An Overview of Distributed Spacecraft Autonomy (DSA)

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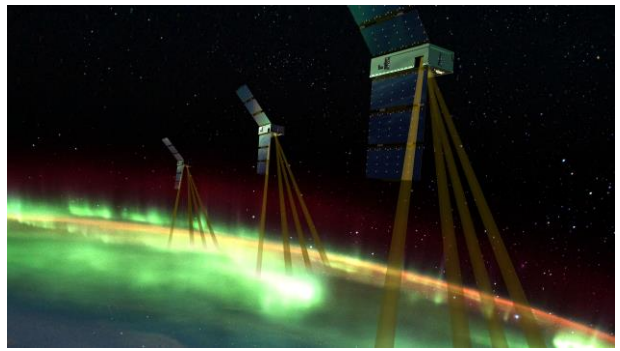
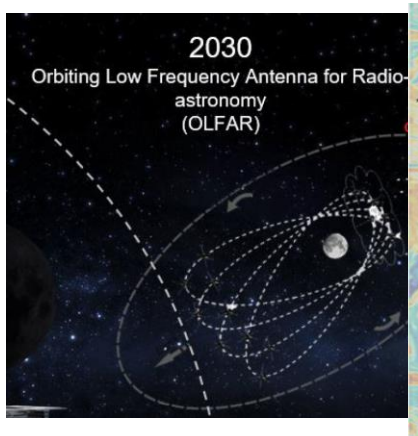
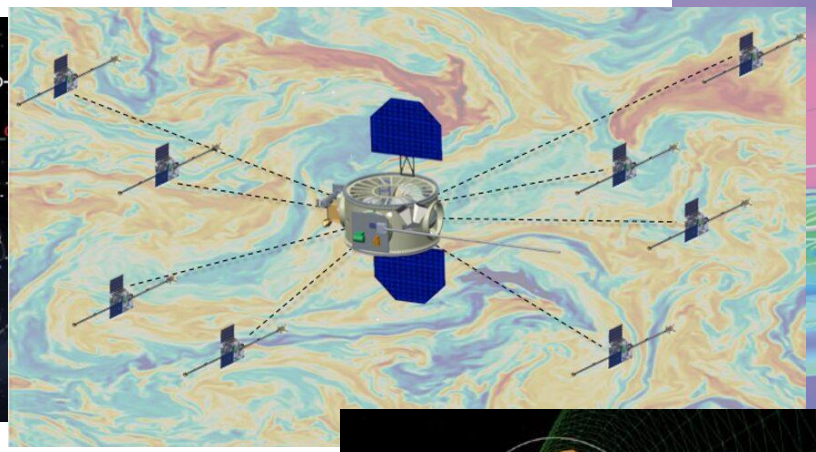
Distributed Space Systems



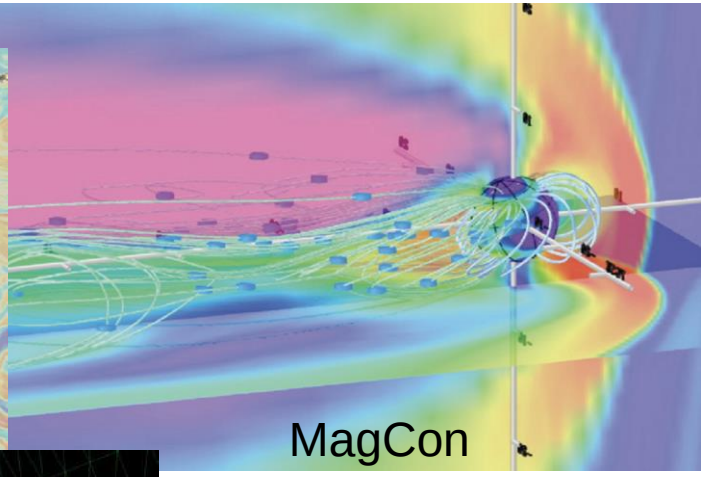
EZIE



OLFAR

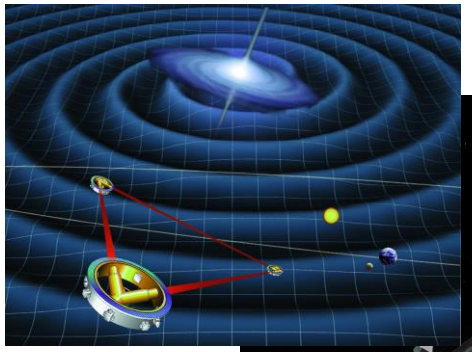


HelioSwarm

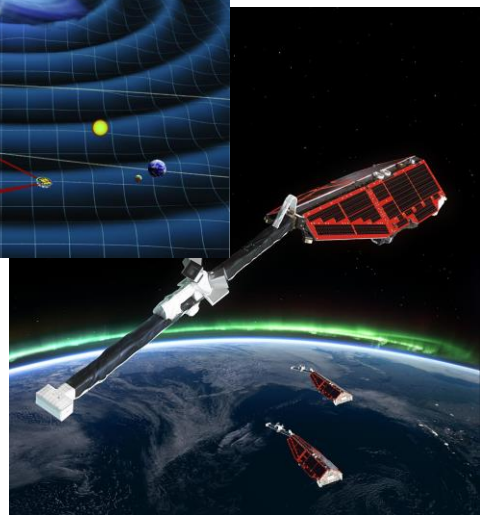


MagCon

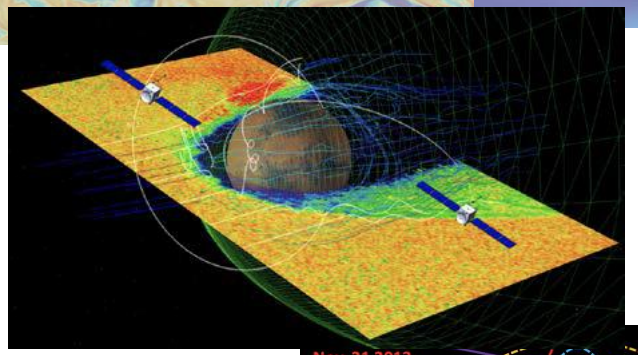
Pléiades Neo



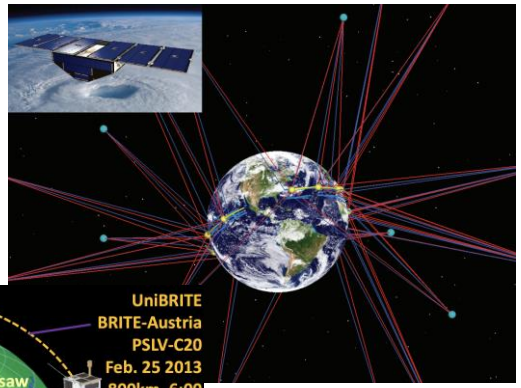
LISA



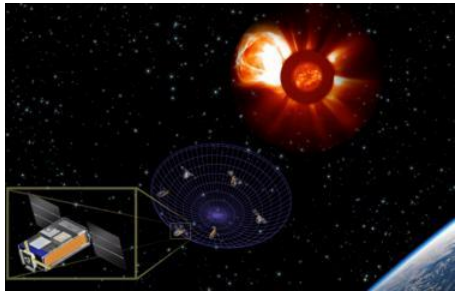
SWARM



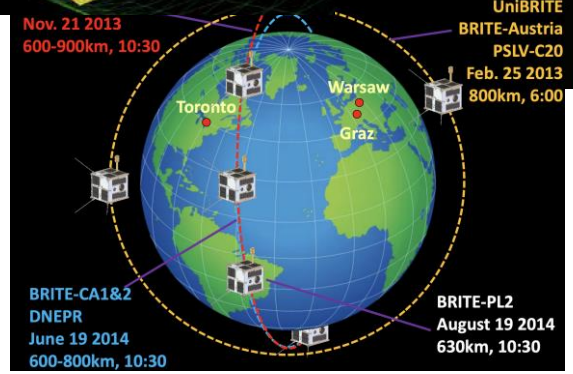
ESCAPADE



CYGNSS



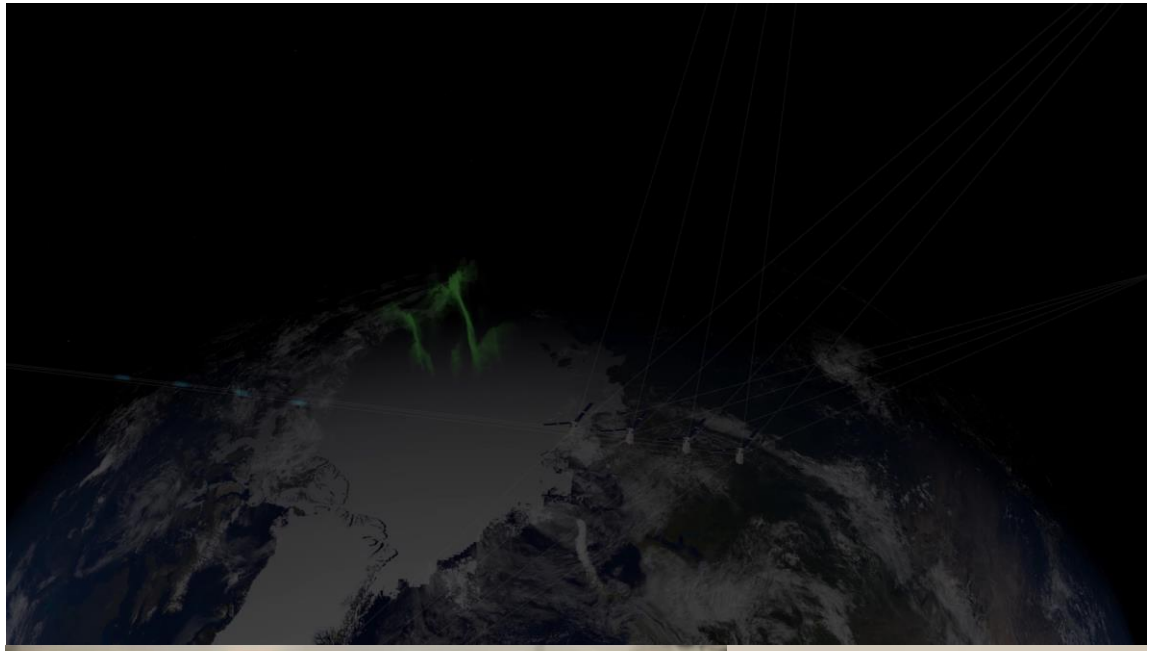
SunRISE

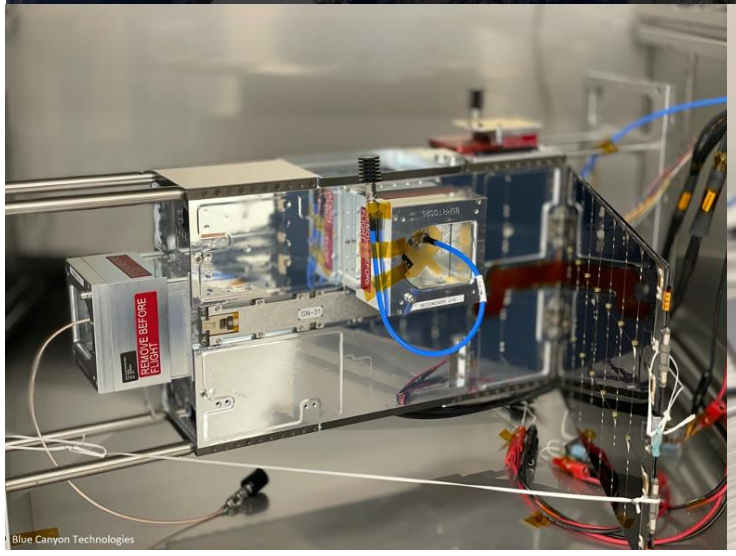


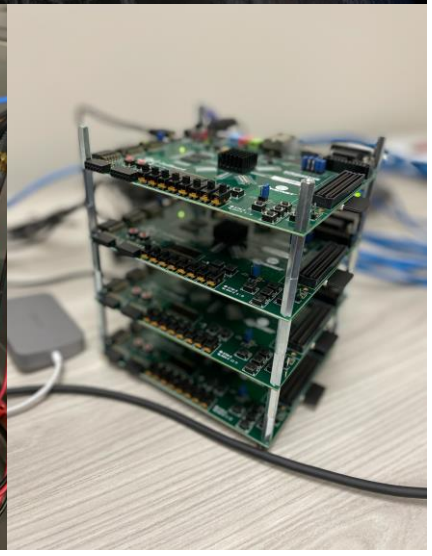
BRITE

Motivation for an Autonomous DSS

- Autonomous decision-making is needed for multi-spacecraft missions due to:
  - latency
  - bandwidth constraints
  - mission complexity
- Autonomy can significantly increase the effectiveness of missions by operating them as a collective rather than individually
- DSA's first and primary demonstration is as a software payload on the Starling 1.0 mission
  - Starling 1.0 is a DSS
  - Starling 1.0 consist of 4 6U CubeSats
- Scalability Study
  - Use case: Lunar Position, Navigation and Timing
  - 21-100 spacecraft at the Moon: increased mission complexity
  - Simulation vs flight mission







Bottom left: A Starling 1.0 satellite during integration and testing
Bottom right: A DSA PiL Stack used for integration and testing

Technical Focus Areas

Distributed Resource and Task Management: demonstrate Executive and Scheduler software modules which are extended from existing single-spacecraft approaches to coordinate large number of independent distributed assets

Reactive Operations: develop algorithms to refine model and optimize collection strategy; leverage algorithms appropriate for dynamic sensing and other real-time adjustments to operations

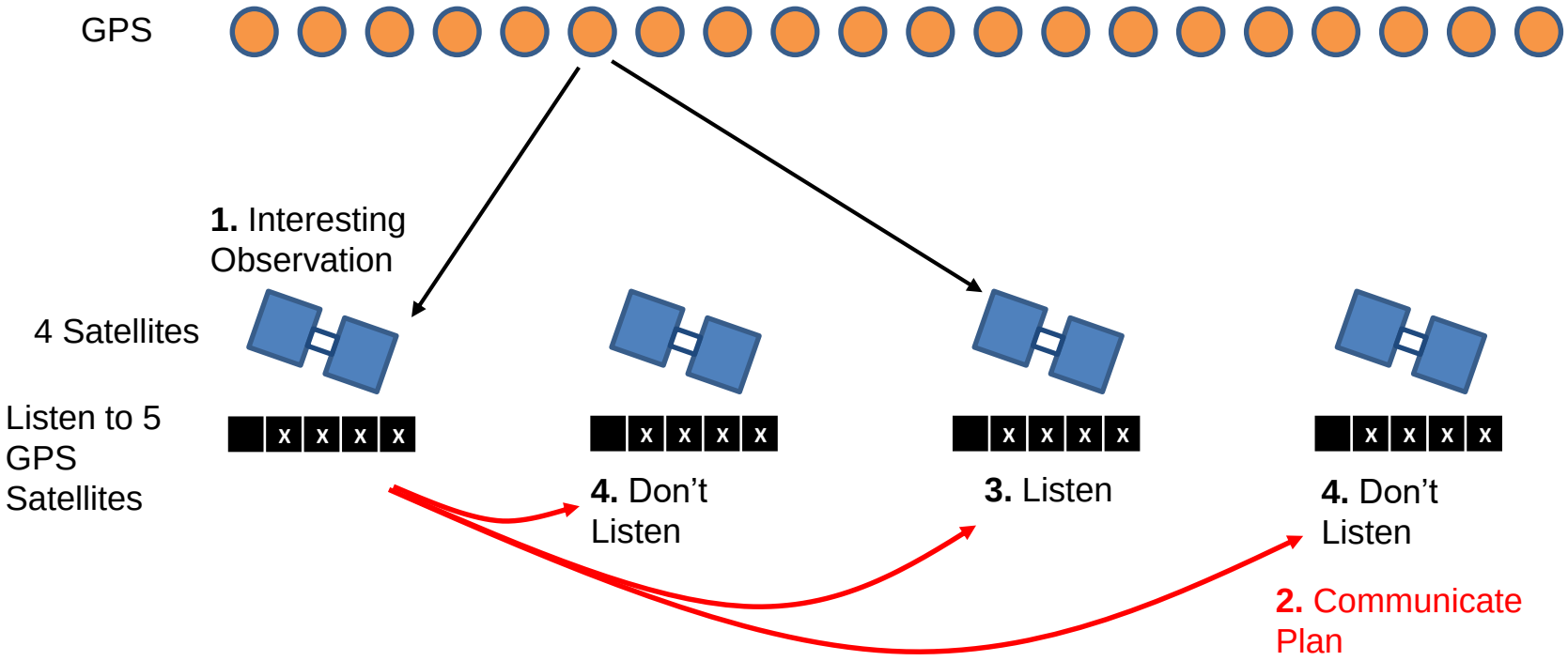
System Modeling and Simulation: capture desired mission capabilities as models of system functions and then iteratively refine these models for scalability

Human-Swarm Interaction: ground control software that enables the ability to command and interact with the spacecraft as a collective

Ad hoc Network Communications: communication infrastructure that is scalable, robust, and automatically self-configuring

DSA Technical Focus: Distributed Resource and Task Management

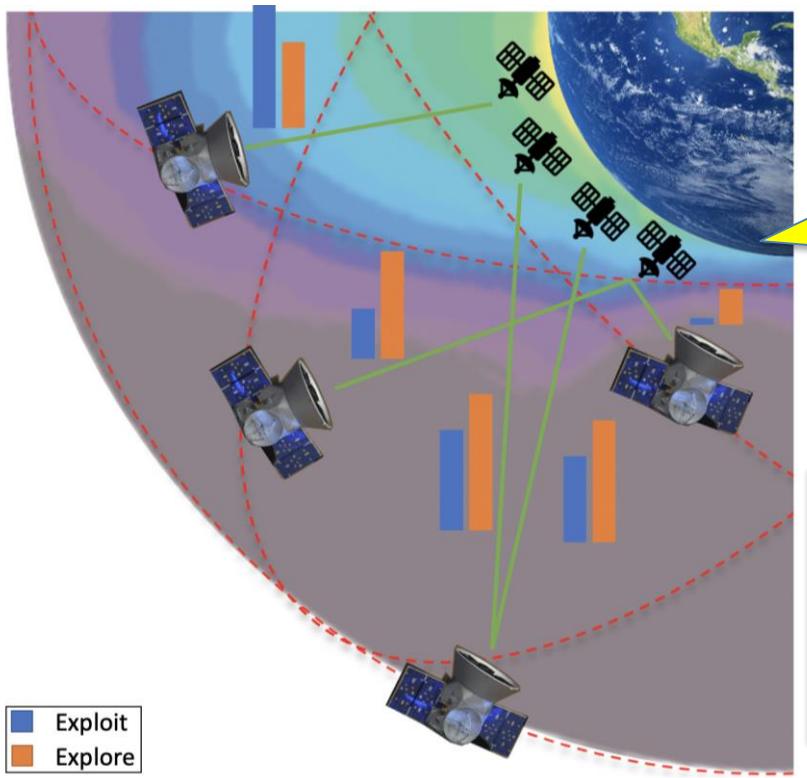
Swarm controllers should manage tasks scalably and collectively.



Spacecraft should generate, communicate, and execute their own schedules.

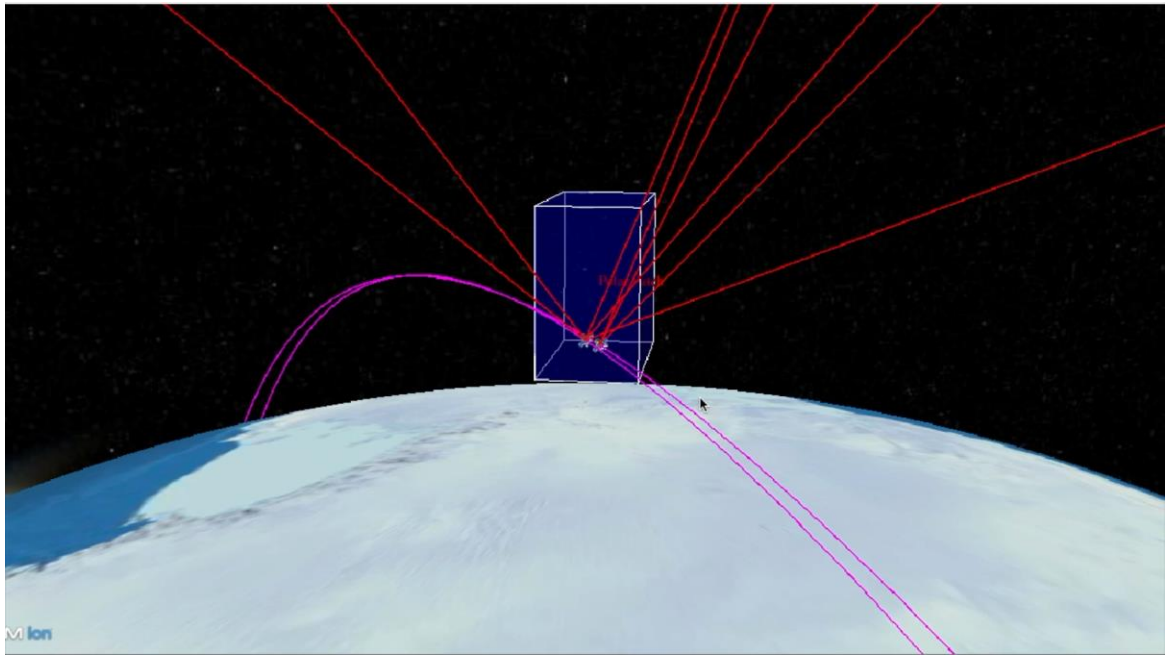
- Some amount of flexibility will always be needed for each spacecraft. Example: to achieve full coverage generate a plan based off current knowledge, communicate it to the rest of the autonomous DSS, then execute

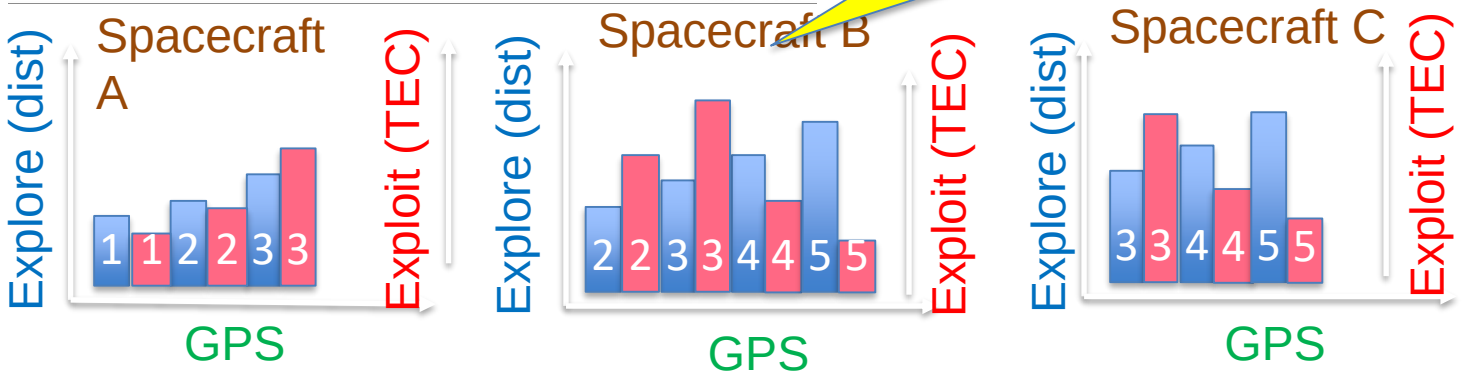
DSA Technical Focus: Reactive Operations



DSA-Starling swarm reacts to a feature, coordinate to cover 'best' GPS satellites

Local information determines benefit of monitoring GPS channel



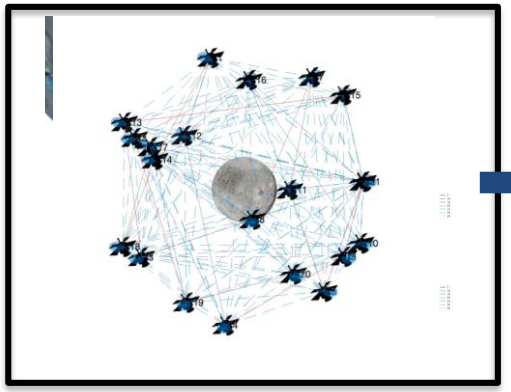


Proposed Autonomy Solution

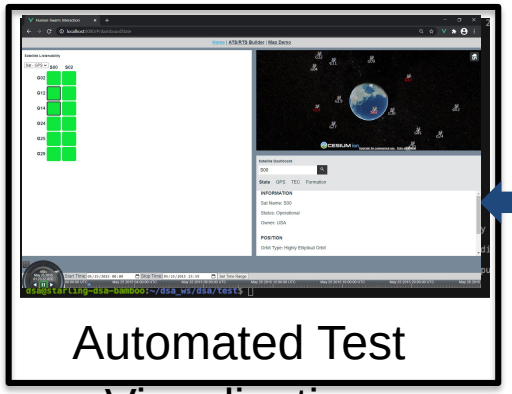
- **Maintain data consistency** of GPS satellites through network
- Each satellite selects channels using ***context*** from the rest of the swarm

DSA Technical Focus: System Modeling and Simulation

Preprocessed Simulation Data

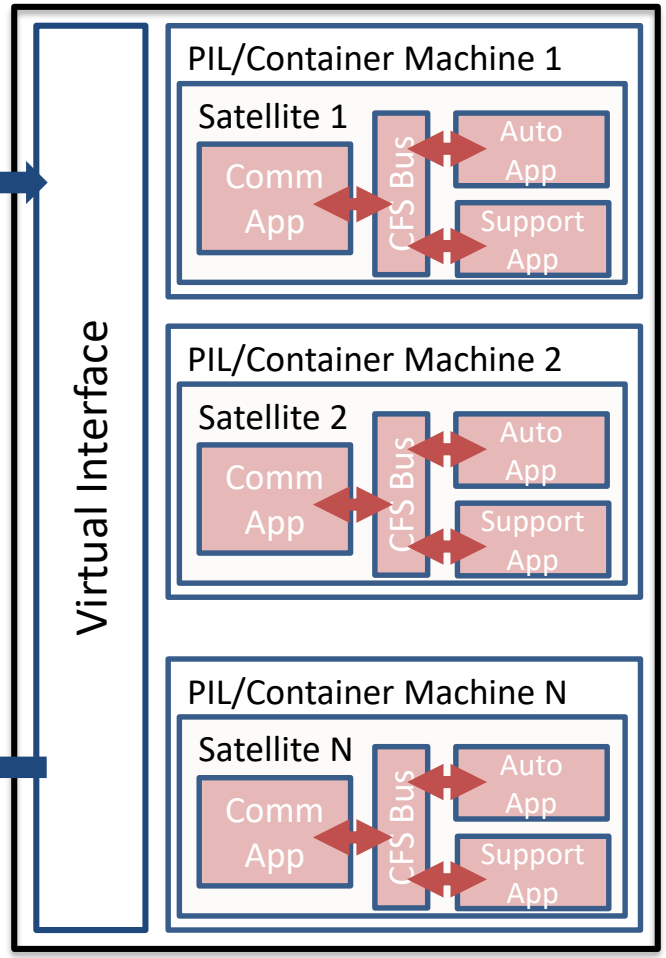


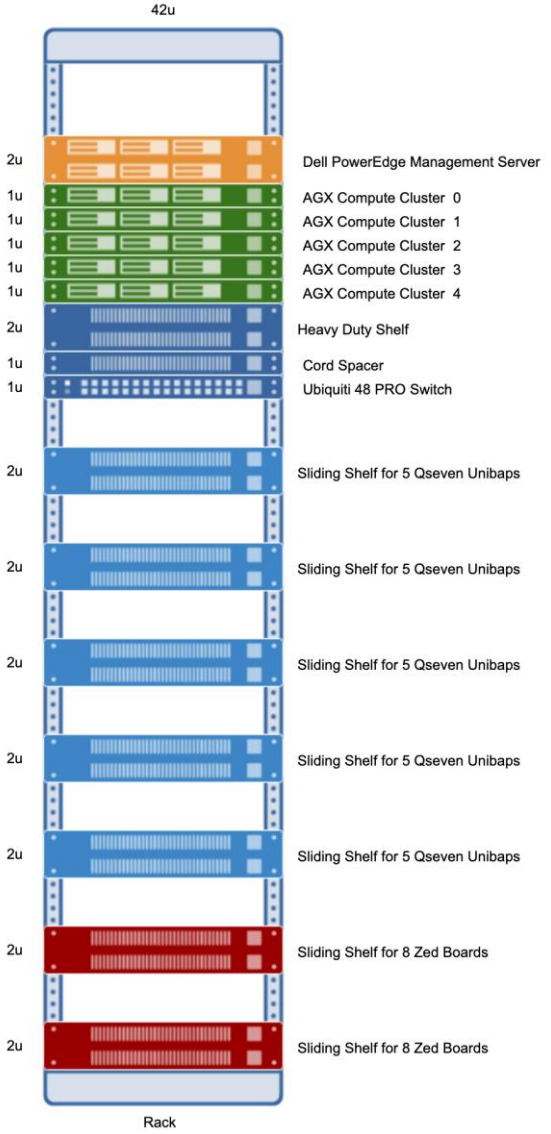
Post Processed Results

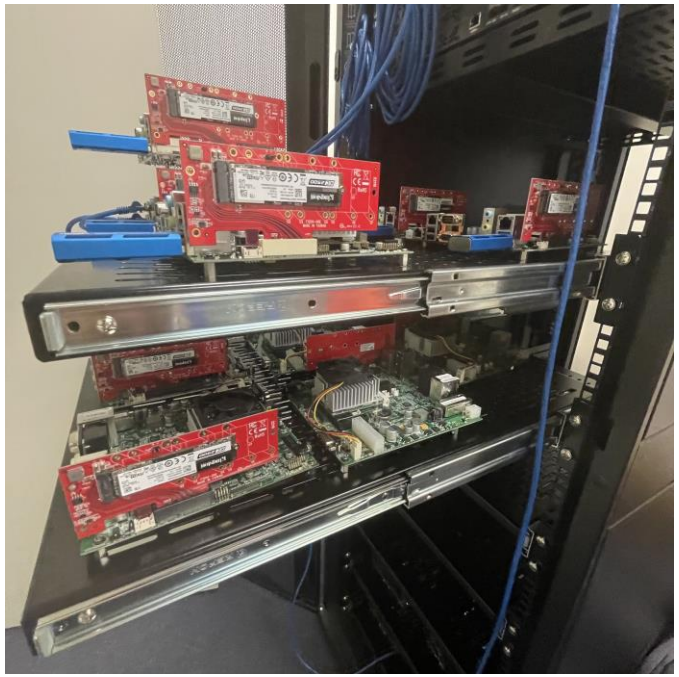


Automated Test Visualization

Real-time Simulation







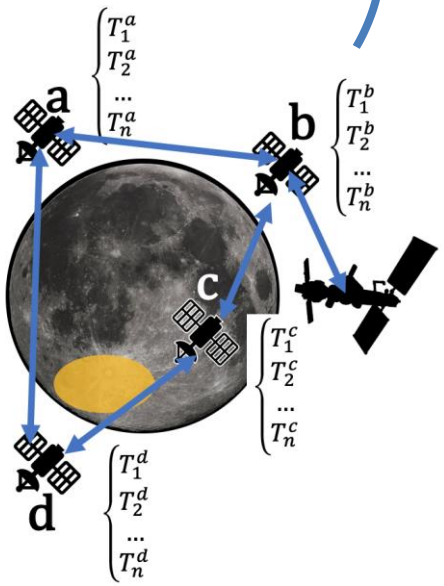
DSA 100 PiL Server rack with Unibap boards pulled out

DSA/Starling Technical Focus: Human Swarm Interaction

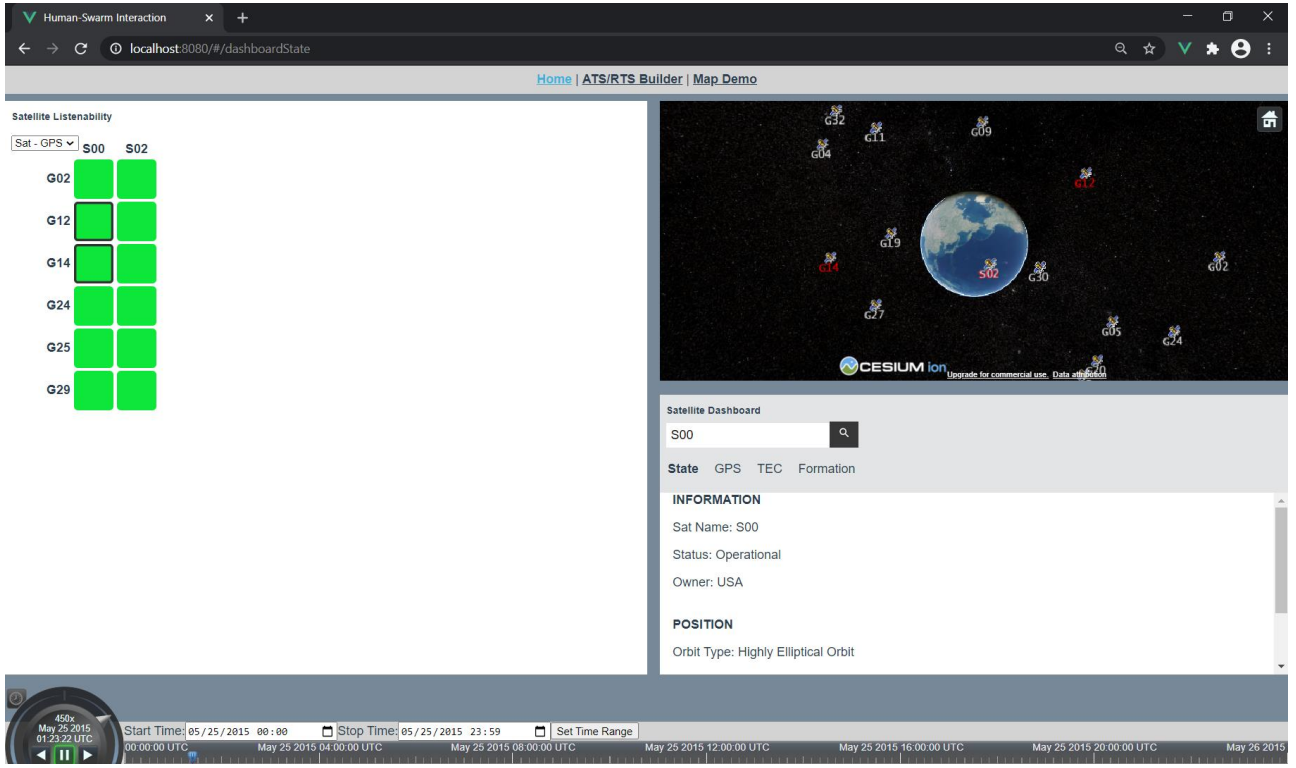
MC setting goals and priorities

Goals

Results



Swarm assigning, balancing, executing, assessing, and reporting

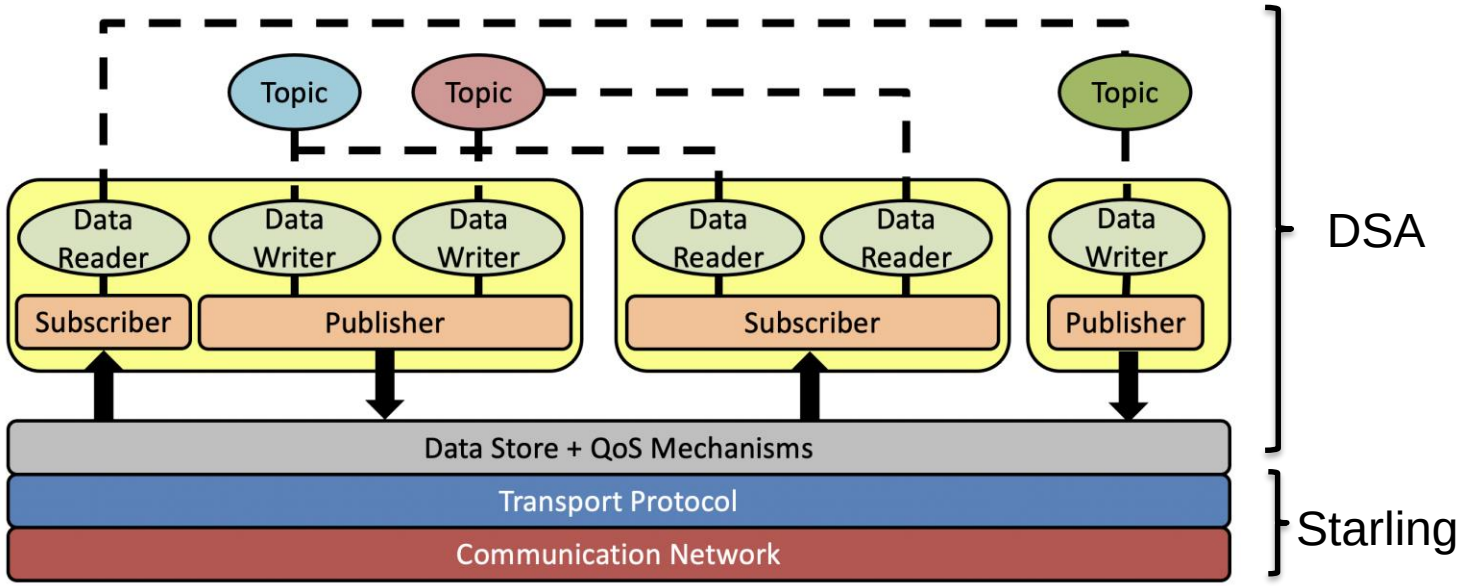


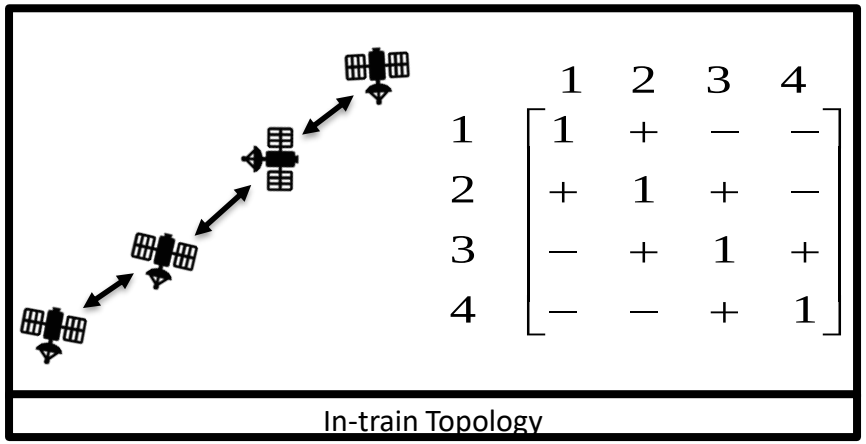
DSA human swarm interaction issues and challenges:

- What is an appropriate level of interaction between humans and swarms?
- How can optimization for autonomy be balanced with optimization for collaboration and cooperation?
- How can controls, displays, and decision support be designed to support central control of a distributed system?

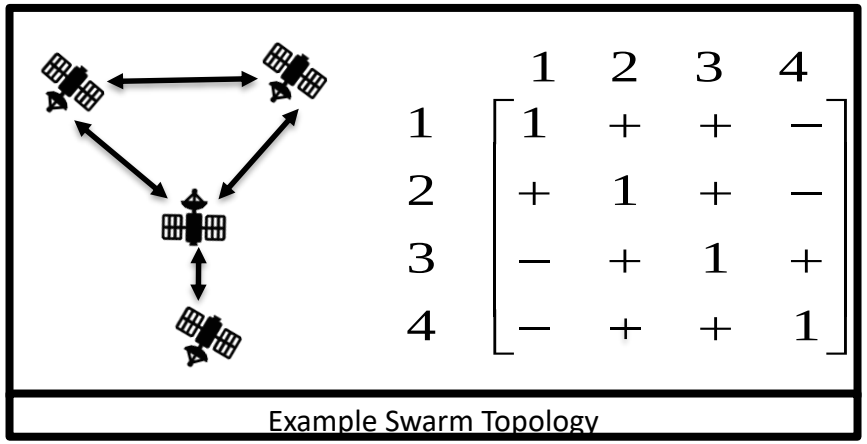
DSA/Starling Technical Focus: Ad-Hoc Network Communications

- Crosslink radios on each spacecraft
- B.A.T.M.A.N. protocol
  - “Better Approach to Mobile Ad hoc Networking”
  - Standard terrestrial network protocol
  - Autonomously self-configuring
  - Built for dynamic topologies
  - Decentralized network control
- DDS network middleware to manage application level package reliability
- Modern network stack development procedures to increase application development speed





In-train Topology

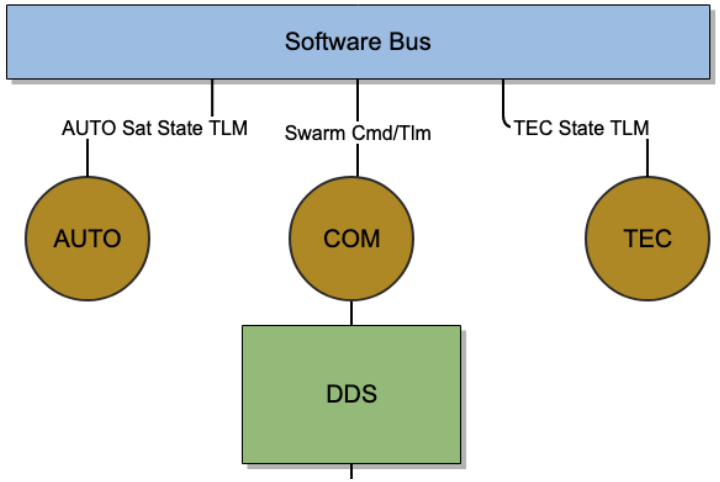


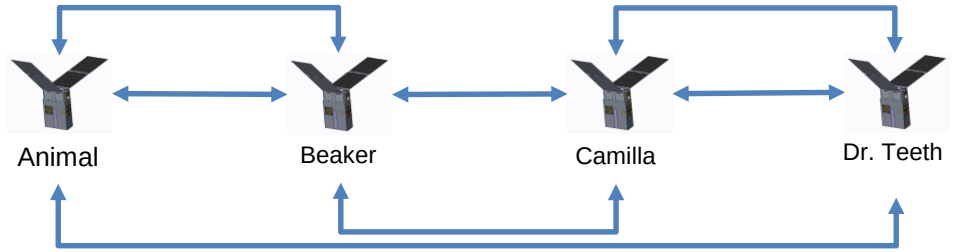
Example Swarm Topology

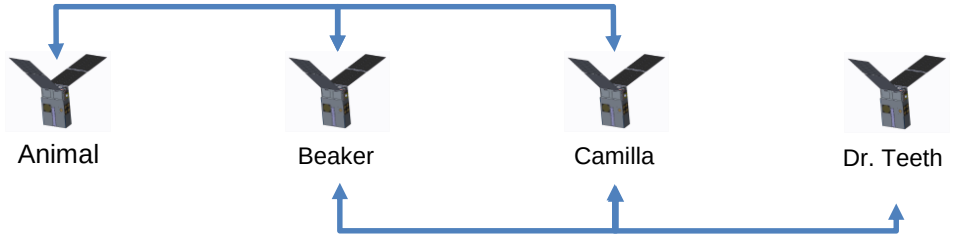
Wang, Nanbor, et al. "Toward an adaptive data distribution service for dynamic large-scale network-centric operation and warfare (NCOW) systems." *MILCOM 2008-2008 IEEE Military Communications Conference*. IEEE, 2008.

DSA Experiments

DSA Demo Examples



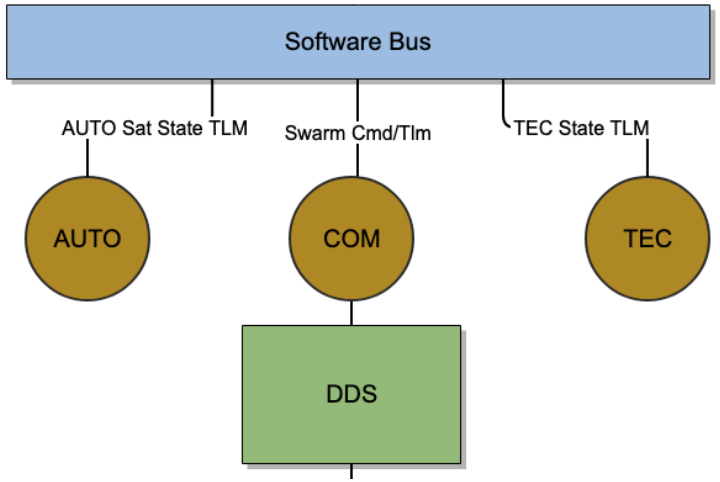




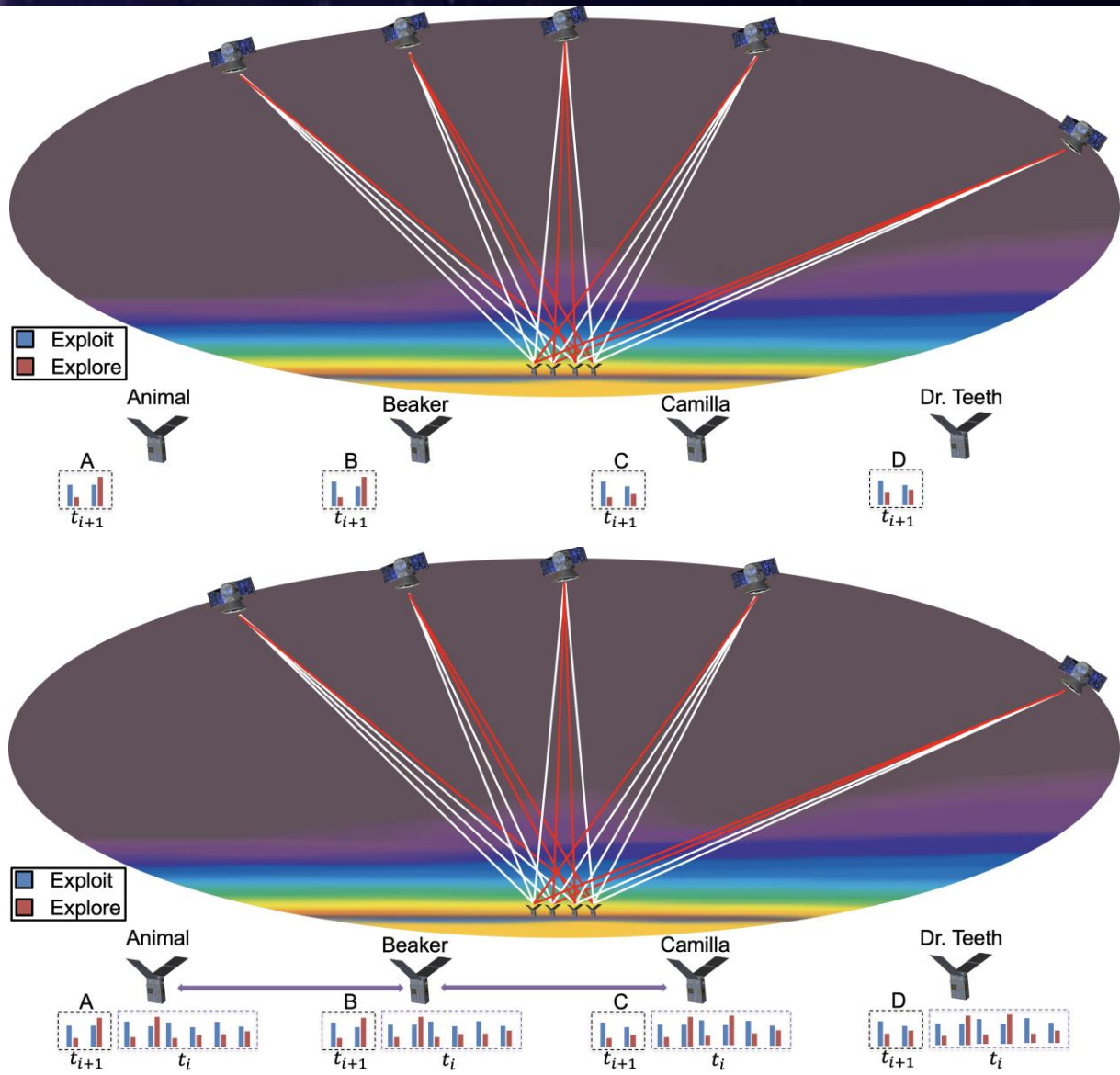
Pairwise, groups of three, whole swarm

- Broadcast network liveliness data
- Broadcast AUTO state telemetry
- Record network state, transmission rates, power use
- Issue swarm commands from every spacecraft
- Verify data integrity and command receipt and execution

DSA Demo Examples

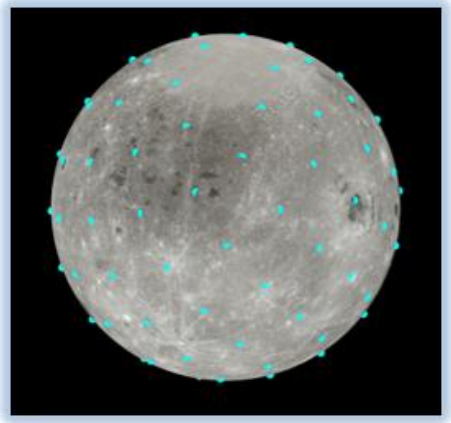


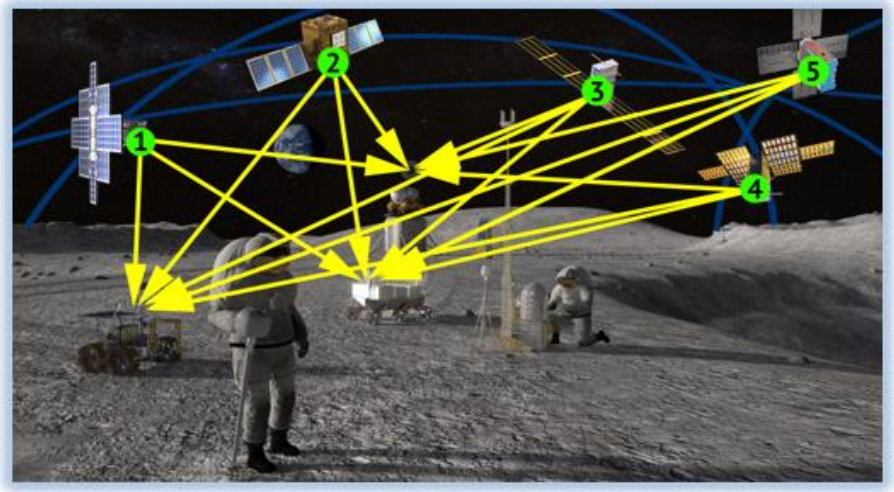
- Start COMM, TEC, and AUTO without the Crosslink. Record three orbits to verify independent behavior.
- Start COMM, TEC, and AUTO running at a reduced rate and maximum feedback with Crosslink. Record three orbits to verify swarm behavior.
- Start COMM, TEC, and AUTO running at a reduced rate and maximum feedback with Crosslink on an available *subset* of the swarm. Record three orbits to verify swarm behavior.



Lunar Position, Navigation, and Timing (LPNT) demo

- LPNT builds & extends existing DSA work
  - Larger than DSA+Starling
  - Service driven
  - 100 Nodes for localization
- (toy problem) Assumes ubiquitous deployment of lunar satellites
- Algorithms for LPNT tested with increasing realism
- LPNT desires "near-future" processors for testbed



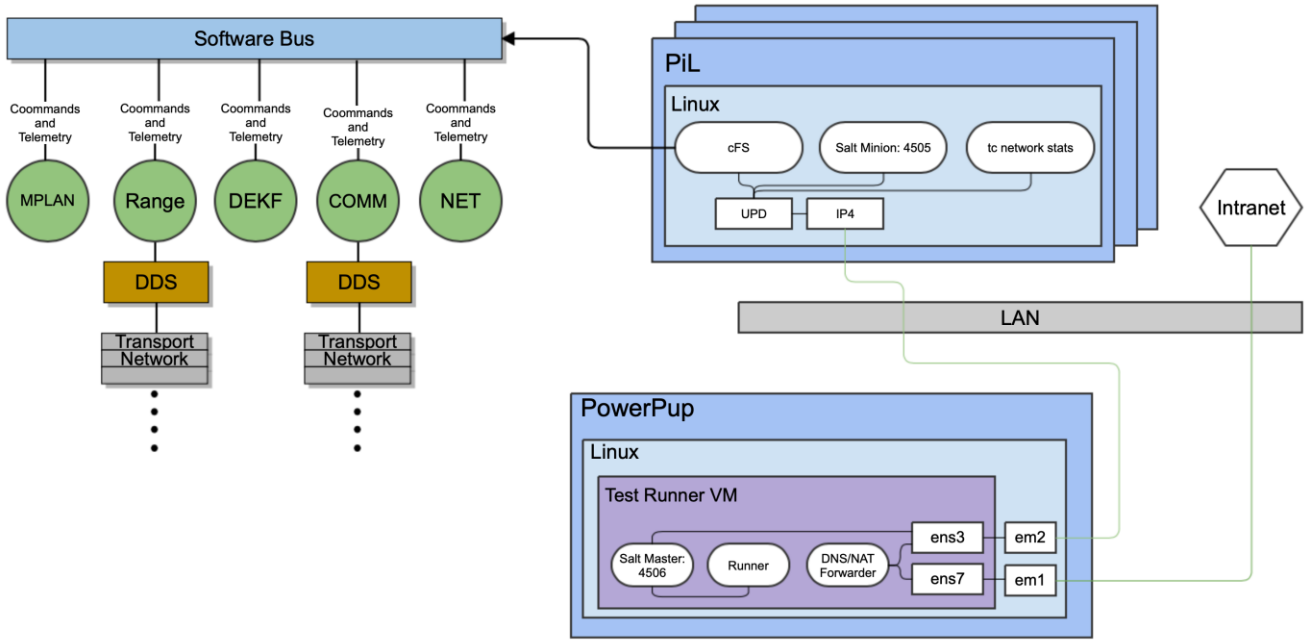


Lunar Position, Navigation, and Timing (LPNT) demo

- We built out LPNT demo!
- Deploying FSW to 100 nodes
- Build testing and deployment system
- Testbed for future Autonomy DSS concepts

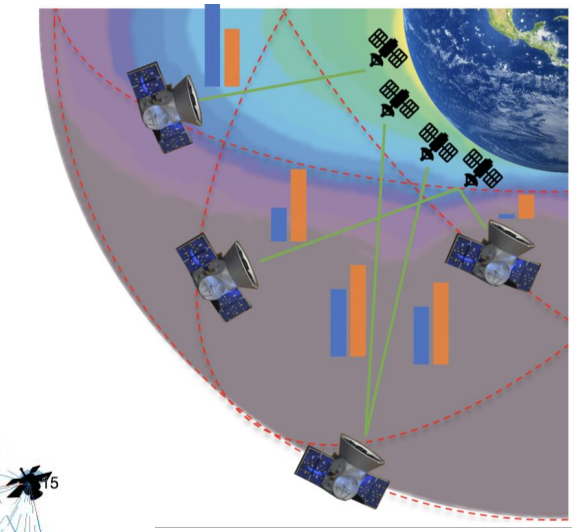
Table 1. Processing unit representation in DISSTRACK

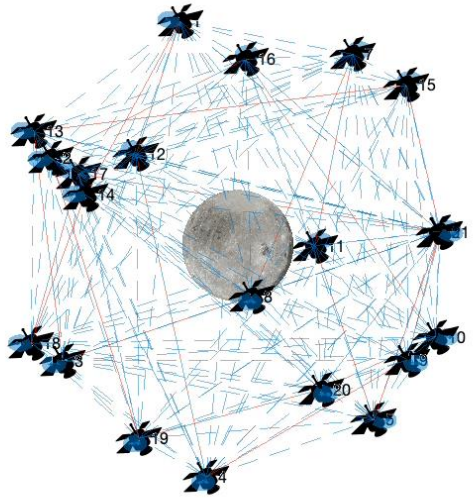
Quantity	Device Model	CPU	GPU	FPGA
60	Nvidia Jetson Xavier AGX	✓	✓	
25	Unibap e2160 Qseven	✓	✓	✓
15	Avnet Zedboard	✓		✓



DSA: Advancing Autonomy for DSS

- DSA's software payload on the Starling 1.0 mission will culminate in a small, in-space demonstration of:
  - Distributed Resource and Task Management
  - Reactive Operations
  - Human-Swarm Interaction
  - Ad hoc Network Communications
- The LPNT Scalability Study increases the size and complexity of the DSS on a different use case, demonstrating:
  - Distributed Resource and Task Management:
  - Reactive Operations
- Both efforts are supported by extensive modeling and simulation
- Together, these efforts show the promise of Distributed Spacecraft Autonomy to enable future DSS





Thank you!

Questions?

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