BridgeSat Laser Communication Scheduling: A Case Study

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ABSTRACT:

Orbit Logic has developed an interactive web-based scheduling system for the BridgeSat Laser Communications Network based on configurable COTS software, customized web pages, and a BridgeSat-defined operations concept. BridgeSat's mission is to speed adoption of optical communications systems by providing operators with a turnkey solution that seamlessly connects satellites to the ground, and accommodates accelerating demand for accurate and frequent data collection from LEO satellites. Satellite Operators login to the BridgeSat web page to view and edit daily data volume downlink requirements and view the status of prior downlinks. The BridgeSat server automates routine daily planning of laser communication contacts to multiple satellites for multiple ground stations by calling Orbit Logic's STK Scheduler COTS application, which provides the scheduling engine for the system pulling data from Bridgesat's proprietary global weather prediction sensors and algorithms. The planning server generates an optimized, validated schedule that is transmitted to each satellite operator and ground telescope for execution. Events drive updates to scheduling including new or modified downlink needs, station maintenance blackouts, weather changes, or actual data downlink volumes (which can vary from planned volumes). Replanning can also be triggered by BridgeSat operators. The impact of changing cloud cover forecasts, lead-time requirements for spacecraft uplinks, and variable high downlink rates which can dramatically change downlink volumes in real time, drove the need for responsive replanning on a regular basis. The solution supports BridgeSat operators, customer technical personnel, and administrators, through configurable permissions and data access rights.

I. Nomenclature

API	=	Application Programming Interface
COTS	=	Computer Off-The-Shelf
NOC	=	Network Operations Center
SOC	=	Spacecraft Operations Center
STK	=	Systems Toolkit
TLE	=	Two-Line Element

II. Introduction

The overall goal of the BridgeSat Planning System is to schedule laser communication downlinks between Ground Stations and Satellites with additional constraints to meet daily downlink targets, avoid heavy cloud cover, and ensure the transfer data to offsite storage.

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III. Modeling in COTS

The BridgeSat Planning System has been built as a custom solution on top of COTS software. Modelling the BridgeSat Laser Communication network with AGI's System Toolkit Professional (STK Pro) and Orbit Logic's add-on module STK Scheduler was fairly straightforward. Satellites and Ground Stations are modelled in STK Pro and STK Scheduler as resources. Ground Station resource attributes include standard options including latitude, longitude, elevation, azimuth/elevation mask, sun keepout zones, and setup time. Satellite resource attributes include priority and the Two-Line Element (TLE) to describe the Orbit (which is propagated by STK). In addition to these base resources, the model includes characterization of satellite daily downlink, onboard storage, ground storage, and weather. Unavailability times can be applied for any resources. Tasks were defined for daily downlink, replenish (to reset the satellite storage to target capacity each day), data transfer (to model transfer rates from the ground station to offsite storage), and data reset (to set satellite storage capacity based on feedback from ground stations). The tasks deplete and replenish resources as appropriate, take into account data downlink and transfer rates, and ensure line of site between the satellite and ground station during downlink. This model was created with no code changes to the COTS product. With this underlying model, the STK Scheduler COTS product algorithms can build a validated, deconflicted, optimized schedule that would downlink the target volume from each satellite to a ground station and then plan the transfer of data from the ground station to offsite storage.

The initial COTS product was good to show proof-of-concept, but the BridgeSat customer wanted a branded application that was available to multiple users that accounted for weather and used their terminology. In order to meet these needs, a custom web interface was created using another of Orbit Logic's COTS products the Order Logic web framework.

The COTS Order Logic framework provides a standard web application including various levels of access management, views, 3D visualization of the plans, and branding options. Access management includes user management, login and security controls, functional level permissions, field level access control, and data access management. Specifically for the BridgeSat Planning System, this access management allows the Network Operations Center (NOC) Operator and/or other BridgeSat personnel to have full control over the system while satellite operators (customers) only see the functionality and data for their satellites. Secured HTTPS communication to the Order Logic host was established through a reverse sever configured with COTS Nginx software. The Gantt view provides one style of graphical view of the downlink and resource schedule and is filtered for each satellite operator to only show their satellites and the ground stations they can downlink to. Meanwhile the 3D visualization in Cesium provides another graphical view of the downlink schedule. With the 3D map view, the user sees ground stations and satellites, and shows a line connecting them during contacts and is also filtered to only show the appropriate satellites and ground stations based on user access. Through simple configuration the website was branded to show the BridgeSat logo on the login page and throughout the application with links to BridgeSat web pages, email addresses, and legal terms.

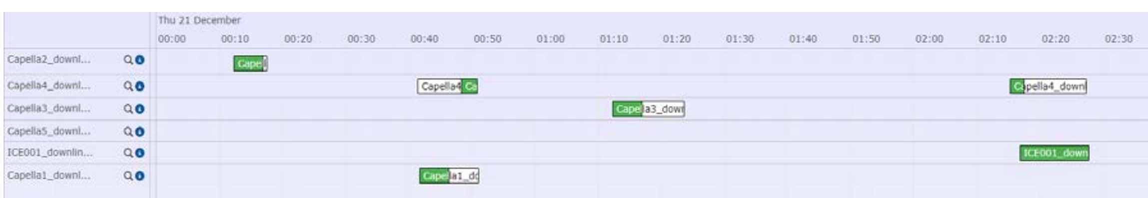


Fig. 1 BridgeSat Planning System - Downlink Gantt

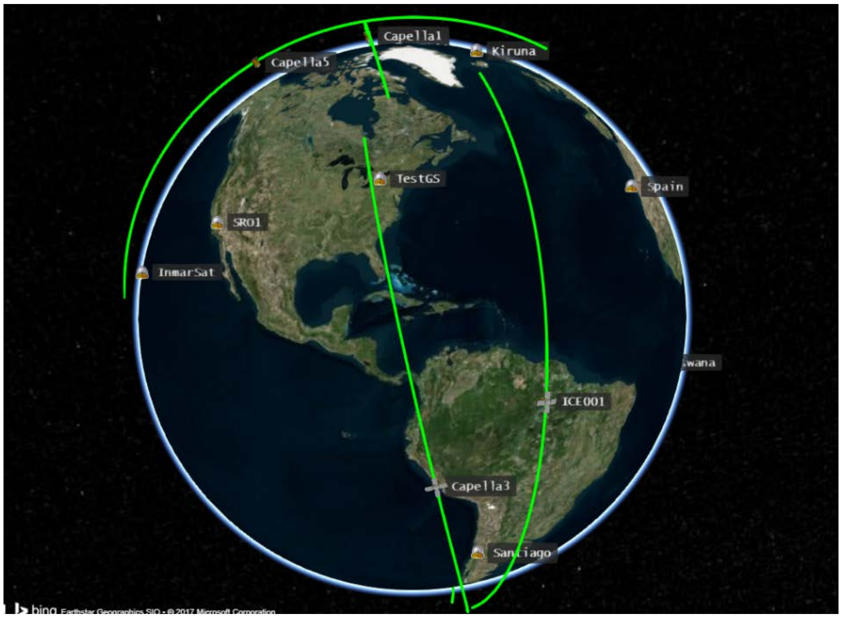


Fig. 2 BridgeSat Planning System - 3D Visualization

IV. Custom Web Pages

Several custom web pages, workflows, and interfaces were created specifically for the BridgeSat Planning System. Pages were created for Satellite Management, Ground Station Management, Planning Controls, and Metrics. The BridgeSat specific pages didn't use the standard STK Scheduler COTS terms such as "tasks" and "resources," but used satellite industry terminology specific to the application. Plus, they collected all of the information for what was actually multiple COTS tasks and resources into more manageable user interfaces. Metrics included the planned versus actual amount of data downlinked for each satellite and could be exported as comma-separated value (.csv) or JavaScript object notation (.json) files.

From the Satellite Management page the user can upload new TLE's, view/edit the target daily downlink volume, view/edit the contract start/stop, define ground station preferences, specify satellite transmit buffer time (amount of time prior to execution of the schedule that the plan needs to be received by the satellite operations center), specify the downlink rate, provide credentials for the remote ground storage associated with this satellite, and/or identify unavailability (blackout) times for the satellite. Note that each field is controlled by the access management layer such that the field would be hidden, viewable, or editable for the satellite operator based on login-specific access definitions. From the Ground Station Management page the user can specify setup time, latitude, longitude, altitude, sun keepout angle, azimuth/elevation mask, maximum allowable cloud coverage, unavailability times for the ground station, ground station transmit buffer time (amount of time prior to execution of the schedule the plan needs to be received by the ground station), local data storage, and transfer rate to remote data storage. The data specified in these custom web pages is persisted in a database and shared with STK Pro and STK Scheduler through the applications' standard APIs.

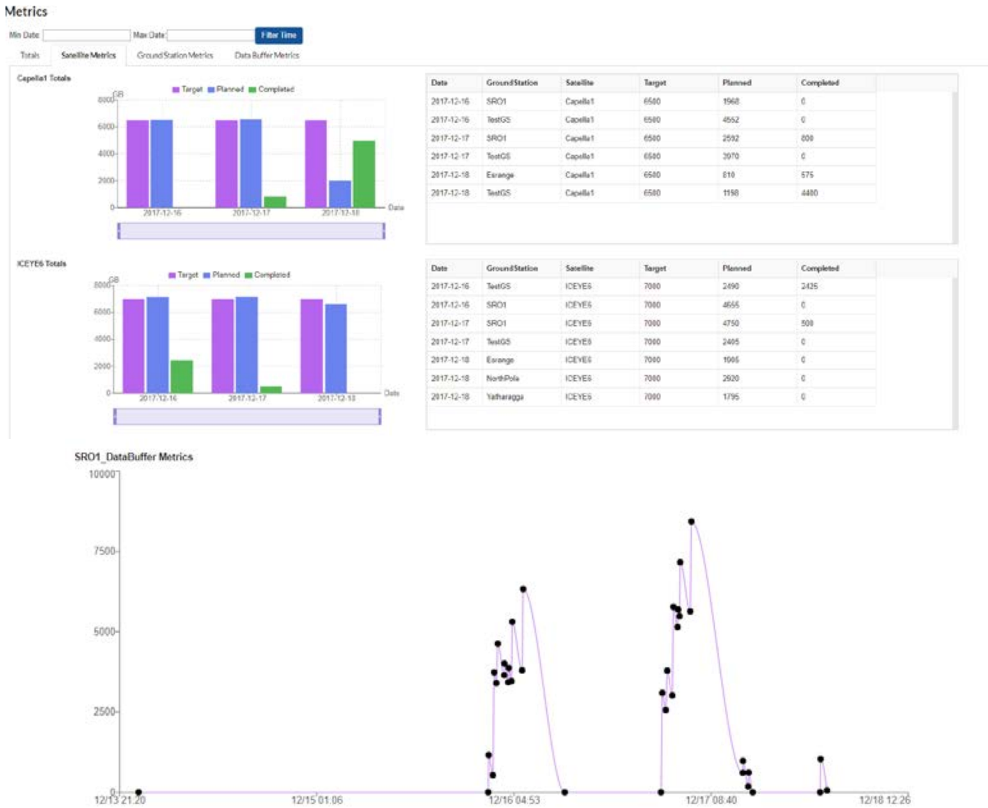
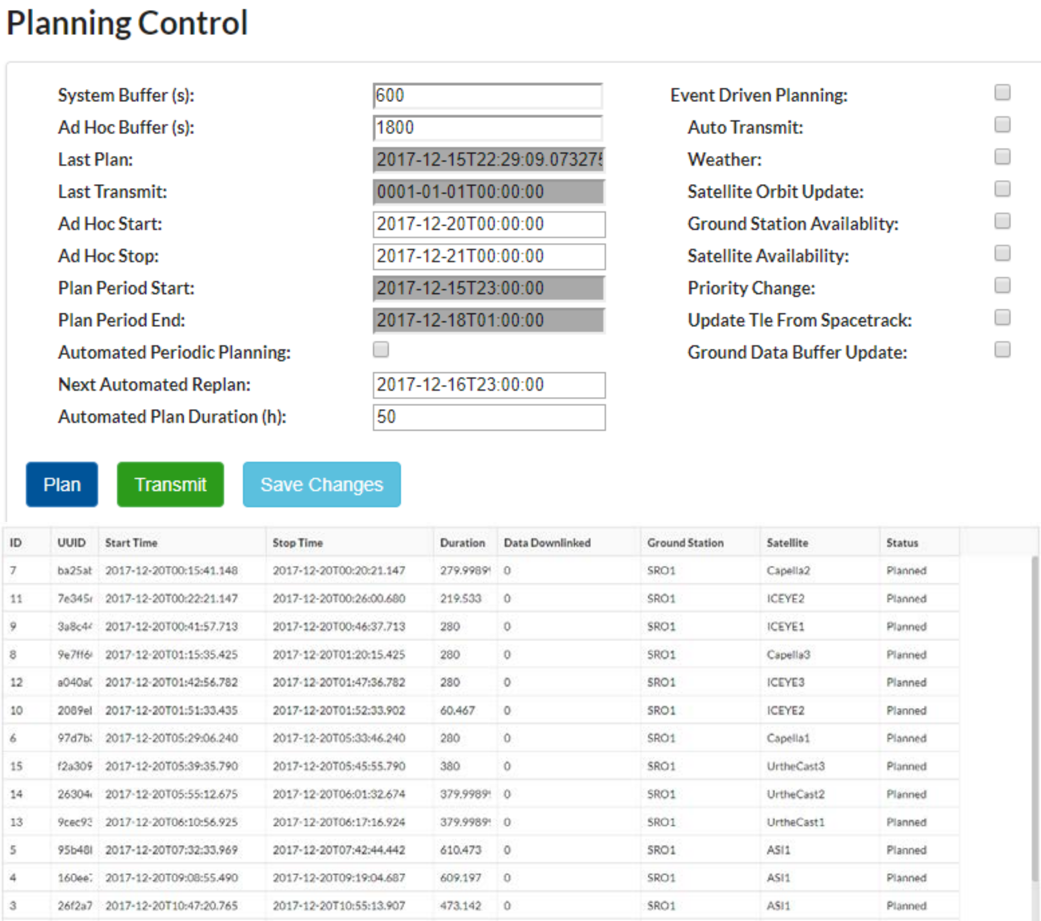


Fig. 3 BridgeSat Planning System - Metrics

V. Custom Workflows

The workflows that were created for the BridgeSat Planning System include a variety of COTS and custom features. These workflows allow ad hoc planning, time-based planning, event-based planning, manual editing of plans, transmission of plans to both Satellite Operation Centers (SOCs) and ground stations, and feedback from ground storage. Within the BridgeSat Planning System for every plan that is created, the planning control workflows need to take into account the transmit buffer times for both the satellites and the ground stations to ensure that there was sufficient time between creating a plan and executing the plan for each of the resources. Any previously planned activities that take place too early to be updated (during the transmit buffer) are locked in place and are not changed in new plans. Any time a new schedule is created the schedule is sent as a JSON document to both the ground station and the SOC. The schedule transmitted to the SOC includes start/stop times for all planned downlinks for the specific satellite and any ground stations that it downlinks to. The schedule transmitted to the ground station includes downlinks for any satellites to that ground station. The schedule is also displayed in table, Gantt, and 3D map visualization. For ad hoc planning, the user specifies a start time and stop time for the plan; the start time needs to take into account not only the transmit buffer times, but also time to get the plan approved before it is transmitted (denoted as the ad hoc buffer) and time for the plan to be transmitted to all stakeholders (specified as the system buffer). The user selects the Plan button on the Planning Control page and the STK Scheduler algorithms create a validated, deconflicted, optimized schedule. The user can then manually edit the start time and stop time for any downlink (which is then validated against all constraints). For time-based planning, the user specifies a trigger time and a duration for the plan and planning (execution of the algorithms) will occur automatically at that time. The default time-based planning used in testing was to create a 50-hour plan at 11 pm each day (i.e. two days of planning performed every day). For event-based planning, there are several events that can be used as triggers including updates to weather, satellite orbit, ground station availability, satellite availability, priority, and ground storage updates. The user has the ability to enable or disable each event as a trigger. When any of the event triggers occurs, a new schedule is created by the algorithms. The user also has the ability to enable or disable automatic transmit of the schedule to the SOCs and the ground stations. There is also a feedback loop that provides information from the ground storage at each ground station back to the BridgeSat Planning System. This feedback loop informs the

BridgeSat Planning System if planned data downlinks were not complete or if the ground storage is nearing capacity. The system then incorporates this information into the next time period's plans. These various planning control workflows all combine to allow various configurable levels of autonomy for the overall system.



ID	UUID	Start Time	Stop Time	Duration	Data Downlinked	Ground Station	Satellite	Status
7	ba25at	2017-12-20T00:15:41.148	2017-12-20T00:20:21.147	279.9989	0	SRO1	Capella2	Planned
11	7e345	2017-12-20T00:22:21.147	2017-12-20T00:26:00.680	219.533	0	SRO1	ICEYE2	Planned
9	3a8c4	2017-12-20T00:41:57.713	2017-12-20T00:46:37.713	280	0	SRO1	ICEYE1	Planned
8	9e7ff6	2017-12-20T01:15:35.425	2017-12-20T01:20:15.425	280	0	SRO1	Capella3	Planned
12	a040a	2017-12-20T01:42:56.782	2017-12-20T01:47:36.782	280	0	SRO1	ICEYE3	Planned
10	2089el	2017-12-20T01:51:33.435	2017-12-20T01:52:33.902	60.467	0	SRO1	ICEYE2	Planned
6	97d7b	2017-12-20T05:29:06.240	2017-12-20T05:33:46.240	280	0	SRO1	Capella1	Planned
15	f2a309	2017-12-20T05:39:35.790	2017-12-20T05:45:55.790	380	0	SRO1	UrtheCast3	Planned
14	26304	2017-12-20T05:55:12.675	2017-12-20T06:01:32.674	379.9989	0	SRO1	UrtheCast2	Planned
13	9cec93	2017-12-20T06:10:56.925	2017-12-20T06:17:16.924	379.9989	0	SRO1	UrtheCast1	Planned
5	95b48	2017-12-20T07:32:33.969	2017-12-20T07:42:44.442	610.473	0	SRO1	ASI1	Planned
4	160ee	2017-12-20T09:08:55.490	2017-12-20T09:19:04.687	609.197	0	SRO1	ASI1	Planned
3	26f2a7	2017-12-20T10:47:20.765	2017-12-20T10:55:13.907	473.142	0	SRO1	ASI1	Planned

Fig. 4 BridgeSat Planning System - Planning Control Page

VI. Incorporating Weather Forecast

The BridgeSat Planning System gets cloud cover forecasts from the NOAA National Centers for Environmental Prediction (NCEP) in GRIB-2 format at a user configurable polling interval. For each ground station, if the predicted cloud cover is above a user specified threshold for a period of time, a weather blackout unavailability period is created and no downlinks will be specified for that ground station during that time. The system has been created to allow for interfaces with multiple weather providers as long as a value is provided for a specific location for a specific time period. BridgeSat plans on pulling in additional weather data in the near future.

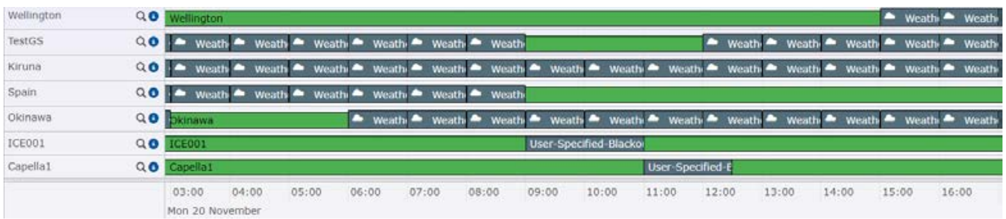


Fig. 5 Weather Blackouts

VII. Conclusion

In conclusion, the planning system now deployed for BridgeSat is more than just planning software; it is the primary customer interface for downlink orders and status, and it is the primary interface for BridgeSat operators to configure, monitor, and control the execution of contacts with customer satellites. The solution was built around a COTS software engine configured to model the BridgeSat system, and wrapped with a COTS web server architecture customized and configured for BridgeSat workflows and interfaces. The solution was integrated with external components of the BridgeSat ground architecture including data storage, customer satellite control centers, and BridgeSat ground telescopes. Configurable for manual and automated planning and replanning, BridgeSat personnel have a tool that can support a range of operational approaches including full manual control to lights-out, data-driven operations. Best of all, the solution allows BridgeSat to add new satellite customers and new ground telescopes to the system, and to configure the system for new data rates and other operational changes without the need for any new software development.