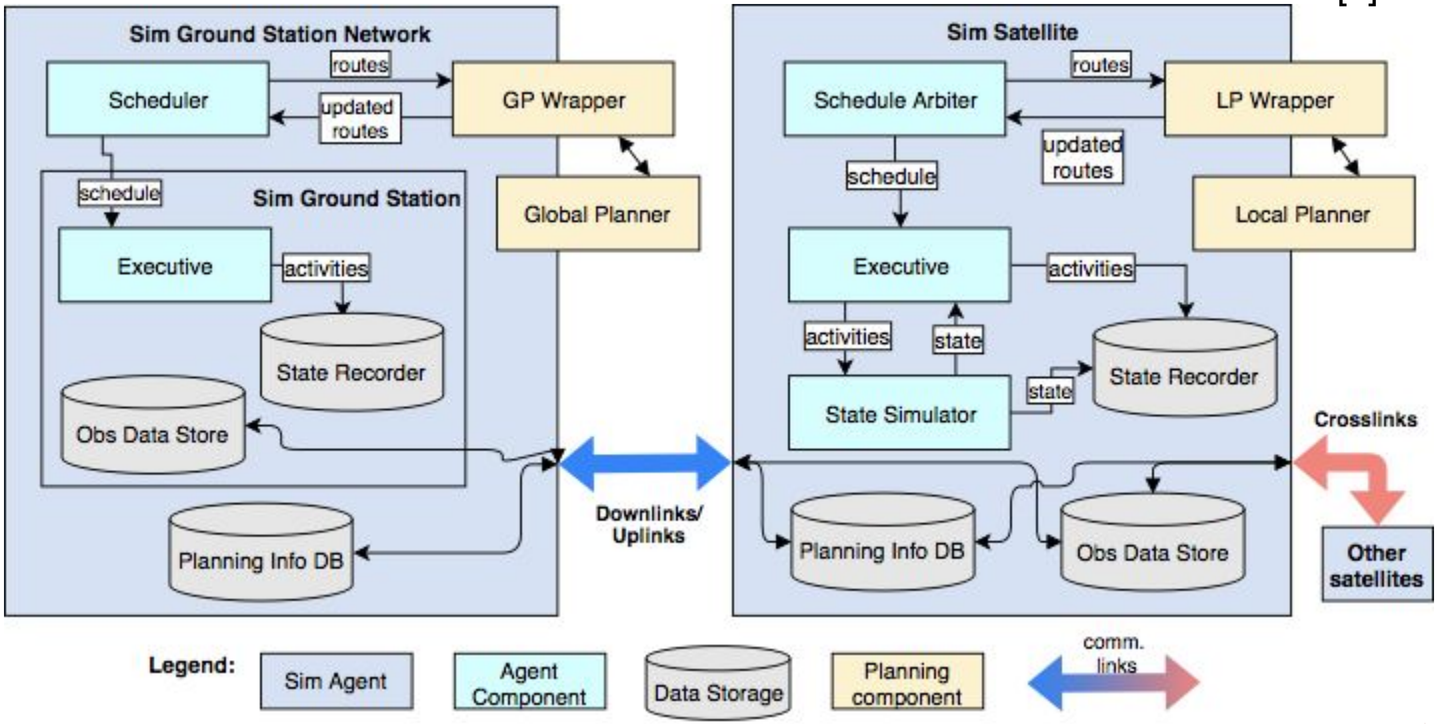
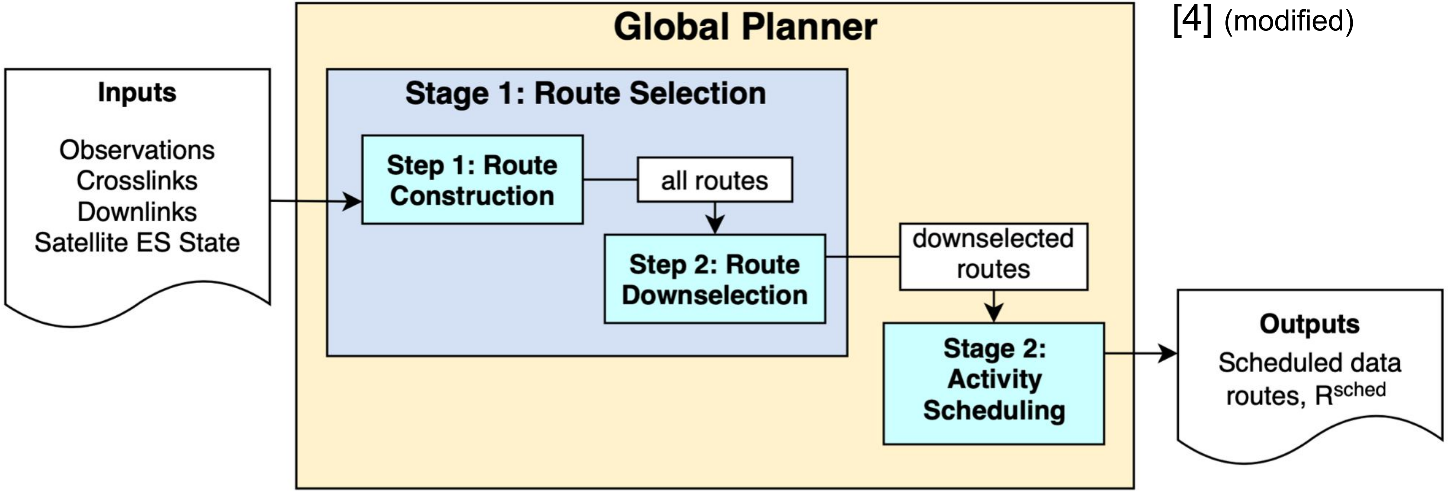


(from Andrew Kennedy's thesis defense 2018)

Global Planner

- Centralized, ground-based P&S algorithm
- Single, integrated MILP scheduling solution

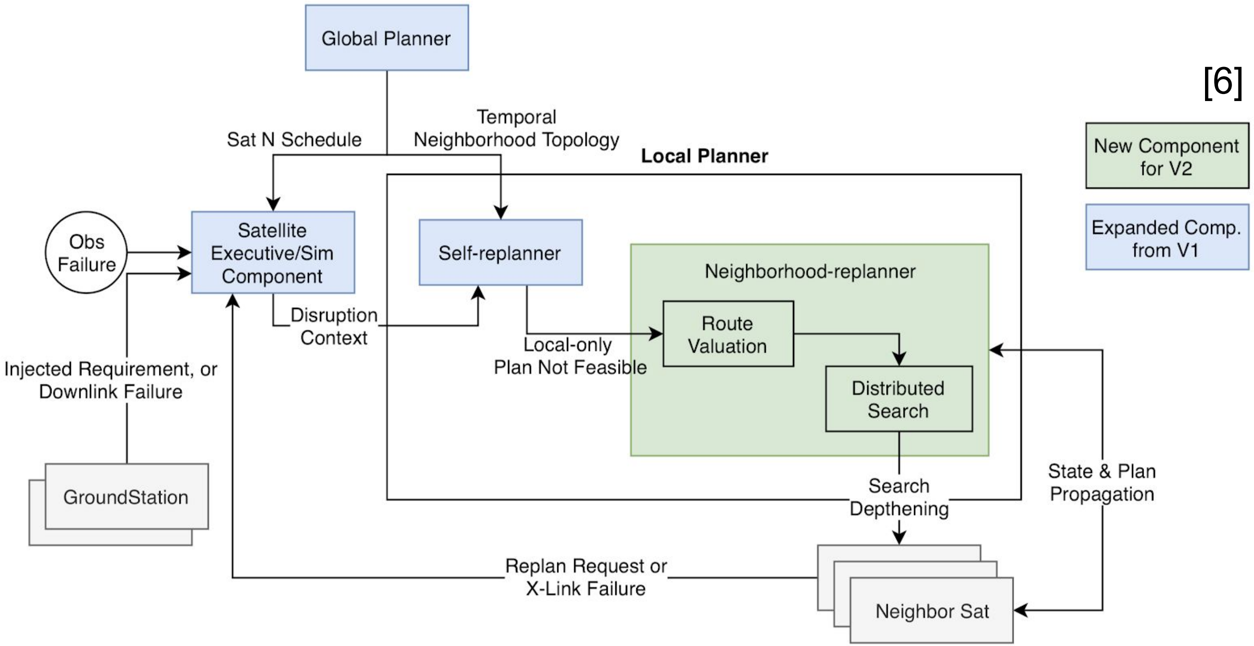


[4] (modified)

Local Planner

- Runs on each satellite
- Performs local, realtime replanning
- Communicates plans to other satellites and ground stations

[6]



Example Cases

	TROPICS No xlink	TROPICS** w/xlink	CYGNSS Nominal	CYGNSS Less GS	Cicero Nominal	Cicero Less GS
Number of Sats	6*	6**	8	8	24	24
Number of Ground Stations	3	3	4	1	11	7
Number of Observation Targets	20	20	20	20	20	20

*not close enough for crosslinks
**modified to have crosslink capability

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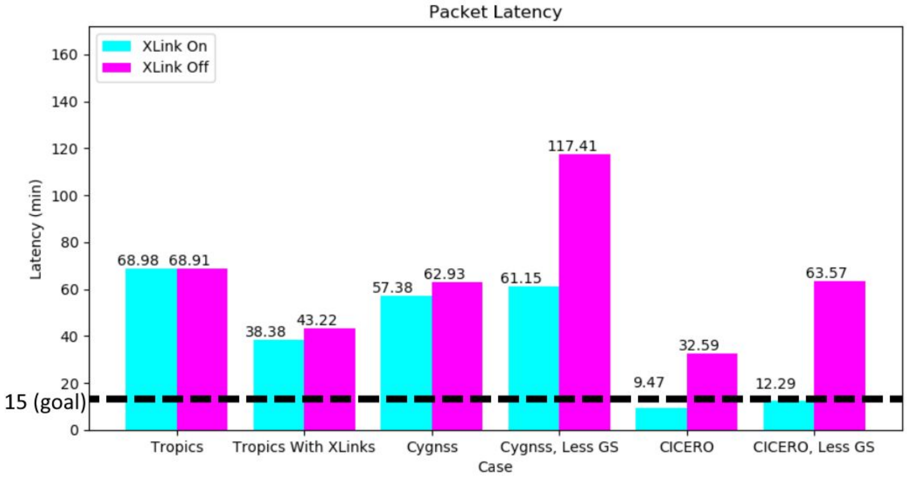
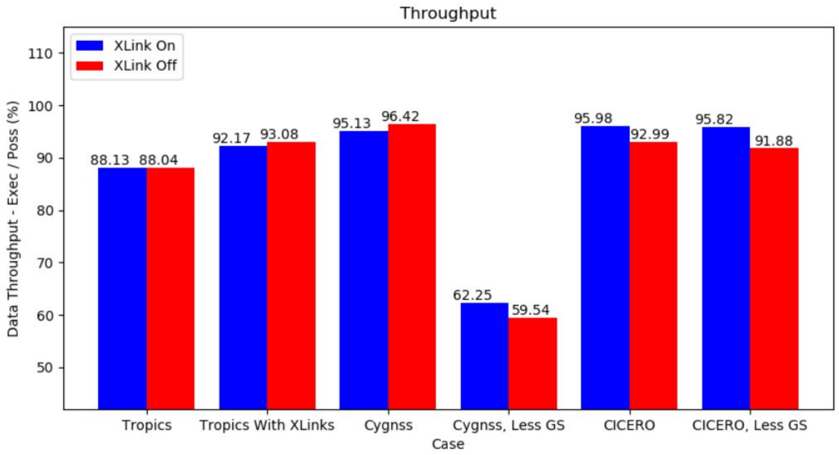
Effectiveness of SPRINT

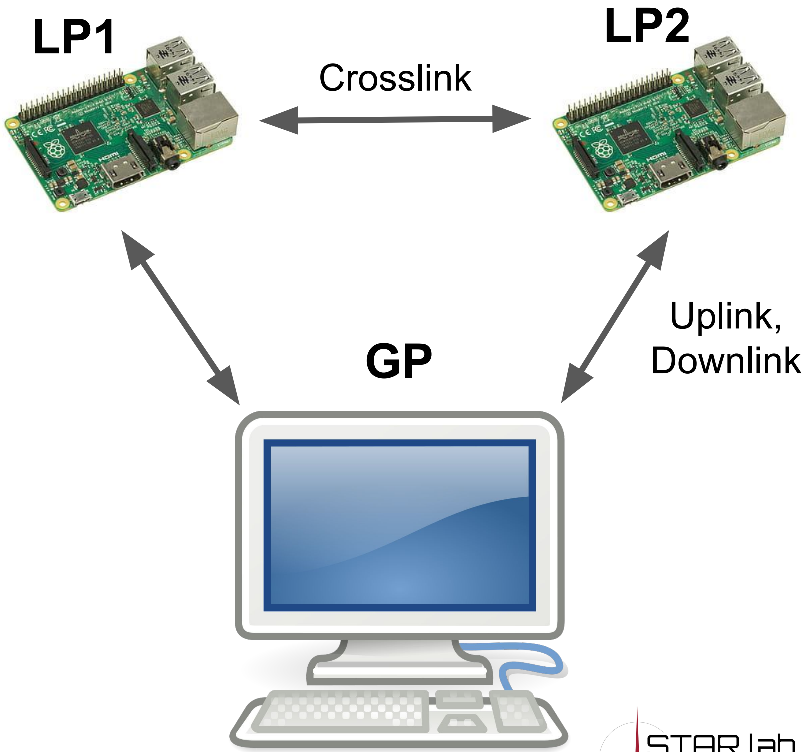
- Optimize for amount of data delivered and latency
- Simulations show some improvements on existing constellations, especially for latency
- **CHARTS NOT FINAL: WILL BE UPDATED**





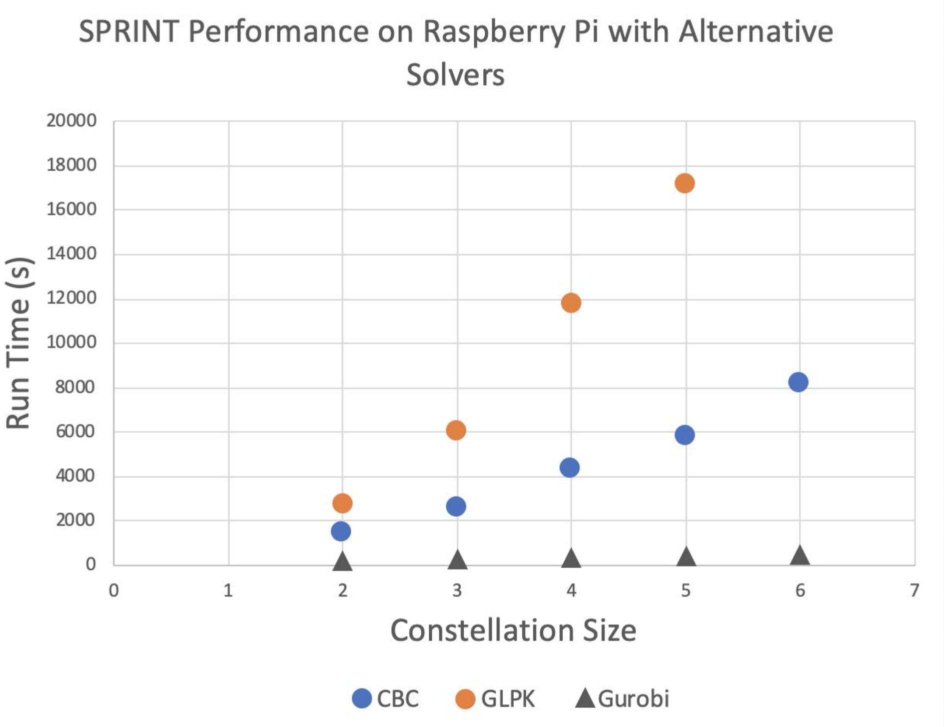
The Hard Road to Hardware

- Raspberry Pi
- A Separated Simulation
  - Each Pi is a satellite
  - Computer is ground station network and simulation manager
- Status
  - Modeling links with multiple satellites with socket programming
  - Next Up: Optimization



Different solvers on Raspberry Pi

- Gurobi is incompatible with ARM processors
- CBC is a possible alternative
- GLPK appears infeasible
- Currently investigating SCIP compatibility



*Gurobi run on Macbook Pro
*GLPK for 6 satellites was stopped after 24 hours

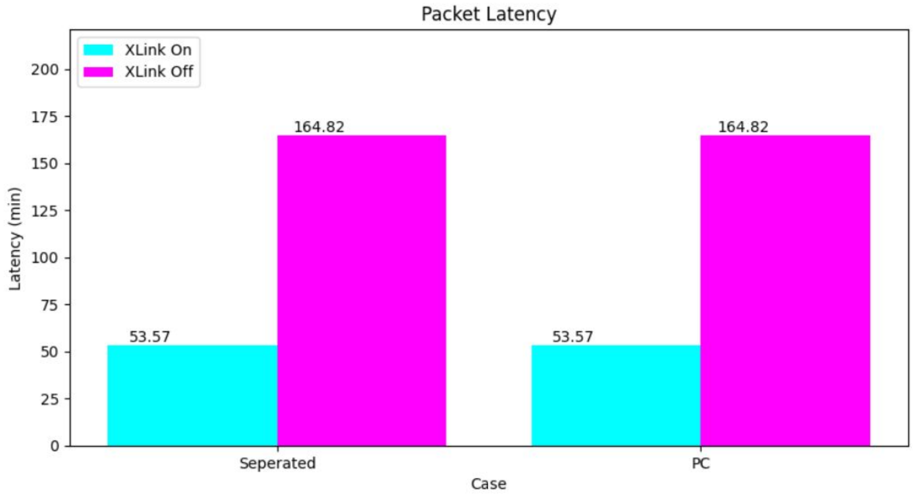
Example Cases for Only Hardware

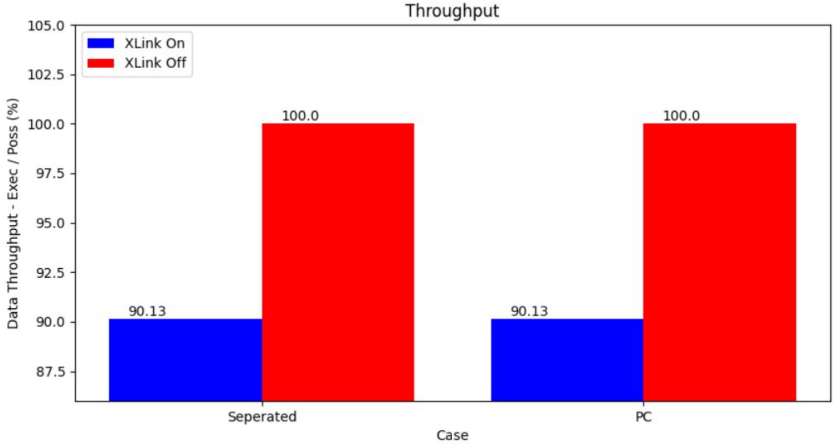
Number of Sats	2
Number of Ground Stations	2
Number of Observation Targets	5
Number of Schedule Interruptions	3

Video Demonstration

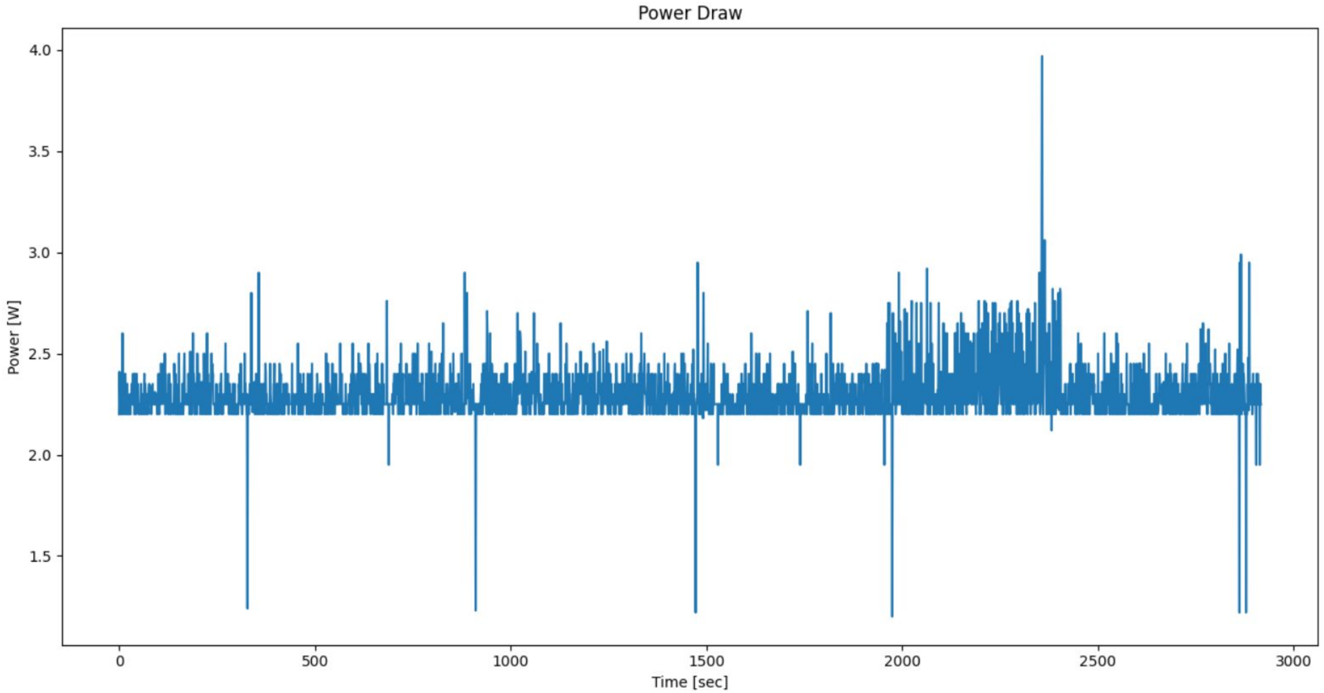
Results of Hardware

Hardware has the same performance as standalone sim.





Hardware Power Draw



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TRL and Space Readiness

Phase 0

- Simulation and planner code development
- Performance analysis
- Initial open source release

Phase 1

- Hardware software development
- Unit testing **(We are here)**
- Multiple flight-like C&DH boards running simulation for extended time

Phase 2

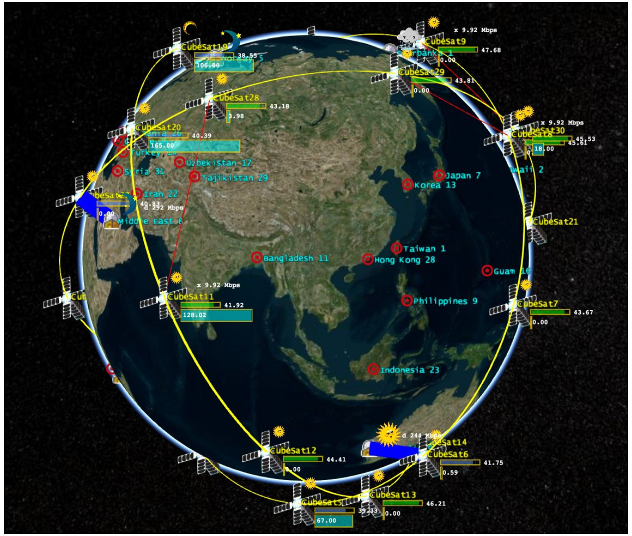
- Development of mission of 2-3 CubeSats with crosslink capabilities
- Environmental testing
- In-Space Demonstration

Phase 3

- Scaled up CubeSat demonstration mission
- Software development for additional small satellite platforms

Future Work and Tests

- Optimization of separated simulation and scaling up to more hardware
- Integration of additional features
    - ADCS, avoidance path planning, propulsion
- Implementation of genetic algorithms for dynamic constellation design
    - User-specified objective to optimize (cost, age of information, data volume)
- Preparation for Open-Source and “Pro” Versions for research
    - “Pro” version interfaces with higher end chips, open-source version offers RPi support
    - In collaboration with industry*
- Plans for demonstration mission



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* NGC and PSS

Thank you!

Any additional questions or inquiries should be directed to marydahl@mit.edu

Sources

[1] R. G. Perea-Tamayo, C. M. Fuchs, E. Ergetu, and L. BingXuan, “Design and Evaluation of a Low-Cost CubeSat Communication Relay Constellation,” in *2018 IEEE MTT-S Latin America Microwave Conference (LAMC 2018)*, Dec. 2018, pp. 1–4, doi: 10.1109/LAMC.2018.8699047.

[2] https://www.newspace.im/

[3] S. Voigt, T. Kemper, T. Riedlinger, R. Kiefl, K. Scholte and H. Mehl, "Satellite Image Analysis for Disaster and Crisis-Management Support," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 45, no. 6, pp. 1520-1528, June 2007, doi: 10.1109/TGRS.2007.895830.

[4] A. Kitrell Kennedy, “Planning and scheduling for earth-observing small satellite constellations”, Massachusetts Institute of Technology, 2018.

[5] A. Kitrell Kennedy. “Initial Results from ACCESS: An Autonomous CubeSat Constellation Scheduling System for Earth Observation”. Massachusetts Institute of Technology, 2017.

[6] B. Holden, II. “Onboard distributed replanning for crosslinked small satellite constellations”, Massachusetts Institute of Technology, 2019.

Backup Slides

SPRINT: Project Goals

- Develop and implement planning and scheduling algorithms for imaging constellations
- Create simulation framework to simulate constellations and their operations
- Create planner to run both on small satellites and ground stations
- Reduce data delivery, latency, revisit time, and improve efficiency
- Create open source toolset for research