A Shortest-path Optimization Algorithm for Ground Station and Satellite Clusters Communication

CUBESAT DEVELOPERS WORKSHOP

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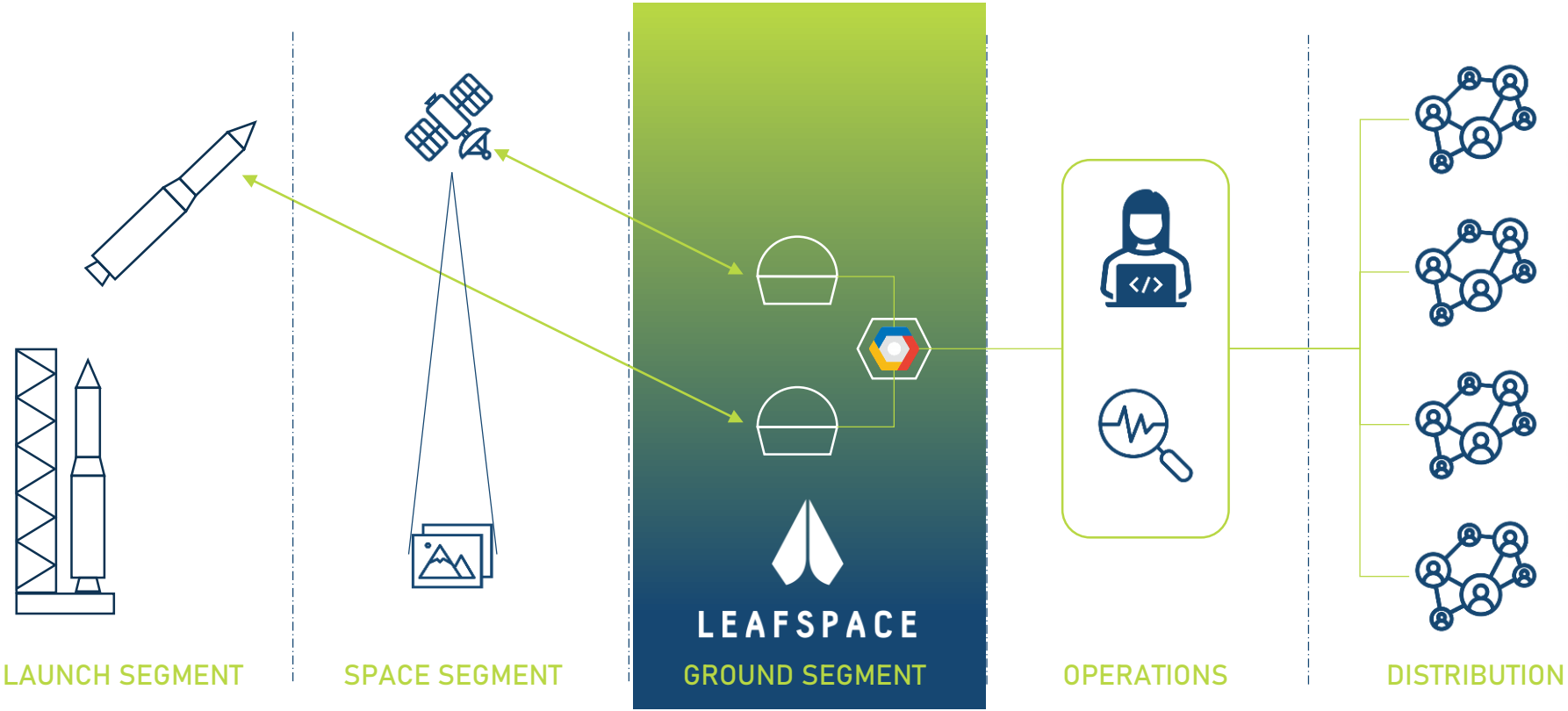
LEAF SPACE AT A GLANCE

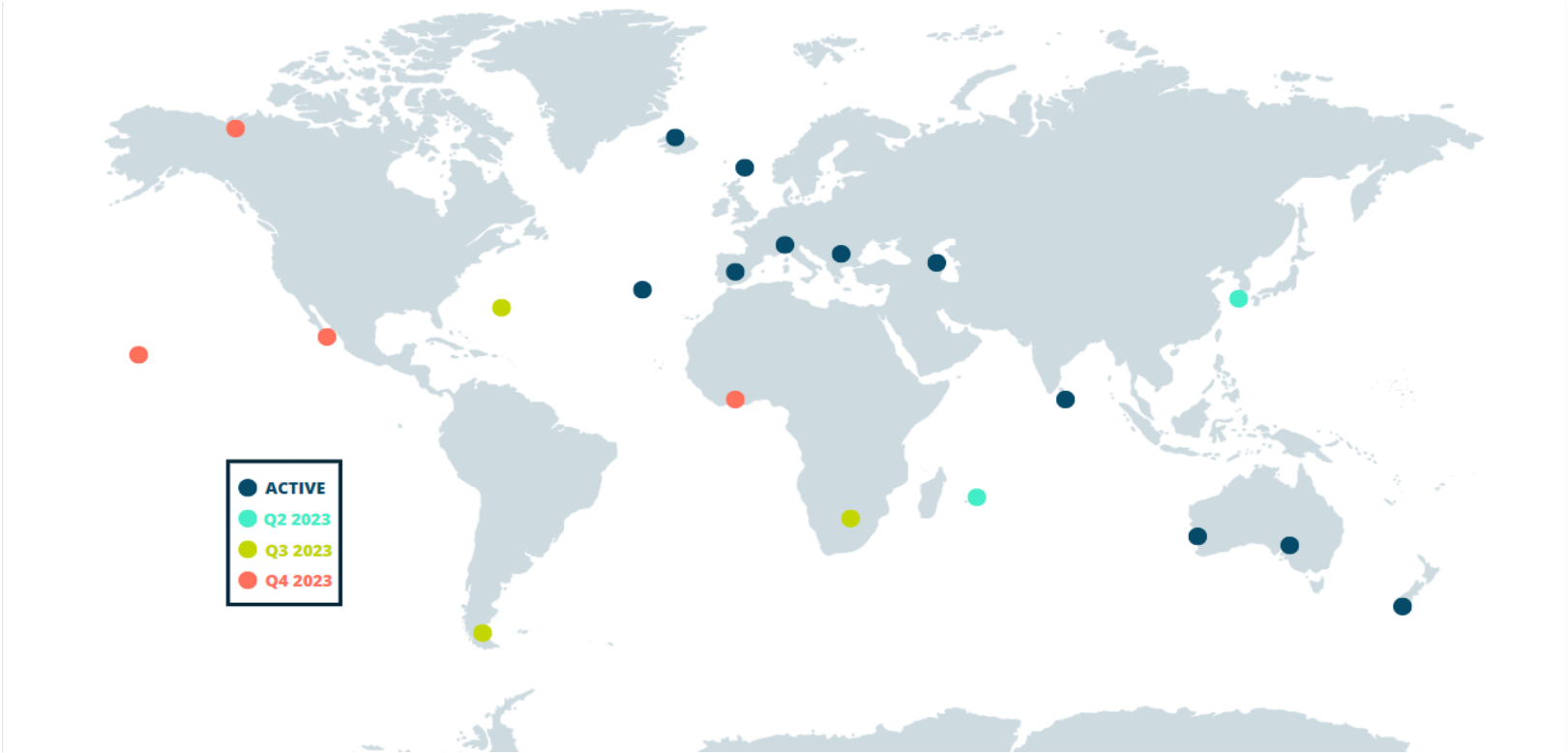
OUR VISION

Be the leading provider of connectivity services to space assets, to enable a sustainable expansion of the space ecosystem

GROUND SEGMENT – THE ONLY WAY BACK TO EARTH

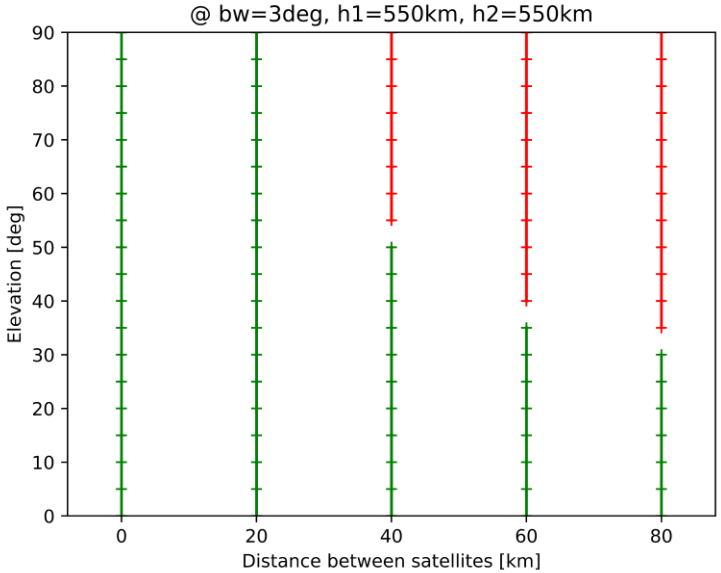


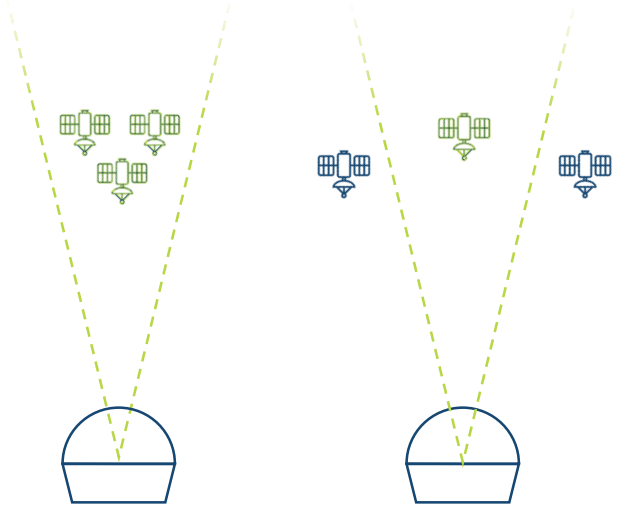
GROUND STATIONS NETWORK



CONTEXT – WHEN MSPA DOES NOT WORK

- Implementation of a Multiple Satellite per Aperture (MSPA) solution in S and X band
- In some cases, MSPA offers limited support for cluster with higher inter satellite distance or at high frequencies (X/Ka Band)





MULTI-CONTACTS

- Divide conflicting contacts into smaller contacts, one per satellites of the cluster, with the following inputs:
  - TLEs of each satellite to be tracked
  - Minimum duration of each contact

And the following assumptions:

- Only one ground station is being used
- The satellites are operated by the same user
- The satellites use same radio configuration and frequency bands
- Each satellite gets only one contact
- The first satellite to become visible will be the first to be contacted
- The last satellite to remain visible will be the last to be contacted
- Constant time between each contacts for repositioning and reconfiguring

IMPLEMENTATION: LINEAR PROGRAM

The constraints are:

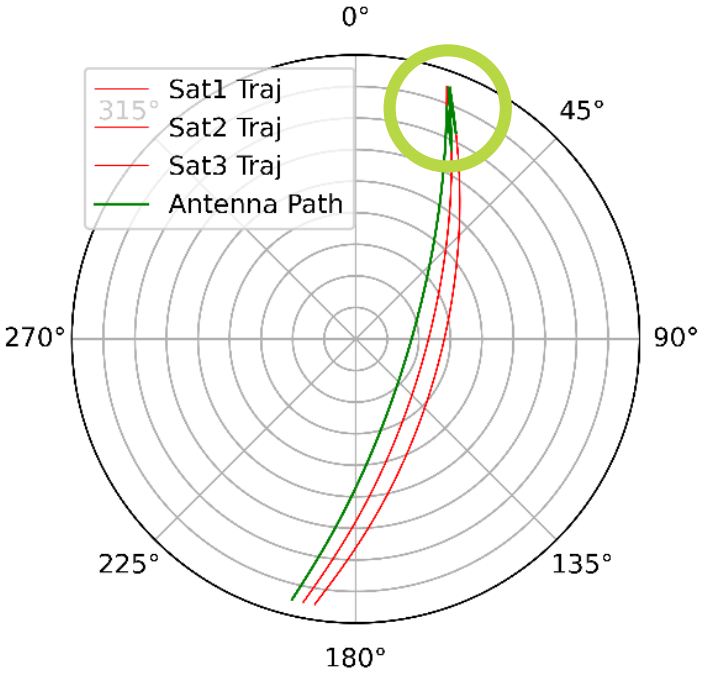
- The length of each contact must be bigger than the required minimum
- The found contact must be contained within the given contact
- Tor each contact, in relation to the other contacts:
  - The aos_f_n must be bigger than $los\_f_m + r_{mn}(los\_f_m)$ (where $r_{nm}(los\_f_m)$ is the repositioning time from satellite n to satellite m at time los_f_m)
  - OR $los\_f_n + r_{nm}(los\_f_n) < aos\_f_m$

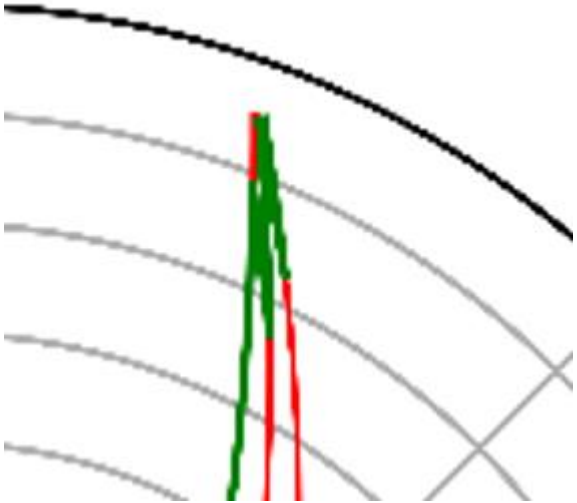
$$\max \sum_{i=0}^{n} c_i$$

$$s.t. \begin{cases} los\_f_i \leq 1, & \forall\, i \in [0..n] \\ aos\_f_i \leq 1, & \forall\, i \in [0..n] \\ aos\_f_i \geq aos\_g_i, & \forall\, i \in [0..n] \\ los\_f_i \leq los\_g_i, & \forall\, i \in [0..n] \\ aos\_f_i < los\_f_i, & \forall\, i \in [0..n] \\ c_i \geq req_i, & \forall\, i \in [0..n] \\ aos\_f_i \geq los\_f_j + r_{ji}(los\_f_j) - \delta_{ij}, & \forall i,j \in [0..n] \mid i \neq j \\ los\_f_i + r_{ij}(aos\_f_i) \leq aos\_f_j + (1 - \delta_{ij}), & \forall i,j \in [0..n] \mid i \neq j \end{cases}$$

$c_i = los\_f_i - aos\_f_i$ with $i \in [0..n] \mid n\ number\ of\ sats$
req_i are the percentage requirements for the contacts
aos_g_n and los_g_n are original AOS and LOS
aos_f_n and los_f_n are resulting AOS and LOS

IMPLEMENTATION: FIRST RESULTS





IMPLEMENTATION: RESULTS

Requirements:

Sat1: 360s Sat2: 120s Sat3: 240s

Original AOS and LOS:

Sat1: 2023-05-01 11:31:20 - 2023-05-01 11:41:08

Sat2: 2023-05-01 11:33:17 - 2023-05-01 11:43:07

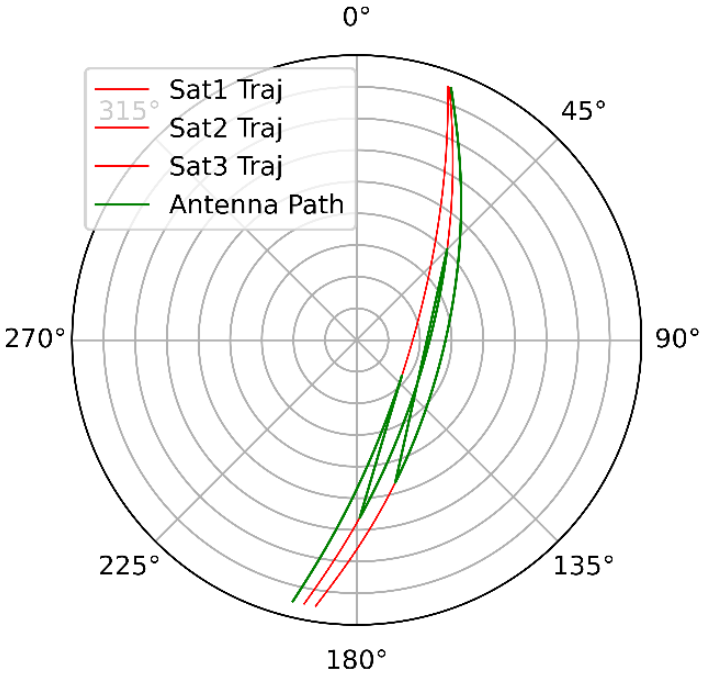
Sat3: 2023-05-01 11:35:15 - 2023-05-01 11:45:05

Resulting AOS and LOS

Sat1: 2023-05-01 11:31:20 - 2023-05-01 11:33:20

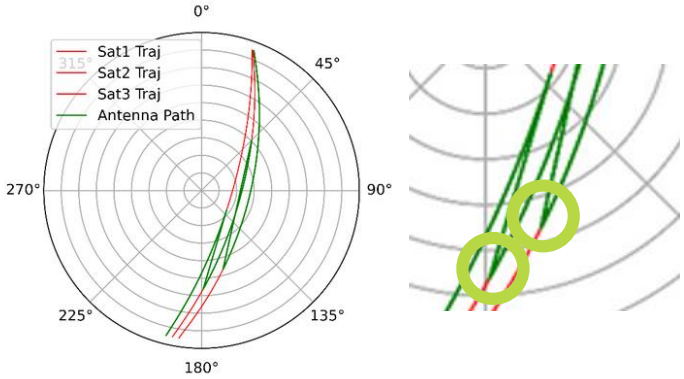
Sat2: 2023-05-01 11:33:50 - 2023-05-01 11:35:50

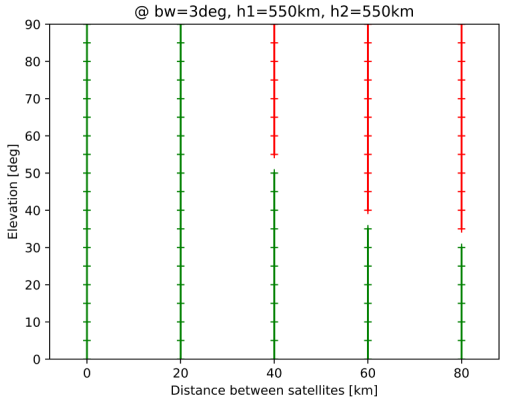
Sat3: 2023-005-01 11:36:2 - 2023-05-01 11:45:05



NEXT STEPS

- Optimize according operational parameters such as elevation and range:
  - Sub-contacts with lower elevation should be longer (PL downlink)
- Create an API and integrate it into our automated scheduler
- Hybrid solution with MSPA at the start of the pass (when doable) and then switch to multi contact
- Consider moving parts and smooth the tracking trajectory





OTHER USE CASES: WINNING THE TLE LOTERY

- Using this technic, we could allow our users to track several TLEs during the LEOP and figure out which TLE matches their spacecraft
- Here the assumption would be that the portion of the passe dedicated to each TLEs is equal
- The user input would simply be a series of TLEs

OTHER USE CASES: PROVINDING PASSES TO MULTIPLE USER

That technic could also be used to provide short passes to multiple users when it is not possible because of conflicting passes in the visibility window

It is however more complicated to implement because:

- Orbits may be too dissimilar
- Radio configuration will surely be different leading to longer reconfiguration time
- Deconflicting must be done between several users instead of with one user

CONCLUDING REMARKS

- Can be used in several operative scenarios where pure MSPA is not available
- API to give control to the user vs blindly optimizing
- Available by the end of the year

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