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Autonomous Monitoring of a Diverse Ground Station Network

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ABSTRACT

Planet Labs owns and operates the largest commercial earth-imagery CubeSat constellation. Planet's ground station network is responsible for the earth-to-space communication link that gathers health and telemetry data, keeps the spacecraft schedule up-to-date, and downlinks the payload data from the spacecraft. The ground station network contains fifteen geographically diverse sites with a combination of leased and owned equipment from multiple vendors. Across those sites, the team monitors over 1600 services on nearly 500 devices. The scale of the network and diversity of equipment present challenges for operations and network health monitoring.

Planet's Ground Station Operations team monitors assets through a combination of active monitoring scripts on timers, event-based monitoring feedback, real-time metric analysis, and periodic automated long-term metric analysis. Active polling by monitoring scripts and real-time metric analysis catch configuration, software, and hardware issues as they arise independent of contacts with satellites and enable operators to quickly fix problems with little to no loss of satellite contact time. Meanwhile, event-based monitoring flags issues when outcomes differ from the expected results based on deterministic actions and uncover issues that are either transient or hidden from an active polling script. Last, long-term metric analysis gives insight into the slow degradation of system components and can be used to schedule targeted preemptive maintenance to efficiently maintain high operational uptime.

With this combination of monitoring approaches and through using a wide array of tools that feed back into specific operator "dashboards" for a fast top-level view of issues, Planet's Ground Station Operations team is able to maintain greater than 99% uptime and less than 90 minute incident response time without continuous 24-hour staffing. In total, the network takes over 2800 contacts per day with Planet's Low Earth Orbit constellations. The Ground Station Operations team emphasizes automation, fail-over, and targeted redundancy to give on-call staff tools to rectify or triage issues quickly, efficiently, and at scale.

HARDWARE DIVERSITY COMPLICATES MONITORING

Planet's Ground Station Operations team handles nearly 30TB of imagery data daily across all of Planet's constellations as of writing. As spacecraft operations optimize and as new iterations of space hardware are launched, total data increases while latency requirements tighten. The combination of the two creates a need for high-availability systems with autonomous and early fault detection to aid operator interventions.

Ground Hardware Diversity

In order to meet requirements for payload data, spacecraft health, scheduling, and general Telemetry, Tracking, and Control (TT&C), the Ground Station Operations team manages a variety of ground-based assets including Planet-owned, dedicated-leased, and shared-time antennas. Ground assets are added to the network as required by the constellation concept of operation requirements. These antennas are a variety of models over many years and from multiple manufacturers.

Ground-based systems can be upgraded over time to add new capabilities, sometimes also causing variation in the hardware or signal chains.

Space Hardware Diversity

Additionally, Planet's on-orbit constellations of satellites are generally split into the medium resolution Dove spacecraft and the higher resolution SkySat spacecraft. Not only do the families of spacecraft themselves have differing Radio Frequency (RF) chains, they also each have multiple spacecraft bus build iterations further increasing the variety of possible hardware combinations. For example, over the history of Planet Labs, the Dove spacecraft has iterated to the SuperDove bus, which greatly increased maximum achievable datarates through both software and hardware changes.[1] Such changes by necessity affected the RF chain.

Autonomous monitoring of systems is critical to the Planet Ground Operations team due to the number of spacecraft, ground assets, and ongoing contacts or passes at any given time. Many assets can be monitored directly, such as servers or routers that can report their own health metrics or software services running on those machines that can have built-in health checks, logging, and status reports. Antenna monitoring can pose more challenges due to the specialized hardware and software involved, but the systems still generally have fault detection and reporting and have well-documented behavioral patterns. Monitoring challenges increase when looking at the earth-to-space RF link. Multiple factors can affect the signal, including RF signal chain faults on either end, antenna pointing either on the ground or in space, slant range, and–at higher frequencies–weather patterns.

Where specific monitoring fails, and as a catch-all for missing or as-yet unrealized monitoring patterns, more general data analysis can take a holistic approach to measuring system health.

SPACE-TO-EARTH SYSTEM MONITORING

Ground operators have direct access to the ground end of the space-to-earth signal chain, enabling more direct link-quality measurements. Planet's constellations use the commercial DVB-S2 standard for high-throughput data downlink.[2] Dove spacecraft make use of Adaptive Coding and Modulation (ACM) to change datarates during a contact as the path losses between the space-segment and ground-segment endpoints vary with contact geometry.

Link-quality metadata is recorded from the earth-based demodulators throughout the contact and uploaded to a cloud-based data repository for future access. A central service analyzes contacts after the metadata is completed, looking for channel lock, channel sync, maximum datarate, and commanded versus actual Modulation and Coding (MODCOD). Contacts are analyzed on a per-antenna basis and multiple unsatisfactory contacts in a row on any one antenna will trigger an alarm for that antenna. Alerts carry information about which demodulators reported possible link-quality issues during the contact to offer as much specificity to operators as possible.

Alerts are per-antenna and only transition from a "soft" to "hard" alert state after multiple failures to prevent problems with any one spacecraft or any one contact from causing false positive alarms. Planet's agile aerospace and constellation concept of operations allow for limited anomalies to arise without impacting operations as a whole. Systems are designed to be robust to individual spacecraft anomalies and automatically handle them or flag them for operators at later times.[3] Because spacecraft anomalies can occur independently of ground anomalies, ground-based alerting only triggers after multiple failed contacts. This reduces false alarms and therefore prevents alert fatigue in operations.

When problems do arise, common patterns can quickly emerge. If a single demodulator does not achieve high datarates, there may be an issue with ACM on that demodulator. Many of the antennas designed for Flock operations carry both left-hand and right-hand circularly polarized block downconverters; if all demodulators on one polarization fail to achieve lock or sync, the downconverter is the immediate suspect. If all channels report problems with commanded versus actual MODCOD, there may be issues with the earth-to-space RF link (additional earth-to-space monitoring is discussed below).

To aid operators in debugging, the ground RF signal chain terminates in a remotely accessible spectrum analyzer in parallel with commercial off-the-shelf (COTS) DVB-S2 receivers.

EARTH-TO-SPACE SYSTEM MONITORING

Generalized earth-to-space system monitoring is more difficult than space-to-earth due to the lack of direct access to the receivers and the smaller amount of metadata available. Additionally, metadata is only available when the RF link is operational; metadata that may otherwise signal a degraded state may not reach servers and tools on Earth at all.

In this case, link quality monitoring relies on Receive Signal Strength (RSS) reported by the spacecraft. Dove satellites pull the RSS measurement from a custom-built transceiver using a COTS RF system-on-chip microcontroller.[4]

Once collected and aggregated on the ground, RSS datapoints are matched to their respective contacts, spacecraft, and antennas. The instantaneous slant range is calculated and added to the RSS for a value normalized over the duration of the contact that theoretically should eliminate any bias introduced by the relatively higher RSS at time of closest approach and therefore the impact of the contact's geometry.

RSS datapoints are subjected to a once-daily ordinary least squares regression with the normalized RSS as the dependent variable and with spacecraft model, individual spacecraft, antenna model, and individual antenna as categorical independent variables. The regression produces coefficients representative of the impact each asset (or asset type) has on the normalized RSS. The model specifically includes spacecraft model, individual spacecraft, and antenna model to account for the impact of each factor on link quality. The period of time (daily) was somewhat arbitrary, but with the intent of balancing a long enough measurement cycle to average out spurious data and outlier contacts with a short enough measurement cycle to allow for trend analysis and actionable results.

Table 1: Example Daily Coefficients

	Coefficient
(Intercept)	106.2448992
satellite_type1	92.93560926
satellite_type2	99.34282129
...	
satellite1	4.46473110
satellite2	-2.57651202
...	
antenna_type1	7.23638468
...	
antenna1	-8.16562556
antenna2	0.57096577
antenna3	-1.05434136
antenna4	0.18068863
antenna5	-1.38378288
antenna6	-1.67493388
...	

The coefficient matrix is saved for each daily run and a separate process pulls the historic coefficient matrices and evaluates the individual antennas' coefficients both for "out of family" results and evaluates the slope of coefficient measurements over time to spot slow degradation caused by cable wear or equipment calibration.

While this methodology has not been in practice long enough to catch any issues with antenna uplink performance, running it over historical data has shown past work performed and indicated possible assets for a closer look in the future. Ideally, by catching equipment calibration issues and wear-and-tear, proactive preventative maintenance can be implemented to avoid disruptive and costly downtime.

Alternative Methods for Similar Quality Measurements

Similar measurements could be taken–possibly with more accuracy–through a spectrum analyzer or power meter attached to a test port on the antenna feed, however that solution represents additional cost and complexity and is not available with all antenna manufacturers or models. While alerting that relies on spacecraft-reported RSS risks possible conflation with factors external to the ground segment–such as terrestrial weather or spacecraft pointing–it also is a more comprehensive measurement and a better indicator of when we should expect successful contacts with spacecraft.

POSSIBLE IMPROVEMENTS

The methodology could be improved by focusing on a continuously learning and evolving model, rather than the discrete one-day periods currently selected. A better method may rely on using a trained model to predict normalized RSS values for upcoming contacts, then generate performance data (and therefore alerts) based on how predicted values match the model.

Additionally, more work could be done to remove outliers from the datasets before generating models either automatically or with some operator flagging of known anomalous satellites or contacts. As it stands, this data is still used in the dependent variable dataset and the method relies on regression to the mean to reduce the effect of such data.

CONCLUSION

Explicit service, process, and host checks create a solid base for network monitoring. Generalized performance checks relying on link quality data and analyzed in bulk can identify additional errors for which it may be more difficult to design deterministic checks. Link quality data can be made more relevant by accounting for path loss, satellite variation, and variation between antenna models. Through bulk data accumulation and trend analysis, Planet's Ground Operations team can identify and mitigate possible future issues before they impact system performance.

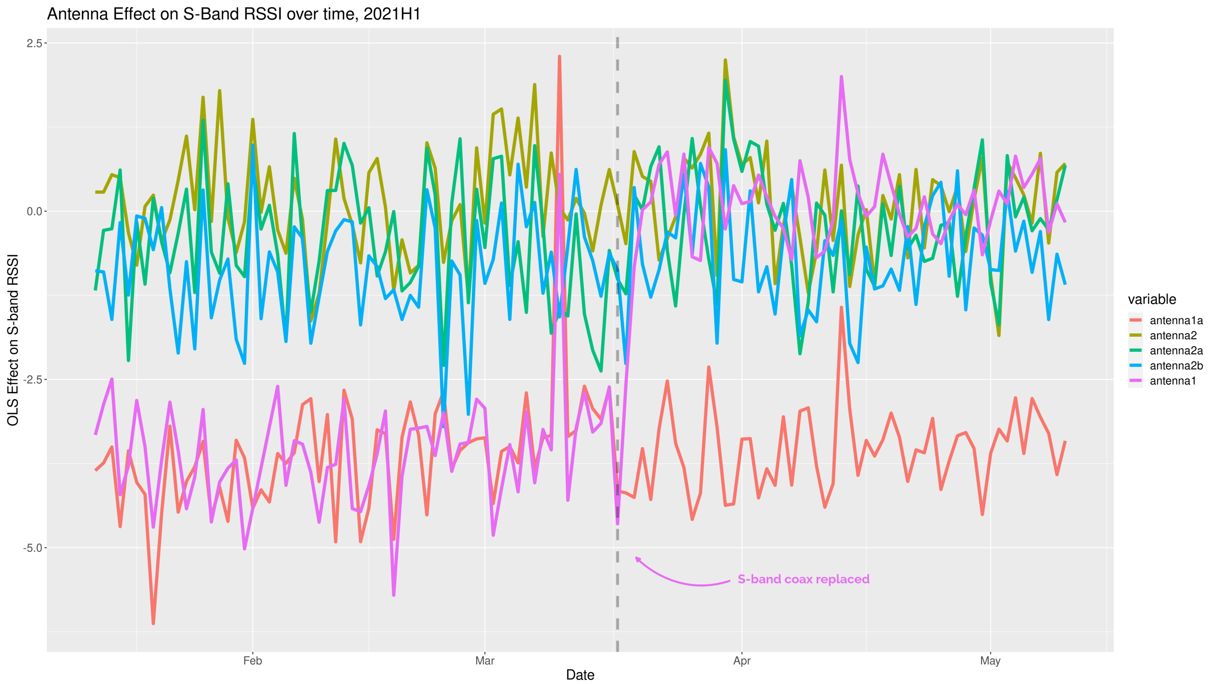

Figure 1: Anonymized antenna coefficient data at a site showing improvements after replacing a coaxial cable

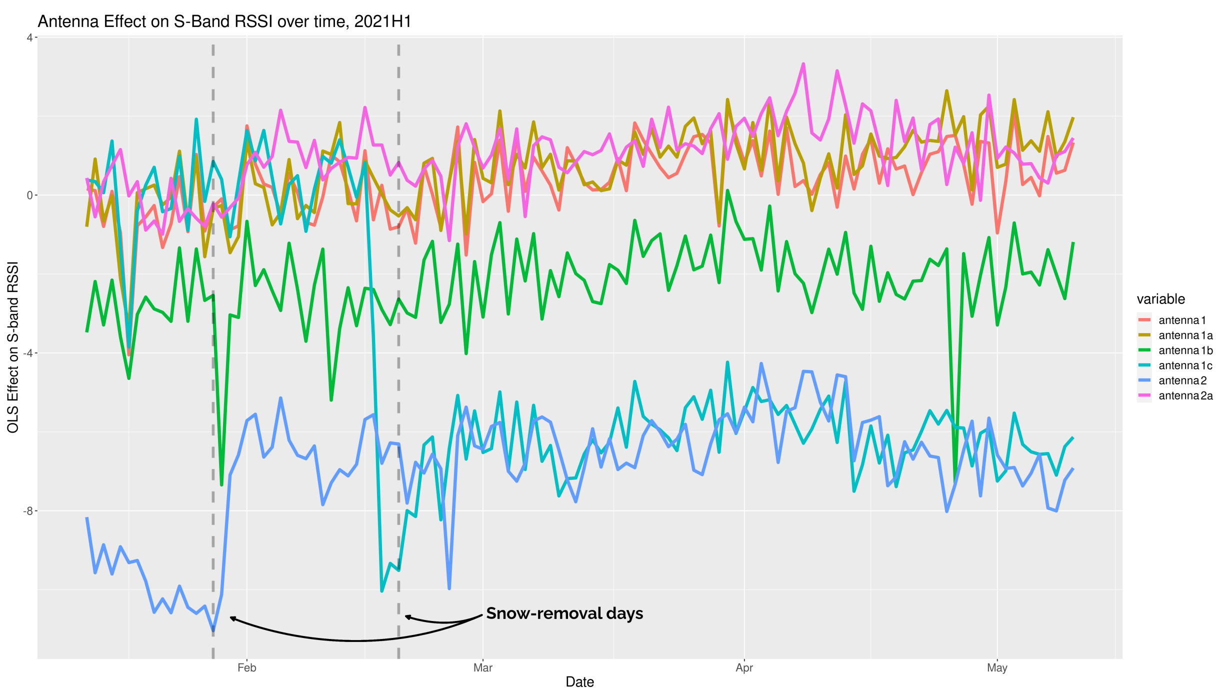

Figure 2: Anonymized antenna coefficient data over time at a site showing the effect of snow removal on dish performance

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