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Merging Diverse Architectures for Multi-Mission Support

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ABSTRACT

Planet Labs Inc. ("Planet") currently operates the world's largest commercial earth observation constellation with over 150 active on-orbit satellites collecting daily medium resolution imagery of the whole earth, and high resolution imagery of targeted areas of interest. In 2017, Planet combined the SkySat high-resolution satellite constellation with its own existing medium resolution Dove constellation to expand its ability to make global change visible, accessible, and actionable. While the two satellite designs use largely similar ground station architectures, nuances in implementation caused early operations to focus on maintaining separate, siloed ground station networks with unique software and hardware.

As Planet looks to expand its on-orbit constellations and diversify orbits to meet customer needs, our Ground Station Operations team has begun work to combine software and hardware architectures to support multiple missions from the same stack. By enabling multi-mission support, we realize benefits in increasing daily average contact duration and minimizing per-satellite contact gaps. This in turn decreases our reaction latency on-orbit and increases our individual ground station utilization to increase our total possible throughput. In this paper, we will discuss our network modeling for coverage and access planning, our general strategies for combining architectures for multi-mission support, results thus far, and lessons learned along the way. Planet's Ground Station Operations team has built out and operates a network capable of downlinking over 15TB of earth imaging data from our on-orbit constellations in a single day and looks forward to continued high-reliability and low cost support of Planet's on-orbit assets in the future.

MONITORING CHANGE FROM SPACE

Planet aims to help life on earth by making change visible, accessible, and actionable. Planet has taken a multi-asset approach to monitoring our earth and capturing changes with a focus both on daily background medium-resolution monitoring and high-revisit high-resolution tasking. Planet began its mission with "Dove" 3U CubeSats, rapidly iterating on design to improve to deliver multi-band medium resolution imagery with a scalable and reliable satellite bus. The CubeSat form factor has enabled Planet to take advantage of diverse launch opportunities, growing the Flock constellation over time to its current state with over one hundred active imaging CubeSats on orbit. In 2015, Planet added the RapidEye medium-resolution smallsats and their catalog of imagery. In 2017, Planet brought in the SkySat smallsats capable of high-resolution tasking. In 2020, the RapidEye satellites have reached end-of-mission nearly five years beyond their initial design life of seven years and have since been decommissioned and lowered in orbit to facilitate their re-entry.

Planet's multi-asset mission continues via the Flock constellation of CubeSats and the high-resolution Skysat smallsats. The history of each constellation, designed and built by separate companies, led to different choices being made about ground station architectures and mission-specific software. Different aspects were prioritized and small differences in the Concept of Operations (ConOps) led to divergent designs in both hardware and software. As Planet seeks to maintain existing background monitoring via the Doves and expand rapid-revisit tasking with additional Skysat launches, we also look to combine ground architectures into a uniform design that is able to take advantage of the strengths of each original design and can operate any on-orbit Planet asset.

Benefits to the Ground Network

By combining ground station capabilities, Planet is able to increase daily average contact duration and minimize per-satellite contact gaps. Not only does this lead to higher utilization of ground hardware, this also in-turn decreases our reaction latency on-orbit and increases our individual ground station utilization to increase our total possible throughput. Lower reaction latency also helps Planet with overall imaging operations such as tip-and-cue change detection and reaction.

Planet's multi-mission ground stations are enabled through OS-level virtualization, utilization of industry standards, platform flexibility, reprogrammable and adaptable hardware, and careful planning and optimization of the ground network design.

OS-LEVEL VIRTUALIZATION OF SOFTWARE

Software and scripts necessary to operate a ground station can often have complex dependencies and unexpected system-level interactions. Developers and teams often have different approaches to problem solving and reaching solutions. Within teams or within organizations, there's often a shared style-guide or mutual consensus on best practices. However, at higher levels, such as between departments or between companies, approaches can vary widely. The potential for problems due to conflicting dependencies or system-level behavior increases dramatically when attempting to merge software stacks between separate organizations. Ground stations with components for antenna-control, tracking, radio-control, payload-handling, networking, and the myriad of support functions are susceptible to any number of system-level failures. Fortunately, modern virtualization tools allow developers to encapsulate run-time environments in containers and reduce the possibility of interactions.

Virtualization managers can combine the tools required to run a component within a container with the exact required dependencies and clearly defined and carefully scoped resources shared with the host operating system.

Virtualization in Action

Planet's Ground Station Operations team has used virtualization to account for variations in on-orbit spacecraft architectures in the Doves, long before adding support for the Skysat constellation. In 2017, Planet redesigned the on-orbit X-band radio (HSD) at the center of its data link, achieving 283 Mbps from a CubeSat platform.[1] Further, in 2019 Planet announced that using the newer HSD2 radio in a multi-channel configuration Dove CubeSats had achieved on-orbit data rates in excess of 1 Gbps.[2] The HSD2 radios aboard newer Doves operate similarly to the older HSD1 radios, but require different ground software to control the link.

Virtualization allows for easy swapping between ground station control software. Shared components are always running, but pre-pass software scripts determine whether the upcoming contact should be HSD1 or HSD2, and bring up the appropriate container. This allows us to seamlessly flow between the two software stacks keeping most components running uninterrupted while changing out those required for the differing on-orbit asset.

Porting Software with Virtualization

Similarly the Ground Station Operations team added certain features of the ground station stack developed for Dove-operations to the Skysat-operations ground stations. The team has long relied on open source Information Technology tooling to monitor station performance, automatically detect issues, and either triage those issues immediately or raise them to a human operator if needed.[3] Skybox–and later Terra Bella–understandably developed different solutions. Through the carefully controlled environment of containers, Planet was able to add its monitoring to Skysat-operations ground stations, adding the familiar monitoring developed for Dove-operations stations with minimal changes to the production environment.

More recently, Planet's Ground Station Operations team has extended antenna command and control tools to Skysat-operations systems, allowing those systems to drive the same antenna platforms as are in-use by Dove-operations systems. Again, by reusing this previously containerized package, the flexibility of Skysat-operations systems were expanded without requiring a change in the underlying operating system or installed software dependencies. In one case, this extension of software capabilities through virtualization has allowed Planet to share medium and high-resolution operations on the same parabolic dish. Since combining operations on that antenna, Planet has observed a 60-70% increase in raw data downlinked at the antenna due to the increased contact opportunities and higher antenna duty cycle.

While Planet's Skysat operations and Dove operations ground stations are not fully integrated as of this writing, their software stacks are well on their way to interoperability on a single hardware platform through OS level virtualization that allows easier management of dependencies and scoped access.

BENEFITING FROM COMMUNICATION STANDARDS

When discussing the merging of these diverse architectures, we cannot ignore the role that industry standards play. Separate design choices serendipitously led both the Skysat and Dove satellites to settle on DVB-S2 for payload data encapsulation. SkySat uses the more-standard video MPEG transport stream over the RF link, while the Doves use Generic Stream Encapsulation to envelop standard IP traffic over the link.

Both ground station systems were built to the same downlink standard and on the same frequency band, automatically creating hardware compatibility between the two. Some software differences remain between how the raw data is handled once extracted from the DVB-S2 frames, however, the overall handling of the data is similar. Once reconfigured, the Skysat constellation becomes nearly identical to a 3-channel Dove constellation from the ground station perspective.

While the common use of DVB-S2 is somewhat of a happy coincidence, we can still take advantage of these similarities to abstract away differences in spacecraft design and therefore reduce the required differences in ground station architecture. We cannot claim credit for these independent decisions, but we can take a valuable lesson; the common reliance on existing standards has allowed for greater interoperability between diverse constellations and a common ground station architecture.

DEVELOPMENT OF MULTI-ASSET TRANSCEIVERS USING SOFTWARE-DEFINED RADIOS

When communication standards are impractical to implement, for example due to throughput constraints or other required link optimization, we can still create a layer of abstraction using programmable hardware radio peripherals. The Dove satellites have long relied on a custom hardware radio for tracking, telemetry, and control (TT&C). Planet released a similar open source packet radio in 2018.[4] Custom TT&C radios can more efficiently cover specific use cases and optimize for data throughput or other special functions such as time of flight distance ranging.[5] However, when combining diverse constellation operations into a single platform, hardware radios require additional support equipment such as splitters, combiners, attenuators, amplifiers, or network-controlled RF switches. The additional RF equipment can be expensive, take valuable space in a server rack, and introduce additional possible points of failure.

Reducing Complexity of Hardware

Planet's ground station team has begun consolidating hardware radios onto a programmable Universal Software Radio Peripheral (USRP) in order to reduce hardware complexity across the ground station network. With the radios emulated in software via a USRP, the ground station is able to quickly and easily swap between the required radios depending on the requirements for upcoming contacts. With this model, the hardware transmit and receive chain remains identical, reducing possible points of failure and required monitoring.

Additionally, the USRP eliminates a need for ground-side custom hardware. While Planet's Low Speed Transceiver (LST) has been highly reliable for operations, the boards are custom PCBs and assembled into a custom chassis. USRP hardware is more commercially available and simplifies the required supply chain.

Emulating a custom hardware radio in the software world can be difficult, however. Vendor datasheets and manuals rarely give in-depth details of the physical and data-link layers, rather relying on customers choosing ground and space radios that are identical or within the same product line to communicate between nodes. This forces the end user to analyze the RF and reverse engineer the protocol in order to change either side of the communications link, which can be technically challenging or costly.

Planet has adopted the ground station software radio stack already created for the Skysat program and is currently working to adapt its own CC1110-based LST to the same USRP platform. Once completed, the two will be interchangeable on the same hardware leading to much closer interoperability.

Programmable software defined radios can replace and simplify extensive hardware RF chains that would otherwise be required for multi-constellation communications. USRPs are able to emulate different hardware radios, making the switch between communications protocols with only a software change and reducing the number of single-points-of-failure. Multipurpose hardware such as USRPs allows Planet to more easily adapt ground stations for multiple constellation support.

CONTACT OPTIMIZATION AND GROUND NETWORK PLANNING

As Planet expanded its constellations with new spacecraft in new orbits, Planet's ground network had to grow to accommodate the new satellites. Of particular importance are the Skysat rideshare on Starlink-8 that launched in June and the upcoming Skysat rideshare scheduled as of this writing on Starlink-11. These launches expand Planet's mid-latitude imagery coverage with high revisit rates, but also introduce new coverage requirements for the ground network. Since all of our existing ground stations are located at high latitudes, we had little existing coverage for orbits in more middle latitudes.

Strategies for Simulation Planning

Contact simulation tooling helped to optimize the new ground network coverage. The simulator ran specific ground station networks against a set of no-drag TLEs. Drag was removed to avoid simulation degradation over-time. The simulator focused on two different optimizers, one which selected contact opportunities in the chronological order that they arose (discarding any conflicts), and the other that selected contact opportunities by order of which satellite within the constellation had the oldest most-recent contact. The latter therefore aided in optimizing for the shortest possible contact gaps across the constellation from the satellite perspective.

A few potential candidate ground station networks emerged quickly simply by way of selecting geographically diverse locations at relatively high and low latitudes (for the required orbit). Occasionally, ground station network scenarios would reveal a small number of long-contact-gap outliers. Human intervention with STK provided a helpful visual of the outlier orbits identified by the simulator and aided in finding better replacement candidate sites.

While the primary purpose of this simulation was to select potential sites to serve new satellites, with a small amount of work the sites could also serve existing Planet constellations on a secondary or tertiary basis. Simulation found that by opening up two of the new mid-latitude sites to Planet's existing high resolution constellation on a secondary-access basis increased the daily average contact duration 13%. Additionally, it reduced the average on-orbit pass gap of the existing high resolution constellation by about 11%. While these results are admittedly not a breakthrough, they represent a non-trivial improvement and enabled quantification of the benefit provided by work to make the new sites multi-mission capable.

Possible Improvements

Further work could incorporate simulated annealing to reduce human analysis. Given a list of ground station candidate sites, simulated annealing would repeatedly select a candidate pool, run a scenario, grade the result, and possibly attempt to tweak the network until a local minimum solution was found. However, such an approach may miss other critical factors such as the regulatory environment in a candidate site's location or existing contracts and industry relations that may make some sites preferable to others.

CONCLUSION

Planet has expanded its constellation diversity, bringing together different spacecraft designs from multiple origins in pursuit of making global change visible, accessible, and actionable. Additionally, Planet has made changes and improvements to its existing on-orbit designs to produce higher quality imagery with a more reliable cadence. While such a diversity of on-orbit spacecraft designs can complicate the required ground station configurations, careful planning can help combine multiple architectures into a single platform to optimize the duty-cycle of high-cost assets.

Operating-system-level virtualization or containerization of software can easily control dependencies and runtime environments. Containerized components can coexist reliably on the same hardware, even when originating from wildly different designs. Through such containerization, Planet has been able to extend tooling historically used exclusively for ground operations of one of its imaging constellations to all active on-orbit Planet satellites.

Additionally industry standards have allowed for common data pipelines and reuse of hardware tooling and software paths. By leveraging standard protocols common to Planet's different on-orbit constellations, the ground network is able to reduce redundant paths and extend previously siloed ground station networks.

Where fundamental communication protocols differ, radios can be recreated largely in software, allowing for easier switching between different configurations on the same platform.

Last, careful planning of future orbital planes and simulation of antenna use allow the ground station operations team to select optimal expansion strategies. Models also help to add quantitative value to ground station homogenization work, demonstrating clearly what can be achieved with tiered access priority structures at available ground stations.

Together, these strategies ease the transition from separate ground station architectures designed for separate, on-orbit constellations into a single, unified design. A common ground station architecture allows for higher utilization of high-cost assets and shorter pass-gaps for individual satellites. Such work decreases reaction time for tip-and-cue imaging or change detection, and decreases overall latency from image capture to publishing ultimately making changes on Earth more visible, accessible, and actionable.

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