Optimizing Communications for Cubesats to Commercial Constellations

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SSC21-P2-27

ABSTRACT

In 2008, Florida International University researchers proposed the world's first Cubesat to Commercial Satellite Network Inter-Satellite Link and created a payload, called PicoPanther, to move data from Cubesats to the Iridium Network. In the years following, dozens of satellites have used the Cubesat to Iridium/Globalstar payload concept and the amount of constellations in Orbit that can be used for Cubesat Inter-satellite links have grown. Cubesats using commercial constellations for communications have the benefit of near instant communication with their Cubesats for health monitoring and data transfer without relying on a global network of gateways. This poster describes software that maximizes Cubesat to Commercial Inter-satellite link contact time under user programmable constraints and automates link decision choices for Cubesats that have multiple constellations in view. The software methods described are applied to a variety of constellation choices currently available and planned.

COMMERCIAL RELAYS

Florida International University (FIU) pioneered research in low earth orbit (LEO) satellite communications to commercial satellite networks (aka commercial relays) using the Iridium Network (2007-2008) to augment situational awareness for cubesats and provide near real time communications [1]. The adoption of using commercial networks, like Iridium, in LEO happened in the next decade [2][3]. Commercial relays offer the opportunity to investigate in orbit anomalies and potentially salvage space craft operations as well as reduce the need for global gateways [4]. The number of networks that are currently in existence or planned that can potentially act as relays have grown significantly since 2008:

Low Earth Orbit (LEO)

- Existing networks include: SpaceX, OneWeb, Kuiper, SWARM, Iridium, Globalstar (Linkstar) & Telesat
- Planned networks include: Analytical Space

Medium Earth Orbit (MEO)

- Existing networks include: SES (O3b)
- Planned networks include: Mangata, Audacy & SpaceLink

Geostationary Orbit (GEO)

- Various existing networks, including NASA's Tracking and Data Relay Satellites (TDRS) and Inmarsat as a relay system with AddValue [5]

The above constellations have unique constraints and not all have been proven as relay capable. Iridium (LEO), Globalstar (LEO) and Inmarsat (GEO) have been proven to work as relay systems. The proliferation of satellite constellations that may act as a relay and that are planned to be purpose built as a relay (Analytical Space, Audacy, SpaceLink) support NASA's goals to commercialize TDRS [6]. The various potential relay orbits and technologies [7] coupled with Size, Weight, & Power constraints create an opportunity for optimizing options to meet mission specific needs. FIU started optimization work for multi orbit relays in 2015.

CONSTRAINTS

There are various constraints that may be applicable when trying to identify the best strategy for reliable communications in commercial relay systems. Some of those constraints are:

Contact time
Orbit, Antenna technology, pointing ability (when needed) and commercial relay orbit & technology all drive the contact time achievable by a LEO satellite to a commercial network.

In Orbit Phases
Separation, initial acquisition and space craft operational environment all drive which technologies make sense for relay systems.

Power
Spacecraft power capabilities and transmit power needed to the relays drive technology options.

Costs & Data Rate
Costs and Data Rates needed for various mission phases drive technology decisions.

EXAMPLE POWER BANK CONFIGURATION & CONSTRAINTS

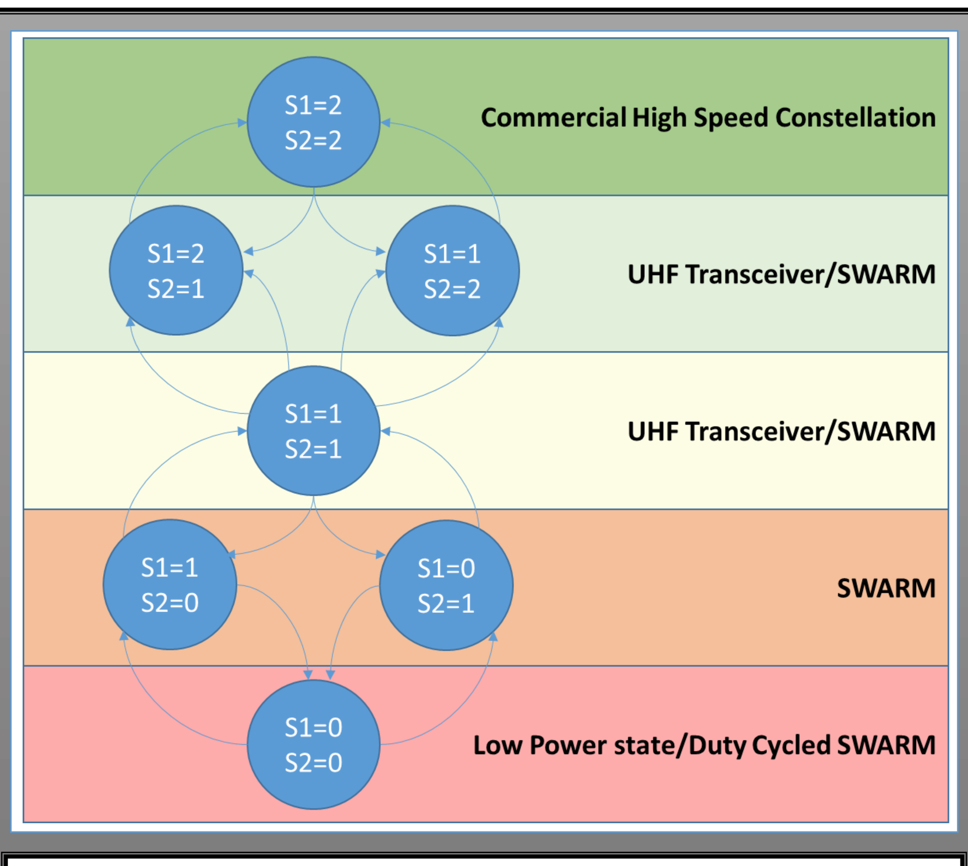

Figure 1. Example of a state machine for a dual power bank small satellite.

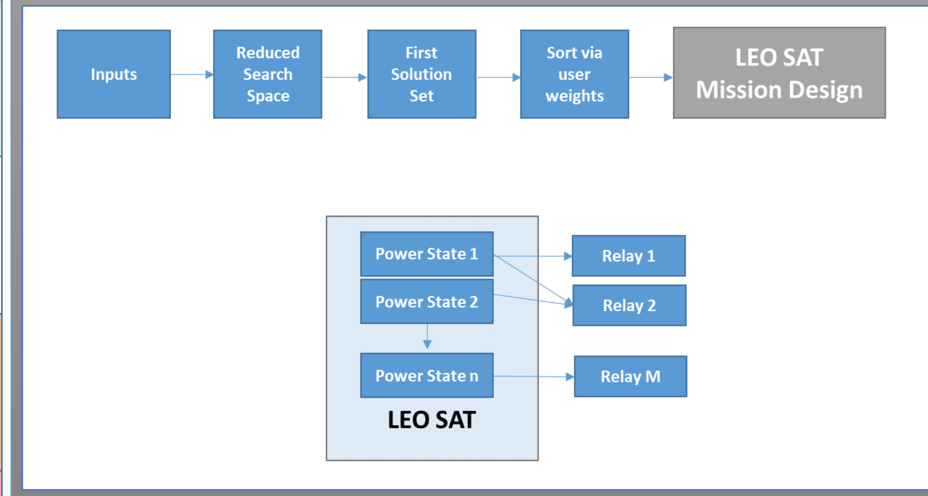

Figure 6. Constraint optimization on the ground for relay selection & flexible decision making in space.

ORBITS FOR A SUBSET OF MULTI-ORBIT SATELLITES

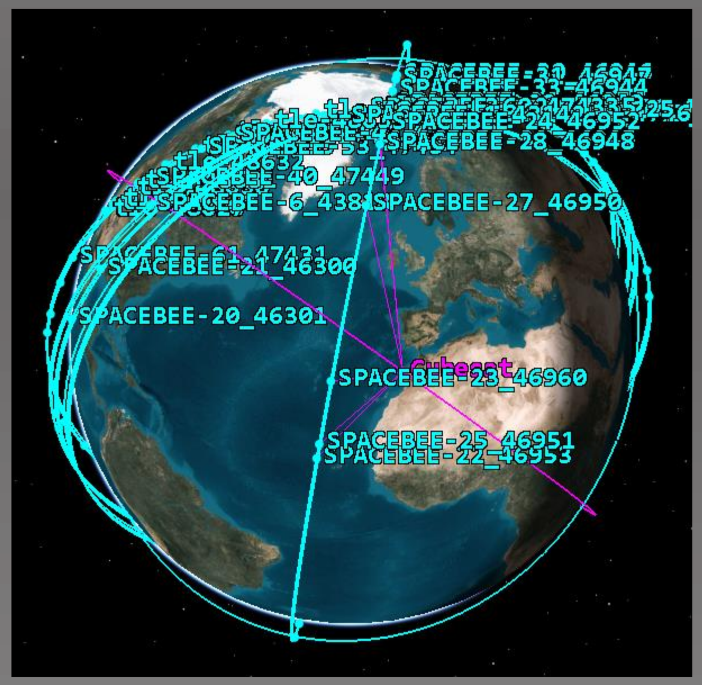

Figure 2. Current (6/2021) SWARM (LEO) SYSTEM.

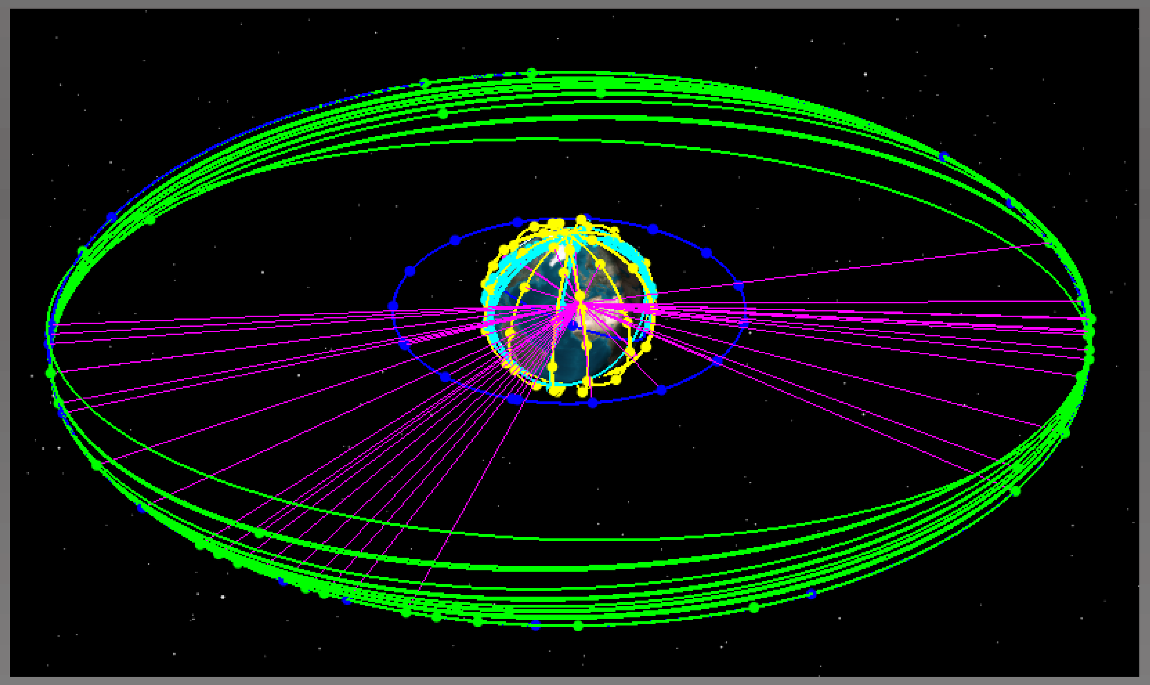

Figure 3. SWARM (LEO), MEO and GEO orbits.

CONTACT TIME FOR A SUBSET OF MULTI-ORBIT SATELLITES

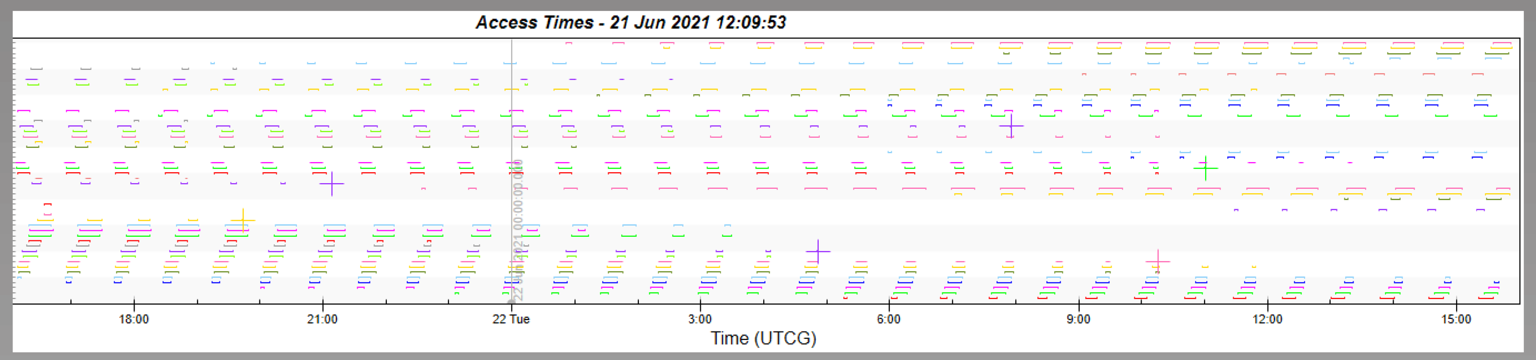

Figure 4. Contact time and durations for SWARM from LEO.

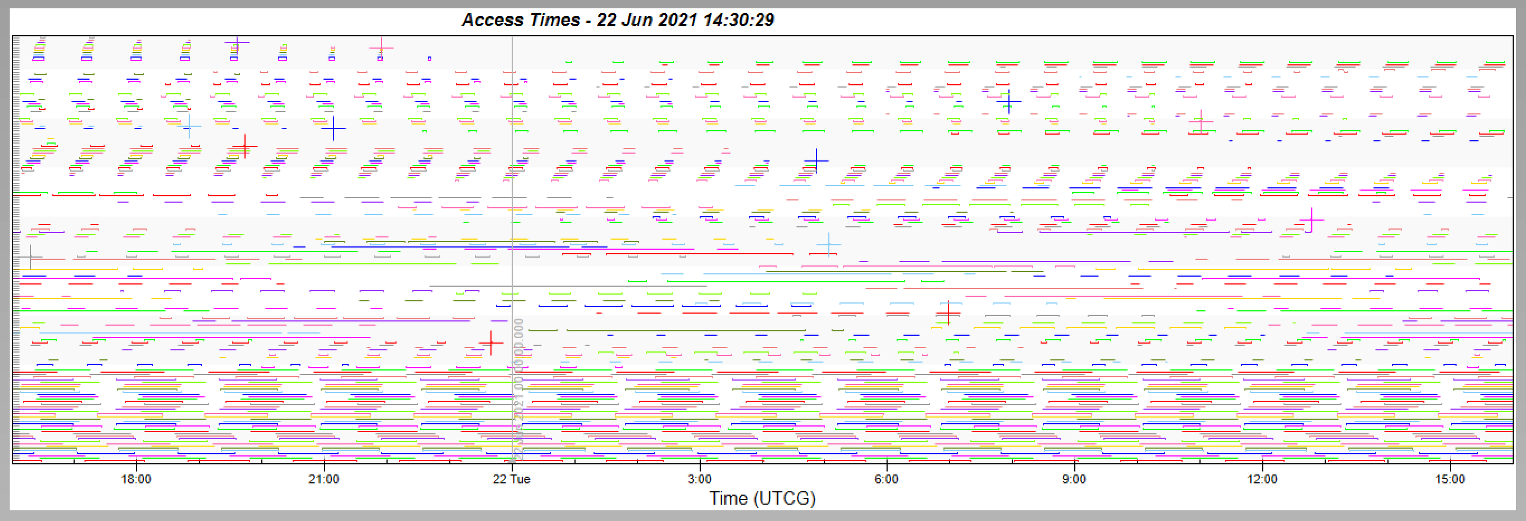

Figure 5. Contact time for various assets in LEO, MEO & GEO.

MULTI-ORBIT RELAYS

To illustrate the advantages of multi orbit relays and to show how system constraints drive the use of various orbits, a mission is proposed with two power banks operating in 5 power states (Fig 1). The lowest power state may force the satellite into a state where no communication is possible except lower power duty cycled bursts into the SWARM network (Fig 2). As the satellite power banks increase, more lower power packets can be transmitted until a state is achieved where the satellite can choose between UHF and SWARM. As power increases, high speed commercial links become useable and the onboard satellite has multiple options open to it to send data back to earth and recover from potential issues (Fig 3).

The aforementioned is an example where multiple orbit options can be used to provide situational awareness for several power options. Technology selection is ultimately driven by the spacecraft constraints with the commercial network. To down select the options, constraint optimization approaches are proposed.

OPTIMIZATION

Optimization problems in the satellite domain aren't new [8]. In fact, GitHub contains repositories that tackle scheduling optimization using CP Solvers and other methods, one such is using CPLEX solvers in python [9].

The amount of options for data relays are much larger now and mission specific constraints reduce the total solution set. For multi orbit relays, the optimization path proposed in this poster puts the highest value on the power constraint. Power limitations drive the relay systems used followed by contact time and on board physical real estate. Contact time is important because rapid handovers will force the satellite attempting to use the relay to reacquire signals too often if the commercial system isn't designed for small burst data. With SWARM, the constellation is meant for IoT and can support the short contact times (Fig 4) of a few minutes to get critical data to the ground. Similar to earth bound communications, the longest contact times for non inclined orbit commercial relays are achieved on Geostationary satellites due to field of view (long contact lines in Fig 5).

The decision of technology selection is made on the ground and incorporated into the LEO satellite using constraint programming. The optimization engine may produce overlapping relay options for various power states, as seen in Figure 1 and Figure 6, that allow for flexibility on board the LEO spacecraft. This flexibility, if it exists in the final solution space, should then be programmed in the spacecraft for awareness of communication options under various power states.

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ACKNOWLEDGEMENTS

The author would like to thank Dr. Jean Andrian and Dr. Kenneth Furton for their support over the last 14 years with FIU's Cubesat programs. We would like to thank Florida Space Grant Consortium as well for their continued support.