Creating a Marketplace for a Constellation as a Service

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Abstract

With the proliferation of diverse small satellites in orbit, many connected via mesh networks, an opportunity exists to exploit fallow capabilities in satellites for which the original mission is complete or in a sustaining phase that requires less than 100% capacity. We outline a marketplace to facilitate matching of needs and capabilities via a multi-agent negotiation framework. Agents have knowledge of the capabilities, constraints, configuration and load on their represented satellite. This knowledge can be imperfect at least temporarily due to communication constraints. Exchanges of information during the negotiation in the form of arguments can improve overall knowledge. Argumentation in negotiation allows for non-monotonic reasoning which can find solutions that conventional cost-function search algorithms won't necessarily find. Ultimately, satellite owners can find additional sources of revenue for their space assets after or in addition to their original mission. Missions can find solutions in existing assets without having to spend the time and money to develop and launch purpose-built systems. The Argumentation and Multi-Agent approach leads to emergent behavior from combining satellites into coalitions. We present a framework to conduct these negotiations and discuss how proposals and arguments may be generated and accepted or rejected. Workloads are managed via containerization and orchestration technology. The overall system is constrained by the realities of space, especially limited bandwidth communications.

The Opportunity

Rapid access to space is realized with repurposed satellites already in orbit

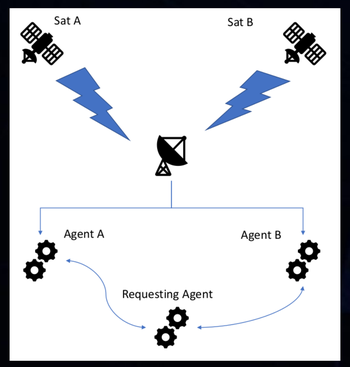
Manufacturing and launch costs are sunk from perspective of owner. Incremental costs associated with providing new service is minimal

High levels of automation throughout the process can keep incremental costs low

Satellites may have excess capacity possibly due to conclusion of original mission e.g. experimental

Constellations of satellites can be operated as a service

Tasks: Imaging (visible, IR, radar), Sensing (radio, AIS), Computation (ML in space), Relay (mesh networking)



Negotiation Framework

Auctions—but unclear/mis-matched requirements & collusion

Negotiations—Exchange offers - buyer reasons to find best value

Arguments—Augment offers to support value proposition

Each agent has a value for each of its outcomes

Outcomes from original mission or from new missions

Tasks lead to outcomes which provide value but at some cost

Costs include energy costs, propellant costs, opportunity costs, …

Opportunity costs viewed in terms of capacity

A satellite has a fixed capacity at any specific time

Its agent chooses to allocate that capacity to maximize value. It maximizes value (V) by maximizing payments (P) and minimizing costs (C)

$$V = \sum_n \left| P_n - \sum_i C_{i,n} \right|$$

Requester tries to maximize its value (V) by minimizing payments (P) while maximizing benefits (B)

$$V = \sum_n B_n - P$$

Agents submit arguments to change Requestor's perception of benefit and therefore value

Requestor only negotiates with N < M total agents submitting bids, motivating agents to submit competitive bids initially

The Challenges

Licensing

- NOAA licenses imaging but mostly just places constraints based upon resolution at the ground and a few things that should not be imaged
- FCC (in USA) licenses radio comms with ground stations and launch
- Many Universities use Amateur Radio frequencies but payment for services complicate that
- Commercial licenses can be limited in time and for a particular set of ground stations.
- Ground stations in other counties add complexity
- Updates on orbit ar non-trivail but do not have to be technically
- Consider a system like TVWS:
  - Spectrum database manager and
  - Radios that check the database before transmitting
  - Comms are conducted on a secondary basis with no interference

Concept of Operations

- Intelligent agent posts RFQ on behalf of Requestor
- Agents acting on behalf of satellite owners examine requirements and their own status and capability to decide to bid. Excess capacity? Can meet requirements? Right place at the right time? (e.g. image location A in daylight w/in next 5 hours)
- Satellite agent evaluates costs and submits bid
- Requestor agent chooses to negotiate with subset of agents based upon initial bids
- Agents negotiate until a deal is reached satisfying the requestor's requirements
- If necessary, requestor provides open, containerized SW for uploading. This implements the logic needed for the negotiated task
- SW is scanned for threats and vulnerabilities before uploading to satellite
- Commands sent to execute the task using uploaded SW
- Results downloaded and SW update rolled back
- Payments are settled according to negotiated terms

Prerequisites & Assumptions

- Software defined bus generically hosts worker agents
- Self-describing Agents allow bus to match up requests with registered agents
- Microservices
- Open Source
- Orchestrated

The above allow secure update on orbit. Hypergiant has implemented this using Kubernetes and USAF PlatformONE in the form of SatONE and our SOSS architecture

Secure but public command interface — *Tacke "Open Source Payload Command Console Application" SmallSat-2021*

Orbital Prediction—*Liu et al "Improved Orbital Propagator Integrated with SGP4 and Machine Learning" SmallSat-2021*

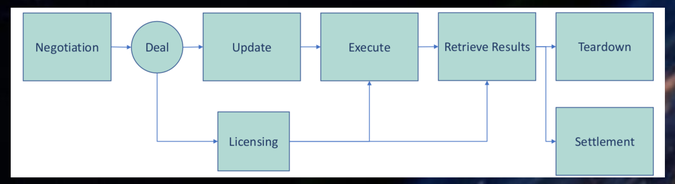
Mission Execution

Consistent with existing functionality?

- Issue with Command Processor

Otherwise

- Create agent as a self-describing microservice with REST API
- Screen agent for vulnerabilities
- CI/CD tools and Kubernetes deploy SW update to satellite as new pod
- Schedule command with Command Processor
- Retrieve results
- Teardown by removing pod



Commitment

Negotiating agent has authority to commit satellite capacity (and operations team if necessary)

Existing mission(s) are commitments

Offers or bids involve (temporary) commitments

Commitments are held until negotiations result in no-deal or until mission is complete in case of a deal

Conclusion

- Highly automated agents can negotiate for revenue producing tasks with minimal incremental costs
- Requestors can gain rapid access to space by leveraging existing assets
- Orchestrated microservices facilitate secure incremental update in capabilities via software defined systems
- Negotiations involve commitment and can use arguments to influence other agents' perception of benefit and value
- Commitment is important to track for integrity in negotiations
- Technical and licensing challenges exist but are solvable with the right effot

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