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Paper: Ground Segment As A Service for Sustainable Use of Space

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Abstract

During the last decade, industry in the space sector has grown at an unprecedented rate. Figures from 2013 to 2022 show an almost 300% increase in satellite launches per year¹. Many businesses centred on building satellites, creating innovative payloads, and data processing have gone from Start-Up to Global Prime in this short period of time. This industry boom has, in turn, created a demand for increased ground contact with a guarantee of reliable communication between the Space and Ground Segments. Significant growth seen in missions operating as clusters and constellations demanding multiple revisits and near-real time operations, has meant that the traditional use case of single or dual site ground stations may no longer be adequate to meet the mission objectives.

Leaf Space utilises its diverse network of ground stations, strategically distributed across the globe to provide reliable communications for LEO missions promoting responsible use of Space. This approach, alongside a single access point into the network, enables customers to achieve regular and consistent ground contacts throughout the mission lifetime, including critical phases such as LEOP and End of Life. This paper will outline the architecture and design philosophy employed by the Leaf Space system to facilitate interoperability, ease of operation, and increased connectivity all whilst abstracting the entire infrastructure from the customer. It is paramount that all partners and entities within the Space ecosystem collectively act responsibly to practice sustainable use of Outer Space.

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Introduction

Industry Growth And Technical Challenges

The overall growth in the small to medium satellites industry, including companies specializing in vertical integration and platform suppliers, has resulted in the ability to procure, assemble and test satellites on a much larger scale. In turn, the emergence of companies operating satellites in clusters and constellations to enable technical con-ops previously only achievable by high-budget and often GEO satellites have become a common approach. This change of industry environment, and overall engineering technology has led to significant changes in ConOps for many LEO Satellite missions.

Historical Approach

In previous years and decades, large companies funneled their efforts into the development of singularly sustainable systems ranging from internal Software Development to Hardware Creation, to Proprietary Antennas covering the full mission development cycle. Often the only external costs and procurement came from areas such as test facilities, some hardware and Launch providers.

Of course, there are benefits to this sole ownership approach; limited reliability on external factors, full control over the system and potentially cheaper in the long term (granted mission success) but with those benefits came a host of limiting factors. Failures at any point of the chain could lead to a pull or overload of internal resources to resolve, adding cost and time to the mission and an inability to work in a parallel fashion. Many failures were costly to resolve as a result.

To mitigate some of these failure cases, redundancy was built into the system at every point, from flight and ground software to physical hardware on-board the satellites and at the ground segment sites. In addition to this, the Mission budget directly controlled resource possibilities, both technically and physically. This could be limiting to many Mission outcomes (especially those coming from newly emerging companies).

Resources such as Ground Segment flexibility would be controlled by Regulatory difficulties, the cost of procuring hardware, installation and maintenance and time spent developing the software to control the system. Often times, proprietary Ground Stations would be located locally to the company, or within the same company for ease of use, licensing and maintenance over time. This Geographical constraint would then have to be factored into the Mission ConOps; for example, accepting that a LEO satellite would only be visible over 4-6 passes per day or creating complex Azimuth maps to factor in local structures or nature.

Present Day Technological Advancement

Conversely to this previous approach, improved and contemporary technology and engineering practices have transformed this approach to Mission design. Each stage of the mission can now be effectively bought, “off-the-shelf”, using software or hardware that have been in-orbit qualified, from companies with heritage purely due to the scale of demand in recent years.

Commonly 'externally procured' items in the Mission Supply Chain now are;

- Batteries
- Solar Panels
 - Array Control Units
- Power Control Units (PCU)
- Avionics
 - Reaction Wheels
 - Magnetorquers
 - Sun Sensors
 - Star Trackers
- GPS Systems
- Propulsion Systems
- On Board Computers (OBC)
- Flight Software
 - Payload Management
- Ground Software
 - Mission Control
 - Mission Planning
 - Payload Management
 - Data Storage
 - Ground Segment Control
 - Satellite Operations
 - Monitoring Systems

All these available resources have meant that the design and building of complex LEO missions has become a far simpler and quicker process. Supply chains are robust, and integration facilities are not having to adapt to 'bespoke' designs, rather, a production-line approach is taken in many cases.

The ConOps design of such missions has also evolved; where once it was commonplace to have redundancy in the form of multiple Radios, Secondary Avionics, Backup OBCs, Additional PCUs it is now far more economically viable to simply fly an additional mission as a back-up. As such, the emergence of 'Clusters' or 'Constellations' has become incredibly common.

The operations of such missions involving more than one Satellite flying usually in phase or formation with each other introduces some additional Operational requirements:

- Increased demand for reliable Ground Communications
 - With more Satellites, often comes increased commercial demand
 - Technology advancements in Radio production and On-Board Processing means tighter SLAs for data delivery
- Limitations of single site Ground Stations
 - Flying multiple Satellites in formation results in overlapping passes, which single site Antenna's cannot support easily
 - Increased demand for globally distributed locations, to ensure reliable and consistent Satellite visibility over the Operational period

Leaf Space's Approach to Ground Station Networks

Global Ground Station Network

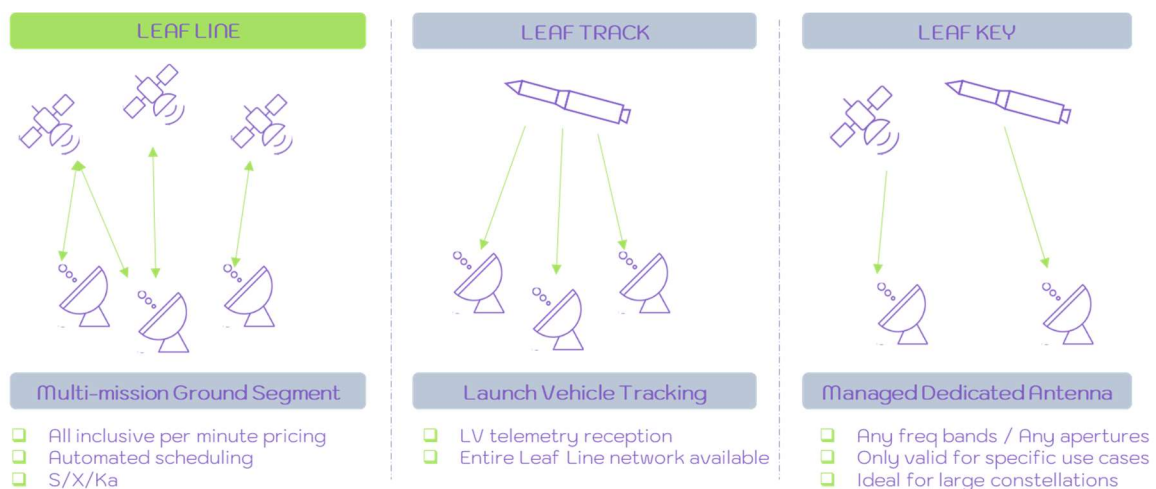
Founded in 2014, Leaf Space S.p.a (and Leaf Space LLC United States entity) provides Ground Station As a Service (GSSA) for space to ground communications. The Service offering is split into three main categories, providing a diverse range of capabilities and support for the complexities of operating missions in Space, as well as the logistical challenges.

Leaf Space noticed the rapid growth and expansion in production of Satellite Constellations and Clusters, as well as demand from Single-Satellite missions for reliable and distributed ground contacts. Extra attention was given to industry could better support these missions during critical mission phases, such as Launch, LEOP and Payload Campaigns; phases where often times, Operators encounter the most problems, and at time, Mission Failure. Leaf Space found a reliable method to allow for fast, and efficient integration with the Global Network, and the ability to support any type of Radio or Orbit.

Leaf Line: A multi-mission, shared, and fully managed Ground Station Network, designed for operators seeking high flexibility, rapid service delivery, frequent ground contacts, low latency, and cost-efficient pricing.

Leaf Key: A fully-managed, dedicated Ground Station(s) solution, ideal for operators of medium-to-large constellations, offering an alternative to significant upfront investments, dedicated personnel, and recurring costs through a fixed monthly subscription plan based on the required ground infrastructure coverage. Leaf Key dedicated ground stations can be hosted at Leaf Space's facilities or at the customer's site.

Leaf Track: A fully-managed, Launch Vehicle tracking using real-time Autotrack and Telemetry reception, deployed on-demand with additional support from globally distributed Leaf Line network.

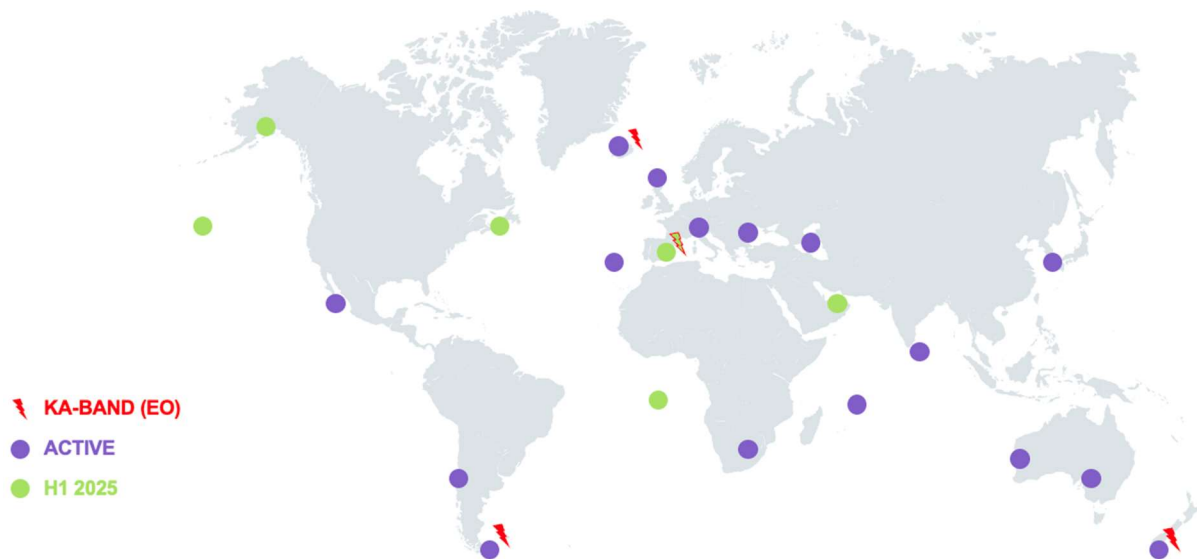


The most used Service to date is the Leaf Line globally distributed Ground Station Network. Over the last 10 years, the network has vastly expanded, with strategic placement and focus on key areas of interest, driven by industry feedback.

This strategic placement of Ground Station Sites allows for better overall coverage for LEO missions but also improves latency of data delivery – key for those missions who have strict SLAs and complex ConOps.

Internally, we are always looking at locations that will continuously improve our range. This involves various teams, including the Mission Management, Mission Analysts and Regulatory Affairs Specialists. From the initial discussions with customers, we analyze the ConOps and requirements to ensure that we can meet their mission goals. This activity also helps us to highlight any gaps for further improvement, and plan for implementation in new locations.

An example of this recently was the addition of our South Asia location, an area that previously was not widely served by Ground Segment providers, and which has proved to be instrumental in supporting the Mission ConOps of many of our customers.



Architecture and Design Philosophy

Infrastructure Abstraction

How Leaf Space abstracts the underlying infrastructure from the customer, reducing complexity.

In answer to the growing complexity of Spacecraft Operations and Mission Management, Leaf Space developed a system that would fully abstract the underlying infrastructure for Ground Station Management from the customer. By doing so, Leaf Space is able to provide access to an otherwise unattainable range of locations, globally, including innovative operational user experience.

The global network is managed by the Leaf Space Smart Scheduler, which utilises the full range of locations. At contract signature, Users specify their specific requirements for pass allocation, minutes of access to their satellite per day, data latency requirements, radio usage and any minimum elevation requirements. This is then stored and used alongside the orbital parameters (beneficial locations are different for mid-inclination or syn-synchronous orbits) to provide an optimised and bespoke schedule of passes for that specific Satellite.

Despite our growing number of Users, and due to careful planning and optimisation, the Leaf Space global network is still left with periods of availability even after the Smart Scheduler has allocated the schedule for the day. As a result, it is possible for Users to easily book additional passes at their convenience. This method can be essential in the event of a period of critical operations on-board a satellite or even while resolving an anomaly or emergency on board. This flexibility allows Operators to have a higher level of assurance for the duration of their mission, that Leaf Space can support in any scenario; often mitigating emergencies and extending Mission Lifetime.

Interoperability

The Leaf Space architecture is designed with interoperability in mind. The overall system is built and configured to be able to implement with any system developed using current industry standards. Additionally, Leaf Space has worked with other industry leaders to pre-integrate with many off-the-shelf Software As A Service systems (such as Mission Control Software, and Ground Segment Control Software)

This design choice helps companies who are both experienced and just starting out as start-ups and spin-offs to integrate quickly and efficiently, without having to sacrifice resources on designing *around* the service.

To access the full scope of our Leaf Line service, users need only to be compatible with API and MQTT, which are the two functions used for accessing the Ground Station Network.

The full management of the Leaf Link service from a User point of view is handled through our extensive API interface. Here, Users can access all scheduled passes, available-to-book passes, and all Mission Operations functionalities. Access is controlled and secure, and integration is simple focusing on Single-Point access for ease of use and operation.

The API endpoints can be integrated into any Mission Control Software (MCS) suite, and for most major MCS providers, the Leaf Space API interface has already been integrated and verified. This means that Operators have full access and full control over the Ground Station and Mission Management; able to adjust and configure based on their Mission Planning environments.

For the majority of data-exchange, MQTT is used as a secure access point. Here, we can also exchange a large range of metrics to give better visibility of the satellite configuration and RF data.

Scalability and Flexibility

The choice of API and MQTT as the primary access points for the Leaf Line and Leaf Track service is imperative when considering overall scalability as demand grows. Customer feedback is constantly being used to input into the overall Roadmap of the Leaf Space industry offering, and the use of these easily accessible and interoperable interfaces means that new and improved functions and features can be made available to customers as soon as they have been developed.

Recent feedback has helped Leaf Space to develop on-top of its extensive list of available metrics and also provide additional flexibility when configuring pass parameters. These features help to support increasingly complex missions and allow for new industry innovation in Spacecraft Operations.

Promoting Sustainable Practices

For the full Leaf Space service, all Regulatory Affairs and Licensing is handled in-house. This approach, due to excellent relationships with the Regulatory Officials at all of our Ground Station Locations, takes the pressure away from the customer and enables the most efficient use of the network for all customers.

Users need only to have submitted an ITU filing, as well as specifying their requirements, and if they have specific locations that would support their mission ConOps, and Leaf Space handles the rest.

Leaf Space has supported many Rideshare LEOP missions, where multiple missions are launched on a single Launch (such as the SpaceX Transporter missions). This approach has been made far simpler, and very common in recent years. Overall, Rideshare Launches provide a far more sustainable approach to achieving orbit of Satellite Missions. No longer is it necessary to procure single launches for satellites, often proving financially impossible and stunting development and innovation within the industry.

Leaf Space utilises both the Leaf Line and Leaf Track service to support these Rideshare missions, but with that extra level of support, comes some new challenges for operations and operators.

In particular, the complexities during this time are:

- Multiple Satellites being launched on different frequencies, all within a very close proximity
 - Dealing with overlapping passes
 - Adjusting priorities based on the criticality of each mission
- Using potentially incorrect TLE or Ephemeris data
 - Due to launch times changing and evolving, or mis-calculation from the customer
- Quick changes of Configuration/Frequencies/TLEs or other mission constraints
 - To support this critical phase
 - For aiding debugging and LEOP for customers
- Not having correct NORADID numbers for all parties

- These don't get confirmed until the Object is recognized and tracked by the Operator

By providing this additional level of support, despite often challenging conditions, Leaf Space can aid in ensuring Mission Success for customers, limiting the rate of Mission Failure and avoiding costly re-builds of Satellites, and Launches.

Conclusion and View to The Future

As the space industry continues to evolve, the traditional model of building and maintaining proprietary ground stations is no longer viable for most missions—especially for the fast-growing small satellite and constellation markets. Leaf Space's Ground Segment as a Service (GSaaS) approach addresses this shift by offering a robust, globally distributed network that abstracts operational complexity, enhances interoperability, and promotes mission resilience.

Through its services—Leaf Line, Leaf Key, and Leaf Track—Leaf Space provides adaptable and cost-effective solutions that support customers through every mission phase, from LEOP to End of Life. Its emphasis on infrastructure abstraction, flexible scheduling, API-based control, and regulatory support reflects a forward-thinking design philosophy that empowers both established operators and emerging players in the space ecosystem.

By facilitating increased satellite visibility, reducing barriers to entry, and enabling sustainable mission architectures, Leaf Space is not only meeting current industry demands but also actively shaping the future of responsible and accessible space operations.