Centralized Scheduler Interface for Communication Link Between SpaceLink's Relay Satellites and LEO Assets

Behzad Koosha, Jim Schwenke, Rob Singh & David Nemeth
8260 Greensboro Drive, Suite 503, McLean, Virginia, USA 22102
{bkoosha, jschwenke, rsingh, dnemeth}@eosspacelink.com

I. Abstract

SpaceLink can augment the hybrid architecture, between multi-orbit constellations, including those supporting Space Situational Awareness (SSA). SpaceLink is building its own commercial transport layer to provide persistent connectivity to assets in Low Earth Orbit (LEO) and deliver data and communications to and from space in near-real-time and with unprecedented security. Real-time coordination of multi-vendor satellite constellations and their dynamic ephemeris, system constraints, and schedules is an incredible challenge. These include orbital ephemeris, relative attitude, optical terminal range of motion, terminal and SV slew rates, SV jitter, and service level agreements that factor into link acquisition times. SpaceLink's planning and scheduling algorithm can manage these challenges. The proposed solution conducts all the coordination and is easily integrated within the satellite command and control operations center to automatically send tasking requests for communication between different satellite constellations. This paper represents a study of the centralized scheduler interface used for the communication link between SpaceLink relay satellites and the hybrid constellation of satellites. We will provide information on the scheduling interface which sends tasking information to the SpaceLink C2 segment via an internal communication protocol to command a SpaceLink MEO satellite to establish and command an optical head to point to a visible LEO satellite.

II. Introduction

The planned sunsetting of the Tracking and Data Relay Satellite System (TDRSS) constellation, coupled with the dramatic growth of the commercial space market, is creating challenges for commercial, civil, and defense users of data relay services from Near Earth to Cislunar Orbits. SpaceLink is building a TDRSS-like capability to significantly increase throughput, provide persistent links to space assets, and securely deliver data near real-time. Increased human spaceflight missions and proliferated LEO constellations have created ground station bottlenecks and a conflicted radio frequency (RF) spectrum for many satellite operators. At the same time, market demand marches inexorably toward immediate data delivery. Expansion and commercialization of activities at Lunar and Earth-Moon LaGrange points will only compound these problems for RF-based space and ground communications.

SpaceLink is deploying a hybrid approach to address these challenges with its optical and RF-based space and ground network. Launching in late 2024, SpaceLink's network of four Medium Earth Orbit (MEO) satellites and ground stations will provide a commercial relay service for continuous optical connectivity to spacecraft in LEO, MEO and GEO, space stations, and other platforms in the air domain.

III. Space Segment Overview

The initial operating capability of our Block-0 constellation (see **Figure 1**) will move data through Optical Intersatellite Links (OISLs), enabling users to transmit data at rates up to 10 gigabits per second (Gbps) and latency from LEO satellite to client destination of <300 ms. Future Blocks will be launched in polar planes to expand the network's coverage areas and add user connectivity in TDRS-Ka and Military-Ka RF bands. SpaceLink moves data to our ground segment with up to 40 Gbps Gateway capacity in Q/V-band. We will integrate our first optical ground terminals (OGT) in 2024 at SpaceLink's Mojave, CA site and can quickly expand to other gateway locations. The Block-0 architecture consists of four equally spaced relay satellites in an equatorial 13,892 km altitude orbit. The relay satellites have four identical diameter optical communications terminals (OCTs) capable of 10 Gbps user links with SpaceLink certified OCTs. Relay satellites are interconnected via 100 Gbps coherent bi-directional optical links for redundancy, load-balancing, and jurisdiction-specific downlink. Each relay has a 0.8 m diameter RF aperture capable of 26 Gbps Q-band downlink and 5 Gbps V-band uplink of system capacity from one of the ground gateway sites.

The relay satellites each utilize an onboard processor for network switching and the capability to support space-based edge processing tasks.

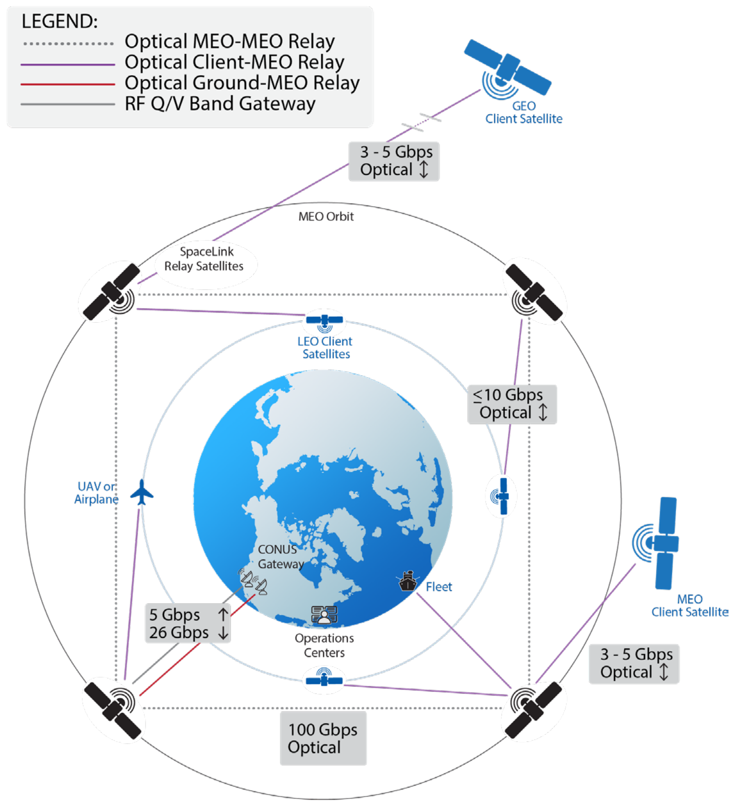

Figure 1. SpaceLink's Block 0

IV. Ground Network

SpaceLink provides a Layer 2 Transit Network from the orbiting constellation to the customer ingest point. We have established two initial regions for Space-Ground access, one in California and one in Hawaii, with ground station expansion sites planned for Australia and the United Arab Emirates (UAE), see **Figure 2**. Each access region will host three geo-diverse gateway sites separated by at least 100 km to provide robustness and achieve >99.9% rain availability for Q/V band RF links. Each ground station site has one Q/V-band full-motion tracking antenna system, and more can be added to increase network capacity. The gateway sites are connected by redundant terrestrial fiber to geo-diverse, cloud provider direct-access points, with Amazon Web Services (AWS) and Microsoft Azure initially supported. SpaceLink employs Software Defined Networking (SDN) to move data across our Layer 2 Transit Network. We offer a high-capacity gateway capable of 40Gbps. We utilize a "Direct Access" connection to our cloud-based distribution network, which supports multiple bands up to 10 Gbps delivery connections. SpaceLink cloud edge processing removes our TRANSEC cover, re-orders and de-duplicates packets as needed, and distributes the packet based upon a Multi-Protocol Label Switching technique (MPLS) through an Internet Protocol Security (IPSec) tunnel that would terminate at the customer's cloud ingest point with the original encrypted data. Each data source would have its own delivery tunnel to the ingest point.

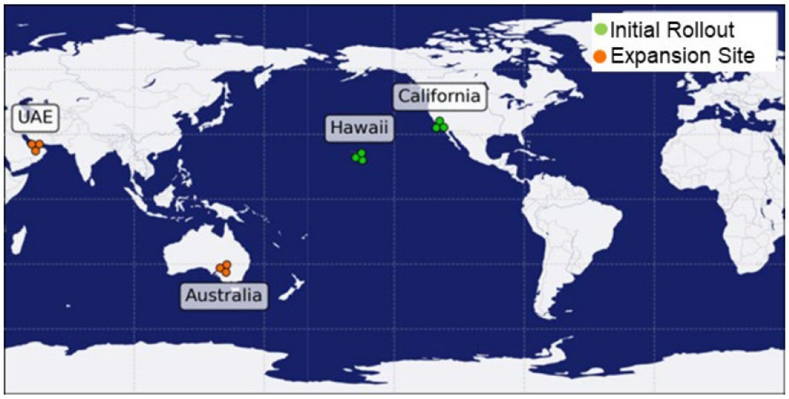

Figure 2. SpaceLink Access Regions

V. Scheduling Architecture

Today's remote sensing satellites in LEO can only download data or upload tasking commands when over a ground station. Typically, this is limited to just six percent of a satellite's time on orbit. Combined with limited data throughput and gaps of as much as eight hours between passes the real-time intelligence needed to make tactical decisions is rarely available. This is coupled with limitations of location and where the ground station site can be established. SpaceLink can augment the hybrid architecture, between multi-orbit constellations, including those supporting Space Situational Awareness (SSA). SpaceLink is a Medium Earth Orbit (MEO) constellation of high bandwidth optical and RF relay satellites, which are urgently needed to provide real-time continuous tasking uplink and data downlink from the proliferating constellations of commercial and government remote sensing satellites. SpaceLink has designed an innovative system architecture, implementing services that provide high security and 100 percent access time so that data is available in seconds when it matters the most.

Ground segment: SpaceLink ISLs enable continuous gateway coverage with operational services for secure anytime downlink of user data into a US gateway, independent of the satellite location. A constellation of relay satellites in MEO can transform the value of the data collected, providing continuous link availability. With optical inter-satellite communications between satellites and high bandwidth V/Q-band communications to the ground, Gbps throughput of real-time data is provided. Real-time coordination of multi-vendor satellite constellations and their dynamic ephemeris, system constraints, and schedules is a significant challenge. These include orbital ephemeris, relative attitude, optical terminal range of motion, terminal and satellite vehicle slew rates, satellite vehicle jitter, and service level agreements that factor into link acquisition times. SpaceLink's planning and scheduling algorithm can manage these challenges. SpaceLink manages coordination and integration within the satellite command and control operations center to automatically send tasking requests for communication between different satellite constellations. See figure 3 below.

- SpaceLink can augment the hybrid architecture capabilities to coordinate the optical heads between multi orbit constellation satellites. SpaceLink optical terminals are compatible with SDA's Tranche 1 standards, so it can also provide a redundant path for the SDA's Transport Layer to provide path plan options in support of scenarios in which there is limited availability of any space/ground assets.
- Each client transmits their desired contact time in advance. Additionally, clients may also send the constraints, or these constraints maybe stored in a SpaceLink database. These constraints may include visibility, client satellite spacecraft safety restrictions, sun exclusions, windows of requests, etc.
- The SpaceLink scheduler takes all these parameters into consideration and runs an optimized scheduler algorithm that minimizes the scheduling latency for the incoming client request.

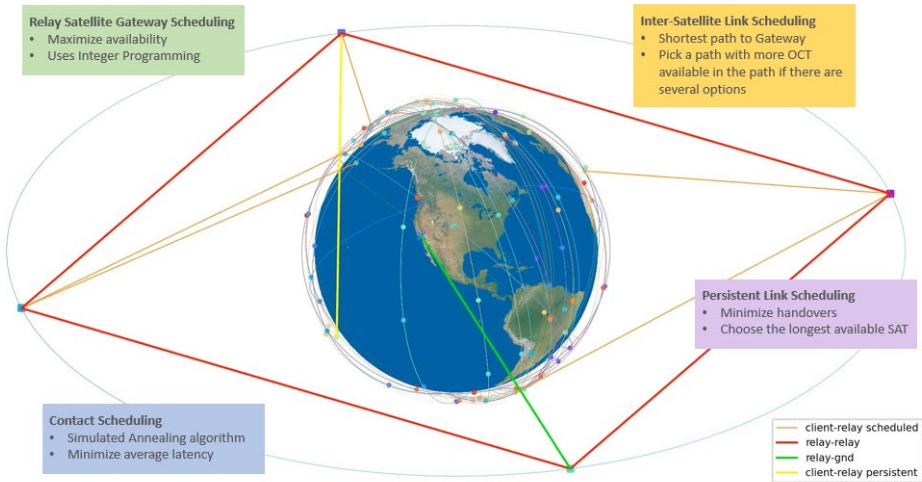

Figure 3. SpaceLink scheduling algorithm steps

In a scenario where there are multiple end users, each client's requests are queued and processed in the order they are received. The algorithm defines priorities based on organization, urgency, service level agreements, and system requirements in near real-time. The SpaceLink scheduler optimizes client requests into a priority queue, where higher priority client requests go to the front of the queue. Each client request results in changes to the schedule (adds/mods/deletes) and those changes are constantly broadcast back to clients.

The proposed algorithm has multiple ways to receive ephemeris and calculate visibilities for the specific vehicles. The algorithm ensures updated visibilities are always available based on the latest ephemeris/TLEs using machine learning techniques. SpaceLink's four satellites are always in sight of spacecrafts above 350 km in altitude. The initial constellation will be launched in late 2024. Subsequent constellations will include inclined orbits that will allow full visibility down to the Earth. The key feature of SpaceLink's constellation include:

1. Continuous line of sight access using the scheduling algorithm in real-time,
2. Client driven real-time tasking & direct downlink of mission critical data,
3. Capability for on-board processing to support real-time activities &
4. Ability to augment proliferated LEO communications satellites to provide a resilient 'fail-over' capability for government communications paths.

VI. Scheduler Objectives

The SpaceLink centralized scheduler interface is used for the communication link between the SpaceLink relay satellites and the hybrid constellation of satellites. The scheduling interface sends tasking information to the SpaceLink C2 segment via an internal communication protocol to command the SpaceLink MEO satellite. The scheduling orchestrator interacts with the client API server, Inter-Satellite link scheduler and the algorithm responsible for establishing the best route. The table below describes different scheduling requests that can be established.

Scheduling Request Parameters	**Selections**
Priority	High: Scheduled with a short notice Low: Usually scheduled well in advance
Preemption	Preemptable: A higher priority request may cause rescheduling Non preemptable: Once scheduled cannot be rescheduled
Contact duration	Persistent: Continuous (internet connectivity or continuous monitoring) Data transfer : for downloading images/videos

	Tasking: Very short duration contacts
Desired window for scheduling	Time window in which the scheduling needs to be conducted
Service level agreements	Desired scheduling latency. In case of preemption a higher priority scheduling not meeting desired SLA will preempt a lower priority assignment that is previously scheduled