SPACE COMMUNICATIONS AND NAVIGATION PROGRAM

CoSMOS

Commercial Systems for Mission Operations Suitability

User Guide

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1.0 INTRODUCTION

NASA's Space Communications and Navigation Program (SCaN) is working to transform communication services for NASA missions from NASA-owned and operated network services to commercially provided capabilities for user missions in near-Earth space. The first goal to assist in this transition is for SCaN to expand commercial direct to Earth (DTE) services to 100% by 2024. The second goal is for SCaN to demonstrate and operationalize commercial space-based relay services for future missions by 2030. The **Co**mmercial **S**ystems for **M**ission **O**perations **S**uitability (CoSMOS) capability is designed to facilitate exploration of commercial system capability and potential application to mission needs. CoSMOS uses results from previous simulation runs to estimate the performance and applicability of a communication system by using a combination of statistical techniques and traditional communication systems computation techniques and algorithms. CoSMOS can be used to rapidly assess the suitability of both Commercial and NASA networks to meet a specific user mission's communications need.

2.0 SCOPE AND PURPOSE

The CoSMOS User Guide is designed to facilitate easier navigation of the CoSMOS tool, currently hosted at http://cosmos.teltrium.com. The sections below will outline the different modules within CoSMOS, as well as how to navigate the modules and use the tool to view and assess attributes of commercial networks, analyze performance information, as well as compare performance results based on a user mission's profile and communications needs. The CoSMOS User Guide will be updated as CoSMOS evolves.

3.0 ROLES AND RESPONSIBILITIES

The following roles and responsibilities are outlined for the CoSMOS tool:

- **User:** The end user of CoSMOS is a SCaN Systems Engineer or Mission Designer. These users may explore the commercial systems, or analyze performance through interactive visuals, data displays, and comparisons.
- **System administrator:** Responsible for managing user access and associated user roles.
- **Engineer:** The engineering team is responsible for the underlying modeling and analyses of commercial systems, resolving technical challenges, and ensuring functionality meets end user objectives from a technical perspective.

4.0 PRIVACY NOTIFICATION

Any system activity may be monitored, and any information stored within the system may be retrieved and used by authorized personnel for law enforcement, management, routine system operations, or other purposes. By using this tool, you are consenting to such monitoring and information retrieval and use.

5.0 OVERVIEW OF THE COSMOS MODULES

The CoSMOS initialization view, as depicted in Figure 5-1, contains the following modules:

- **Main Menu:** Provides access to the Algorithm and Design Document, the User Guide, Manage Project Details, Create New Project, Load Previous Project, and Close Current Project options.
- **Account Management Menu:** Provides the Account Settings, Log Out, and the Engineering Dashboard Option (*Administrative Option Only*).
- **Quick Access Panel:** Provides access to the Mission, Project History, and Reporting tabs. From the Mission tab, users may specify mission parameters, specifications, and constraints. Project History and Reports may also be accessed from here.
- **Visualizer Panel:** Contains the visualization of the user defined mission and/or user specified system.

- **Network Options Panel:** Provides an option to filter between all networks or DTE ground locations, options to filter all given networks, and a top-level view of all systems listed by Network name.
- **Results Panel:** Provides four tabs; The Network Selection tab, the Analytics Tab, the Performance Tab, and the Comparison Tab.

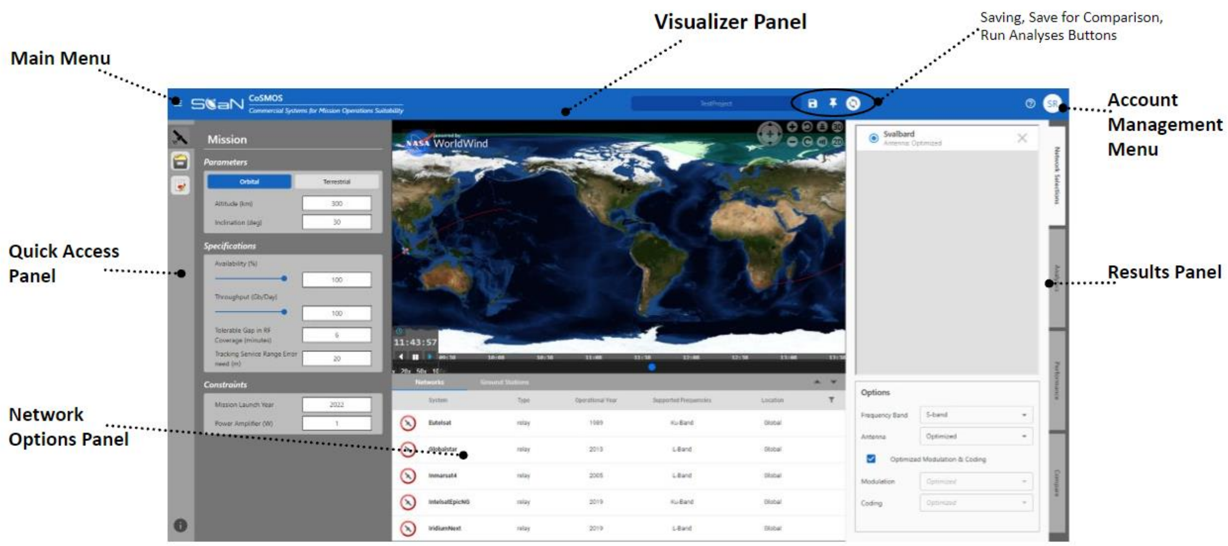


Figure 5-1: Opening View of CoSMOS

Sections 6 through 12 provide a more detailed look at each of elements of CoSMOS, and in Section 13, several example scenarios/tutorials are provided.

6.0 WELCOME AND PROJECT MANAGEMENT

6.1 Introductions to Missions as a Project

Upon initial login, the CoSMOS Welcome screen contains two options: **New Project** (1) and **Load Project** (2), as seen below in Figure 6-1.

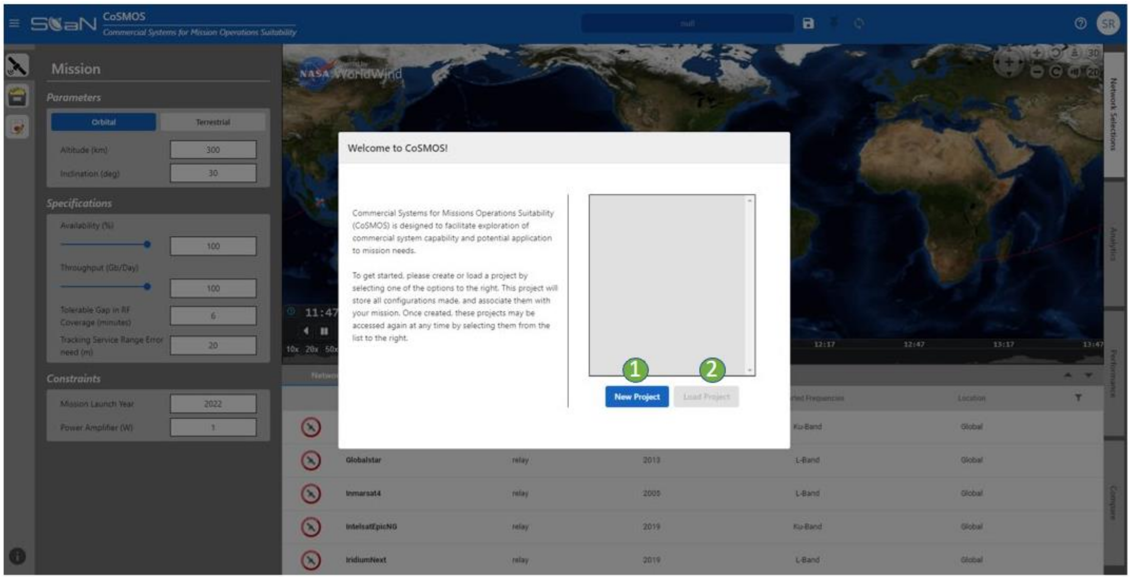


Figure 6-1: Introducing Missions as a Project

6.2 New Project Dialog Box

Starting a new project or loading a previous project opens the New Project Dialog box, which contains three text fields: **Project Name** entry (1), **Mission Name** entry (2), and **Mission Description** entry (3), as seen in Figure 6-2. Once all three of these fields have been completed with a unique project name specified, click the "Create" button (4) to start the project and analyses.

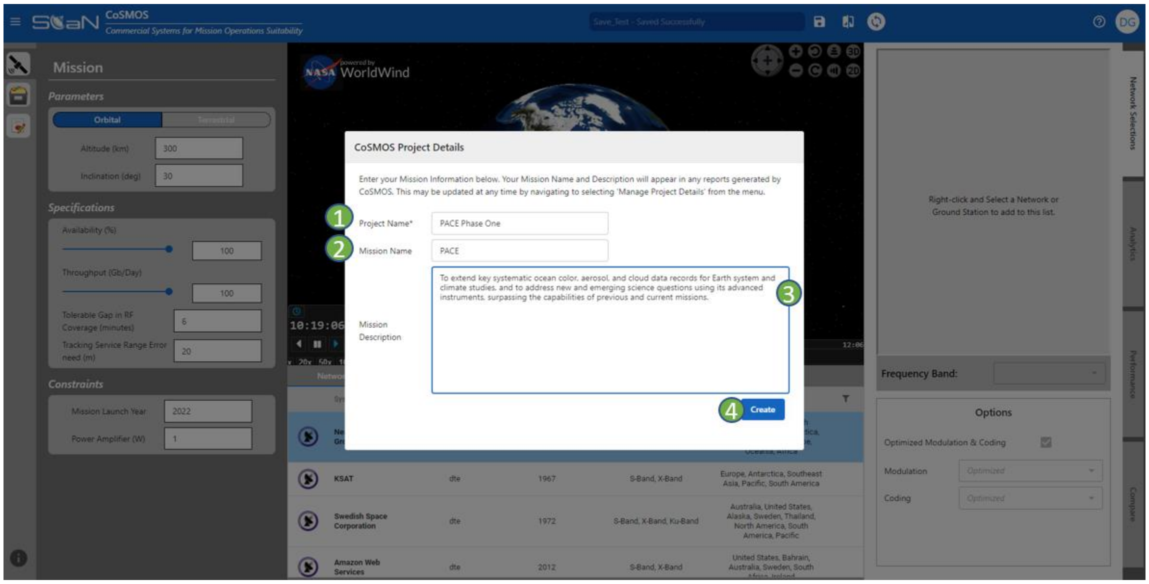


Figure 6-2: New Project Dialog Box Example

6.3 Managing Projects and Items Accessible from the Main Menu

After a project has been created, the user can access the project description and make updates via the main menu drop down. The current project can be closed, prior saved projects can be opened and edited, and CoSMOS documentation can be accessed. The main menu drop-down has several options that are explained in Table 6-1.

Table 6-1: Drop Down Menu Options

Component	Functional Description
Algorithm and Design Document	Takes the User to the Algorithm and Design Document. [Note 1]
User Guide	Take the User to the CoSMOS User Guide.
Manage Project Details	Displays the dialog containing the project name, mission name, and description.
New Project	Close the current project and prompt the user to start a new project.
Load Project	Allows the user to be able to load a previous project.
Close Project	Closes the current project and prompts the user to start from the initial view.
Note 1: The ADD explains what is “under the hood” of CoSMOS. It details the algorithms that are behind the calculations for the Performance Metrics, Burden Calculations, and Optimization techniques that are employed on the back end of CoSMOS.	

7.0 QUICK ACCESS PANEL

7.1 General Mission Requirements

Upon starting or loading a project, mission parameters are displayed within the Quick Access panel along the left side of the window. These mission requirements may be changed as needed to meet mission objectives. Figure 7-1 below shows the default view of CoSMOS when launching a new project.

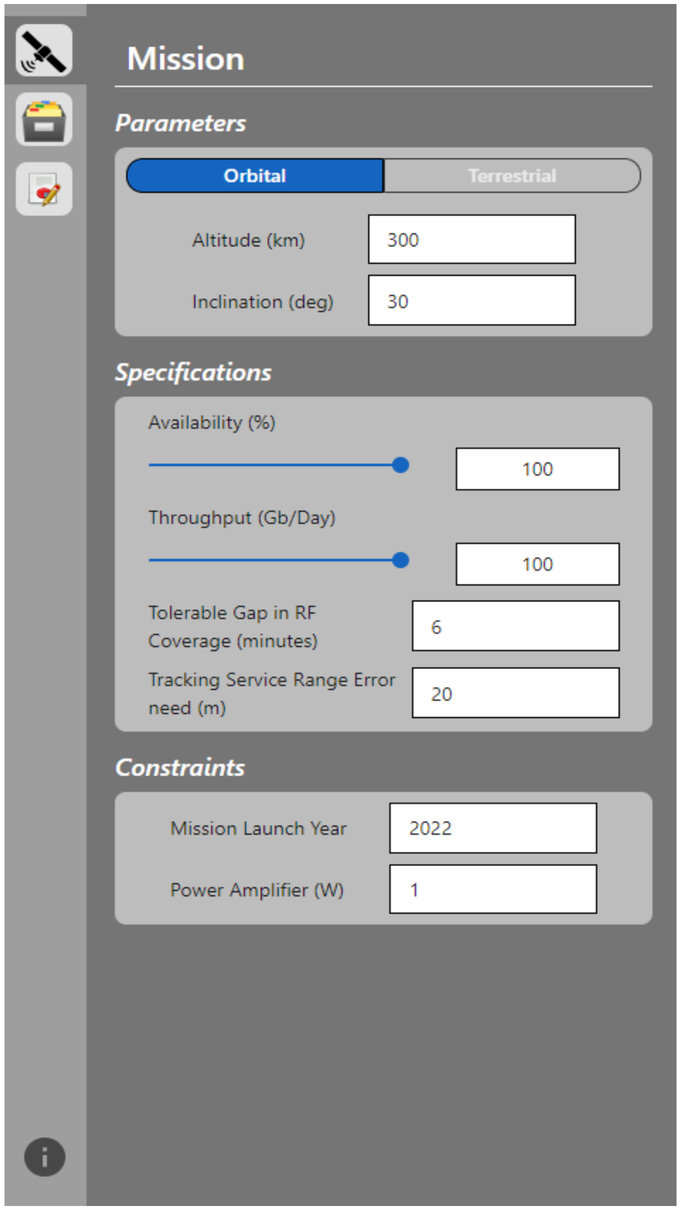


Figure 7-1: General Mission Information Tab

The Mission Requirements Panel has three sections: the Mission Parameters section, the Mission Specifications Dialog section, and the Mission Constraints section.

Mission Parameters Section

The first section contains an option to choose whether the mission is orbital or terrestrial. If the orbital mission option is chosen, a prompt to enter the mission's altitude and inclination will open (Figure 7-2**Error! Reference source not found.**). If the terrestrial mission option is chosen, a prompt to enter the mission's latitude and longitude will open (Figure 7-3).

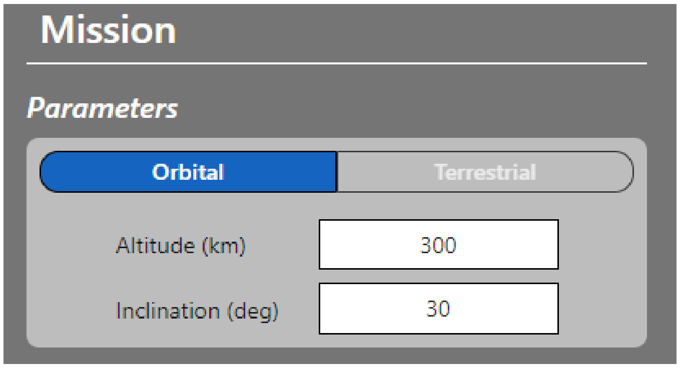


Figure 7-2: Mission Parameters Section (Orbital User)

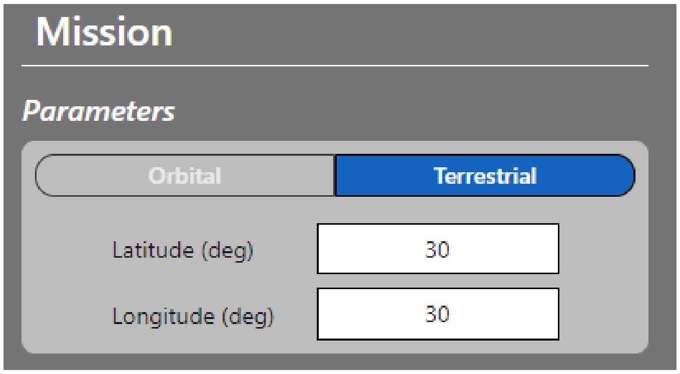


Figure 7-3: Mission Parameters Section (Terrestrial User)

Mission Specifications Section

The Mission Specification section contains four subfields. These fields are the mission's objectives for Availability, Throughput, Tolerable Gap in RF Coverage, and Tracking Service Range Error. The Availability and Throughput selections can be entered manually or can be set using the sliders to the left-hand side of the box, as depicted in Figure 7-4.

The entries made by the user here do not change the output results, but they do influence the ranking function and how CoSMOS displays if a given commercial system meets the mission's specifications.

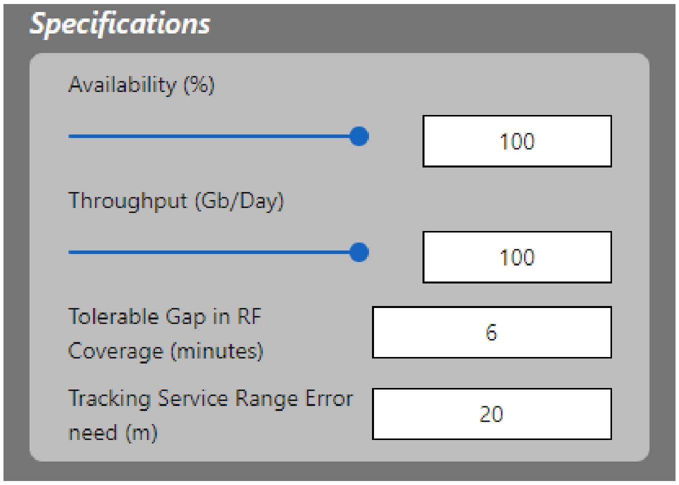


Figure 7-4: Mission Specifications Section

Mission Constraints Section

The Mission Constraints Section contains two subfields. These fields are the user defined operational year and the selected power amplifier, as seen in Figure 7-5. The Mission Launch Year is used to compare to commercial system operational year as a check displayed in Output and Ranking, and the Power Amplifier selection is used to link performance analyses.

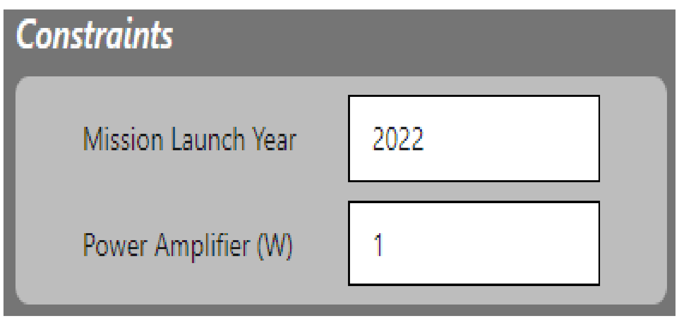


Figure 7-5: Mission Constraints Section

7.2 Project History

The second option on the Quick Access panel is the Project History tab, shown on the left in Figure 7-6. This button provides the user with the entire history of any analyses, reports, and/or models that have been previously associated with a project.

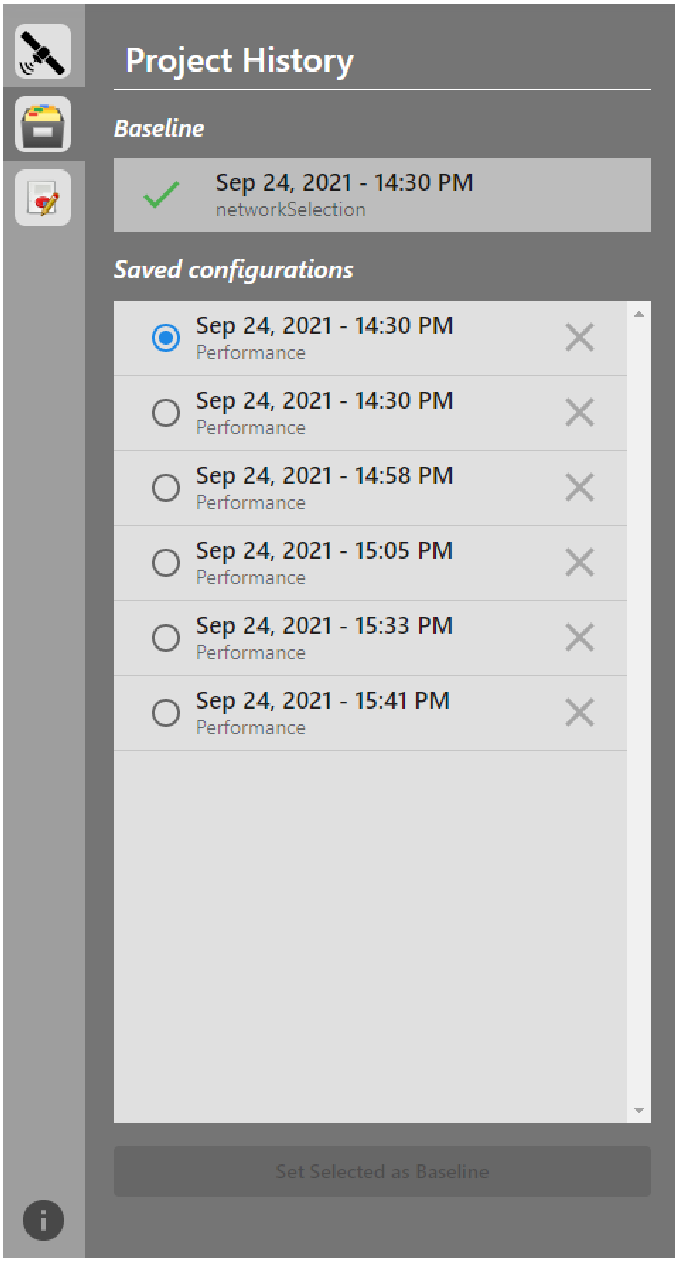


Figure 7-6: Project History Button

7.3 Reports

The third option on the quick access panel is the Reports view, shown in Figure 7-7. This tab allows the user to print a pre-defined report template of the current mission analysis they are performing. The report is auto-populated with information from the user's current analysis, including information on the selected network(s). The back-end capability and structure of reports is modular and flexible; new template options can be easily customized and added to the report options in future releases.

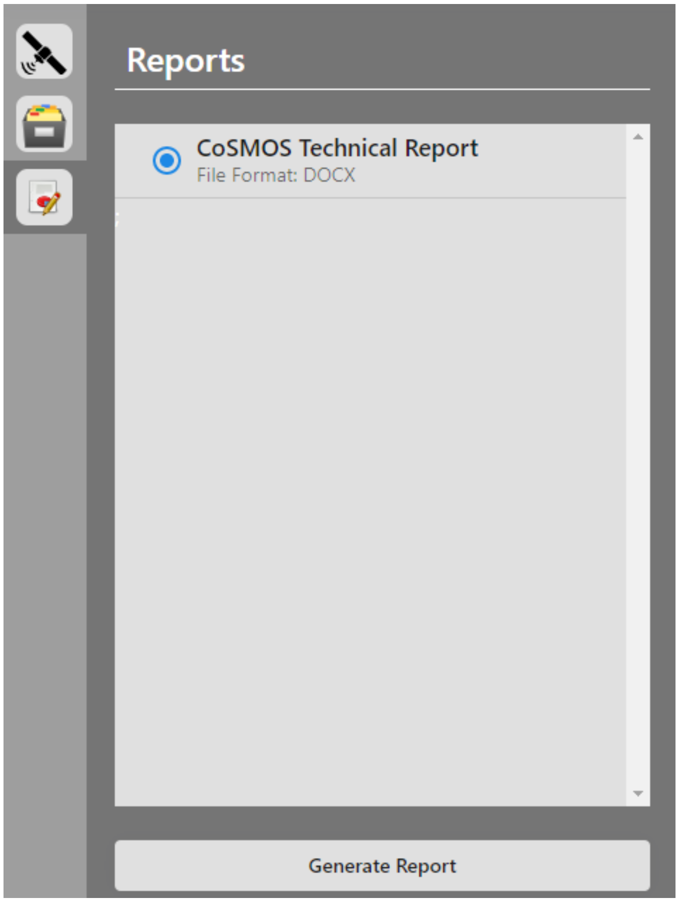


Figure 7-7: Reports Tab

The last option on the Quick Access panel is the "Information" button. This button will provide the users with an access link that will take them to the User Guide. If there is any confusion about the general flow in CoSMOS analysis process, those questions can be answered by reviewing the introductory material and tutorials in that guide.

8.0 VISUALIZER PANEL

The visualizer panel within CoSMOS has three viewing options. The Default view, depicted in Figure 8-1, is a blank 3-D view of Earth and the default user satellite has no DTE networks, DTE Ground Station locations, or Relay Networks, have been chosen for an analysis. The second view is a 2-D view of any DTE Ground Station locations or DTE networks a user has selected for an analysis, with the ground location's coverage cone corresponding with the input mission altitude, as depicted in Figure 8-2. The final view is that of a relay network selected by the user for analyses, as depicted in Figure 8-3. The display of the relay network shows the coverage cones of the relay satellites projected to the altitude of the mission. In the top right corner of the visualizer screen, there are a series of buttons that allow the user to alter the current view of the visualizer. The user can zoom, pan, rotate, and change dimensional views. On the bottom left of the visualizer screen, there are animation controls allowing the user to start, stop, pause, fast forward, and rewind the visualization.

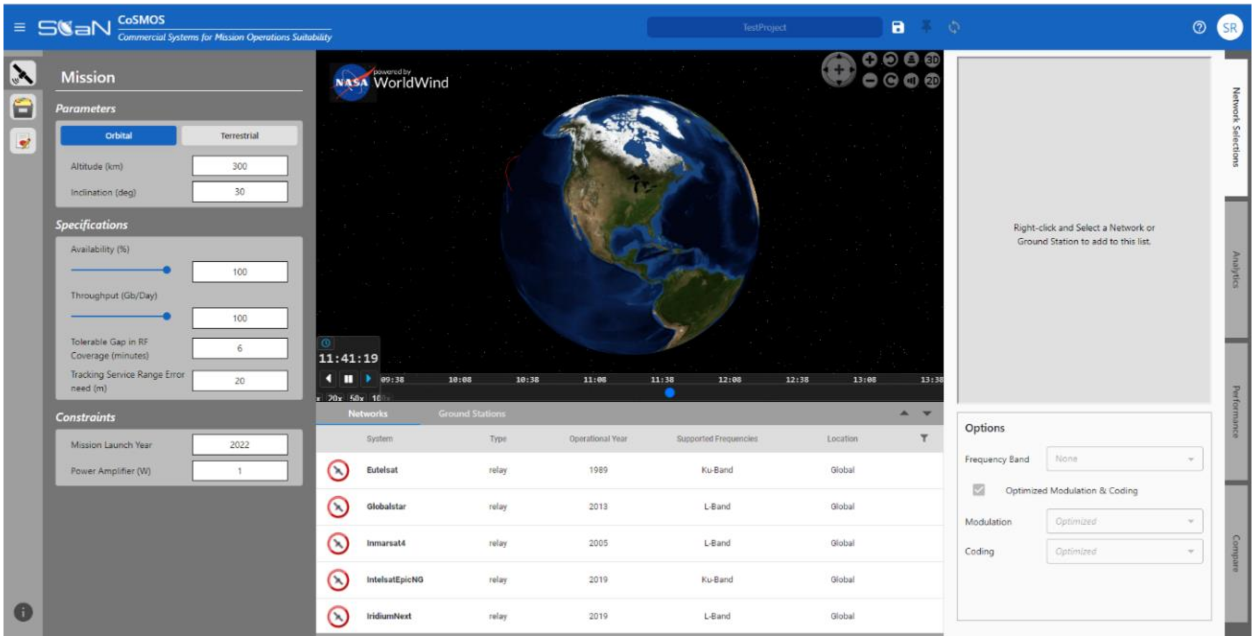


Figure 8-1: Default Visualizer View

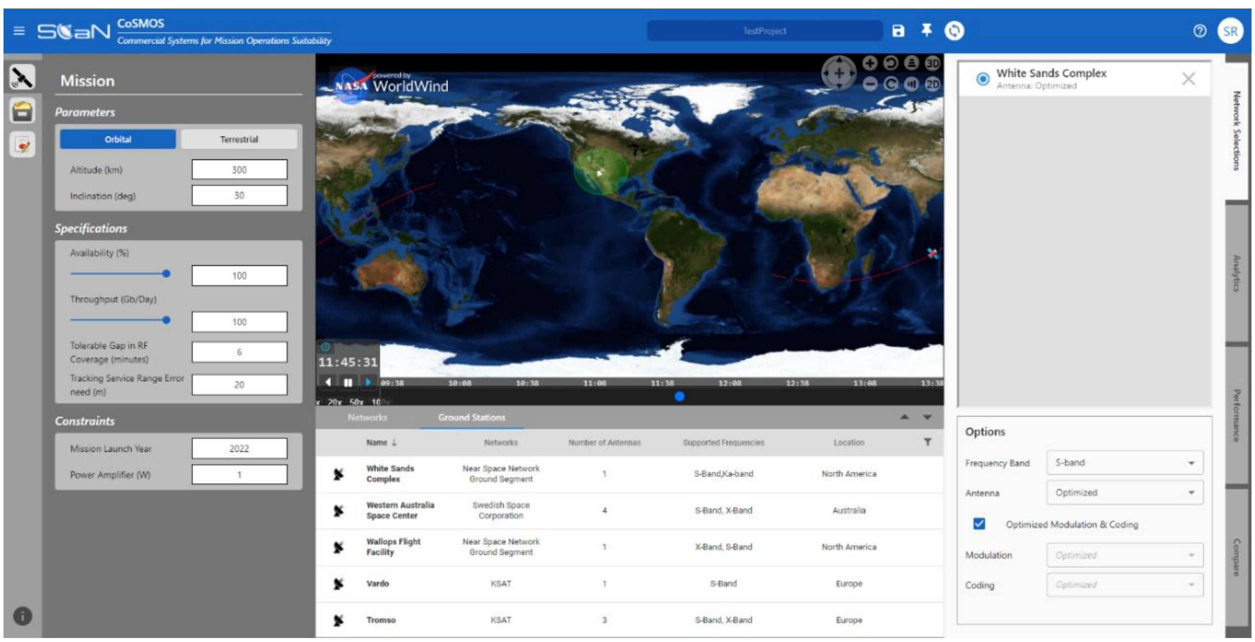


Figure 8-2: DTE Ground Station View

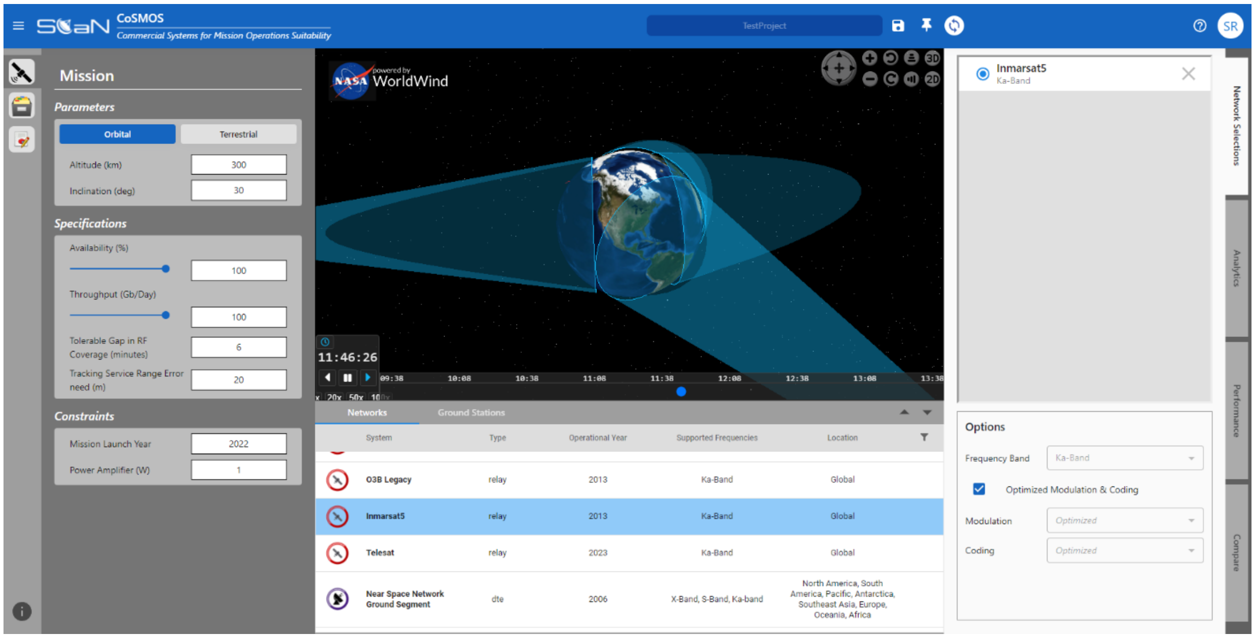


Figure 8-3: Relay Network View

9.0 NETWORK OPTIONS PANEL

The CoSMOS network Options panel includes Commercial Relay Systems and Tracking and Data Relay Satellite (TDRS) services such as Ka-band Single Access (KaSA) and S-band Single Access (SSA), as well as DTE networks – both commercial and the legacy Near Space Network (NSN) government ground sites. Table 9-1 lists the current networks included in CoSMOS.

Table 9-1: CoSMOS Network Options

Network Name	Relay System	DTE System
Amazon Web Services		X
Eutelsat	X	
Globalstar	X	
Inmarsat4	X	
Inmarsat5	X	
IntelsatEpicNG	X	
IridiumNext	X	
KSAT		X
Near Space Network Ground Segment		X
O3b 7MPower	X	
O3B Legacy	X	

OneWeb MEO	X	
SpaceX 1110	X	
Swedish Space Corporation		X
TDRS KaSA	X	
TDRS SSA	X	
Telesat	X	
Viasat3	X	

There are two main filters that can be used within the Network Options Panel. The first filter allows the user to filter between DTE Ground Station locations or NASA and Commercial Relay Constellations. The second subset of filters allows the user to be able to filter by five characteristics: name, network type, operational year, supported frequencies, and location. Users can filter within the Network tab (Figure 9-1), or the Ground Stations tab (Figure 9-2).

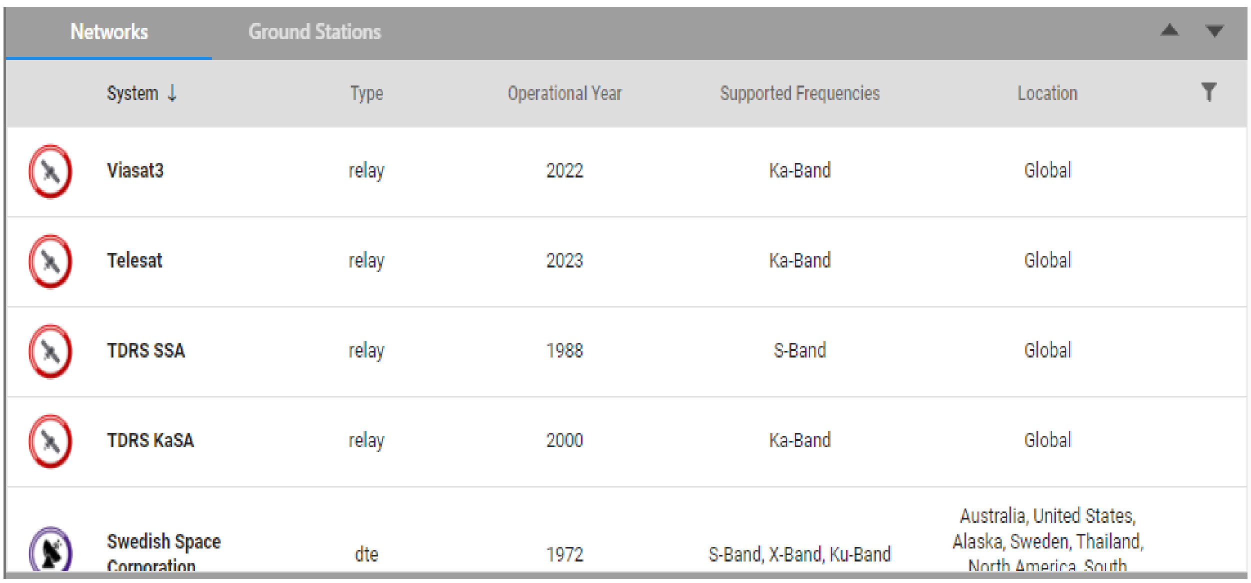
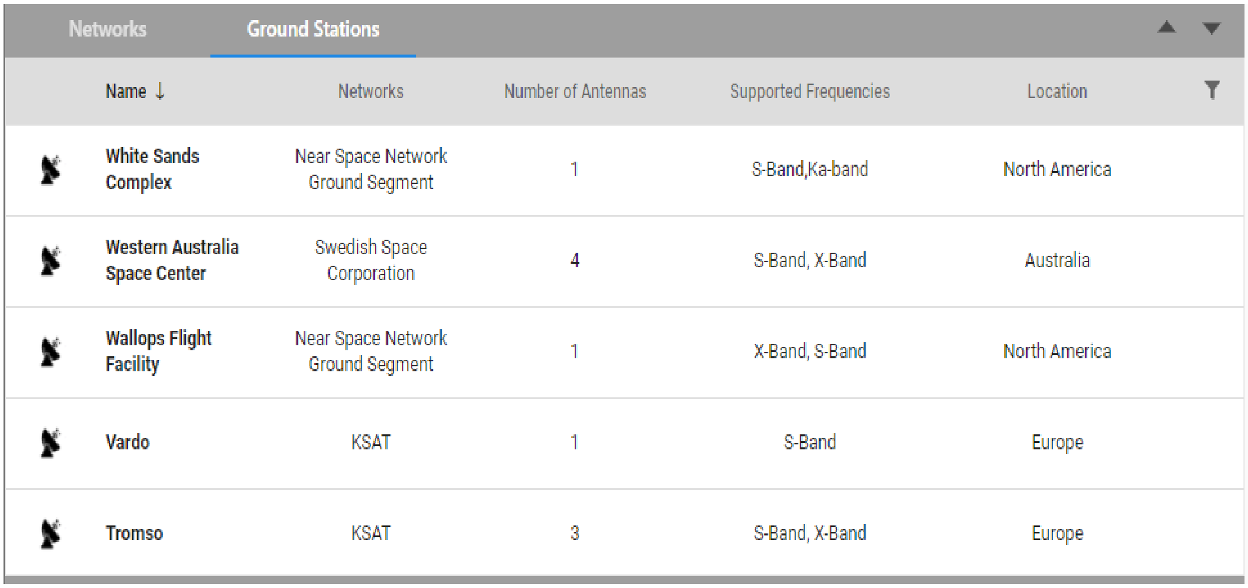


Figure 9-1: Filtering Information Networks View



	Name ↓	Networks	Number of Antennas	Supported Frequencies	Location
	White Sands Complex	Near Space Network Ground Segment	1	S-Band,Ka-band	North America
	Western Australia Space Center	Swedish Space Corporation	4	S-Band, X-Band	Australia
	Wallops Flight Facility	Near Space Network Ground Segment	1	X-Band, S-Band	North America
	Vardo	KSAT	1	S-Band	Europe
	Tromso	KSAT	3	S-Band, X-Band	Europe

Figure 9-2: Filtering Information Ground Station View

For any network, users may access a network overview and properties table by selecting the network from the Option panel. As shown in Figure 9-3, DTE systems are categorized by network, Ground Station location, the antennas that are associated with that location, the bands associated with the antennas, and the modulation / demodulations and coding's that are associated with a particular antenna. Relay systems also follow a tree structure which includes network overview information, constellation configuration data, transmit and receive characteristics and ground / gateway information (Figure 9-4). More information on the network details and structure is included in subsequent sections (9.1, 9.2).

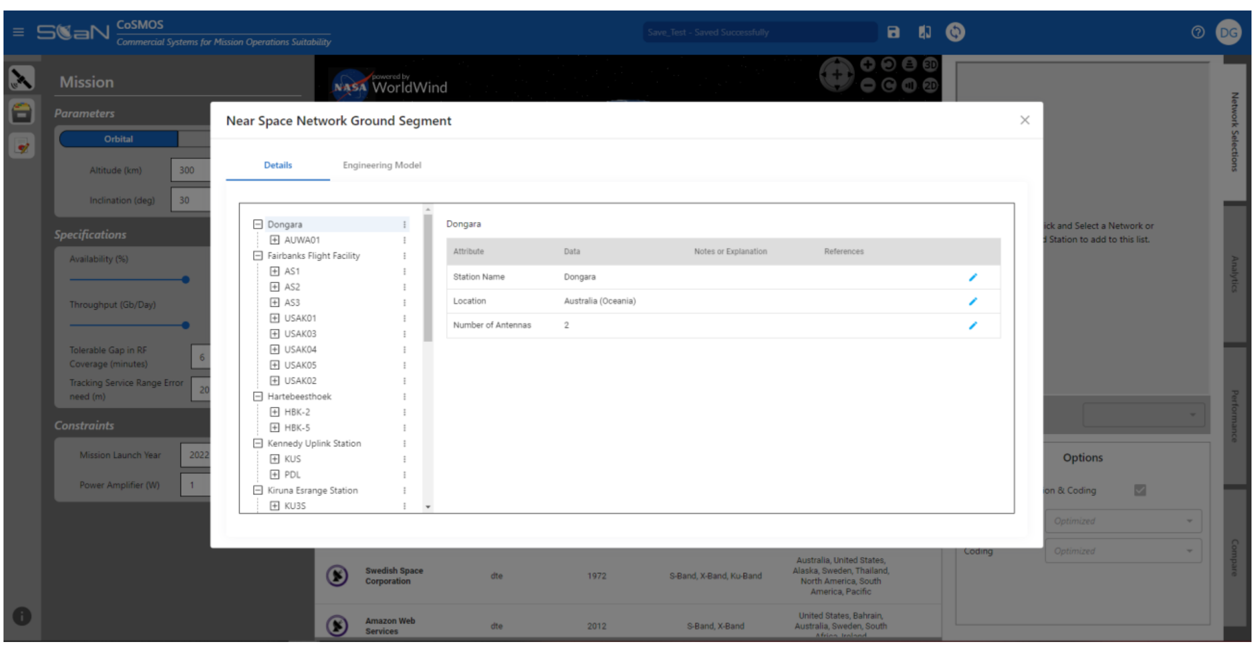


Figure 9-3: Expanded Network DTE Library Dialog Box

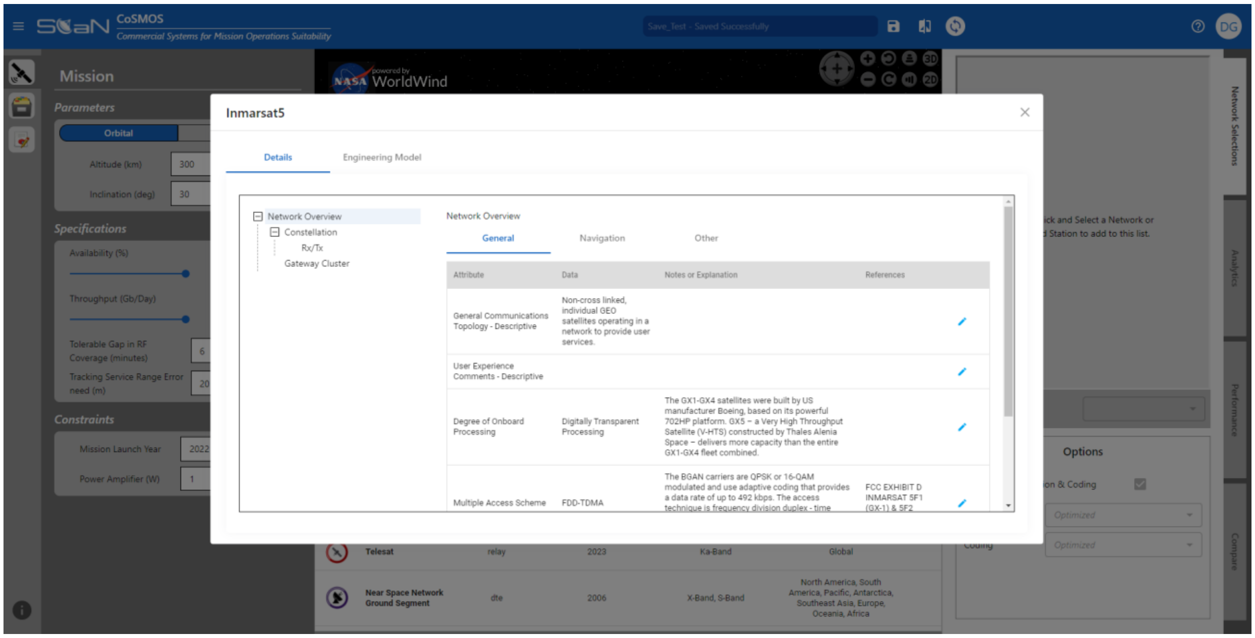


Figure 9-4: Expanded Network Relay Library Dialog Box

Once the desired systems have been identified and selected, click on the "Save Project" button (Figure 9-5) to retain the system for analyses.

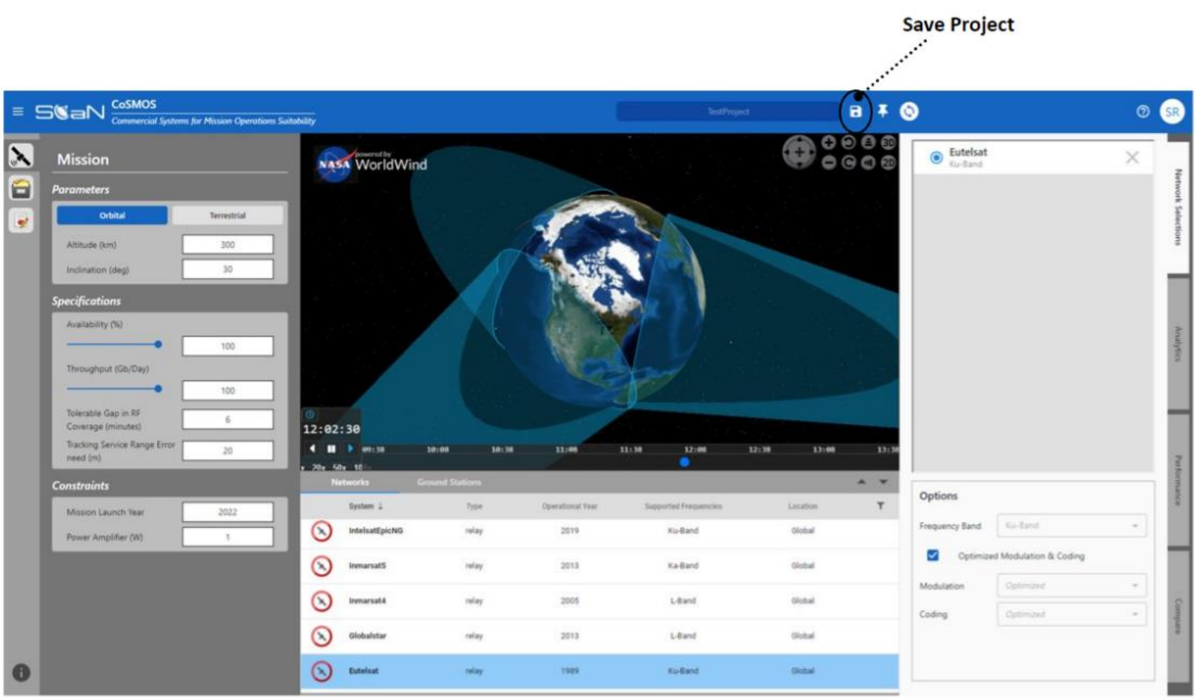


Figure 9-5: Saving Project Configuration Button

9.1 Relay Network Information Structure

The Relay Network Information structure contains four subcategories: the Network Overview, Constellation Overview, Rx / Tx Information, and Gateway Cluster Information. The Network Overview has three panels: the General panel (which defines the general information for the network constellation), the Navigation Panel (which defines the navigation properties of the constellation), and the Other Panel (which holds any miscellaneous information related to the network constellation). In each of the populated fields, for all metrics associated with all subcategories, there is both a Notes or Explanation Field and a Reference Field. The Notes or Explanation Field defines where the information for each populated field came from and/or how it was appropriated. The References Field provides a link to the document and/or documents that the populated information was pulled from. Each Relay Network follows this explicit format.

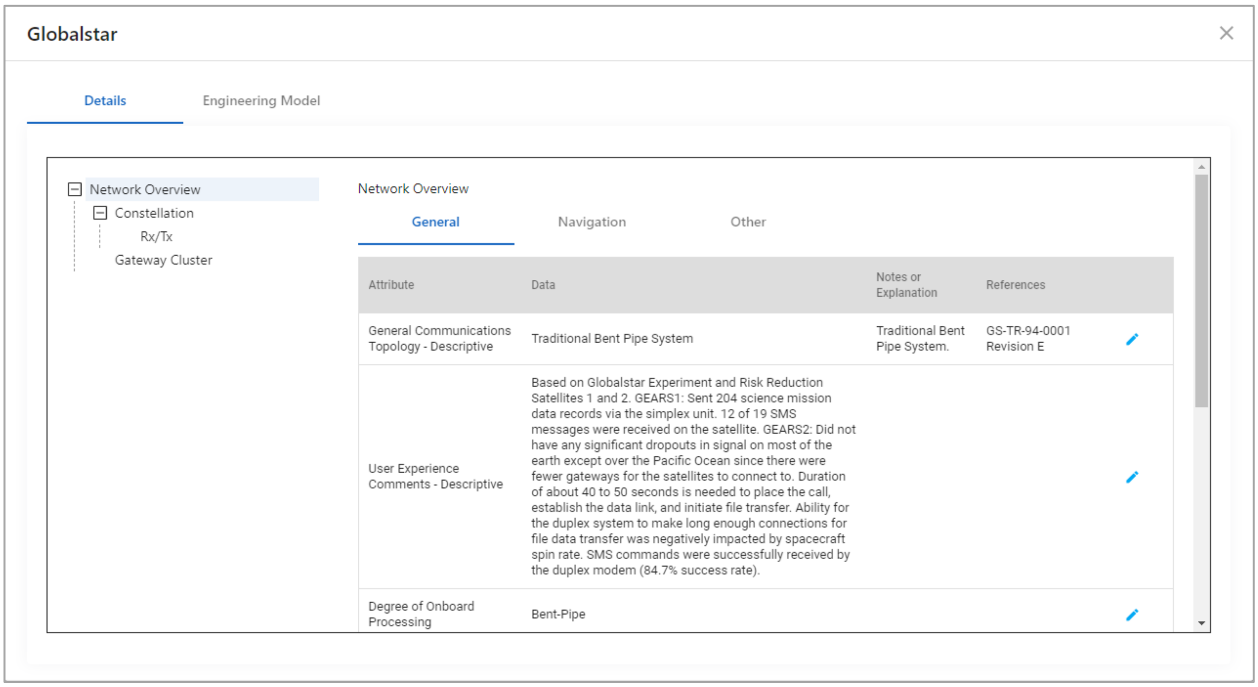


Figure 9-6: Library Page - Globalstar

Within each of the relay system libraries, the following information can be found:

Table 9-2: Information and Attributes for Relay System Libraries

Information Type	Attributes
System level capabilities and target customers	System level capabilities describe whether network users are maritime, aeronautical, terrestrial, and/or user satellites
Constellation Topology	The number of shells, the altitude of each shell, the number of planes per shell, the inclination (measured by degrees) by plane, number of satellites per plane, the total number of satellites, phase offset (measured by degree), plane distribution (measured by degree), half cone angle (measured by degree)
Relay Communications Topology – General	The satellites are all cross-linked. Each satellite can have four Ka-band inter-satellite links: one each to neighbors fore and aft in the same orbital plane, and one each to satellites in neighboring planes to either side. 48 L-band beams supporting user links on each satellite, and 13 feeder links. Service links are

	TDD between the uplink and downlink signals (TDMA on both links). 252 carriers with carrier spacings of 41.667 KHz; can be combined to provide wider bandwidth.
Receiving Beams (RX)	• Max Return Data Rate (Mbps) • Return link modulation • Return link coding • Satellite-to-Satellite (SSL) return link frequency (associated unit for the frequency: MHz) • User Terminal Emitted Isotropic Radiated Power (EIRP) • Satellite-to-Satellite (SSL) Relay Gain/Temperature (G/T) • SSL return link bandwidth • Satellite-to-Ground-Link return link frequency • SGL EIRP • Gateway G/T (decibels/kelvin - dB/K) • SGL return link bandwidth • Return link required (Eb/No) • Return link implementation loss (dB) • Return link frequency band (MHz) Spectrum Regulatory Status - return link frequency [actions applied or filed for a particular system by the Federal Communications Commission (FCC)]
Transmit Beams (TX)	• Max forward data rate (Mbps) • Forward link modulation • Forward link coding • SGL forward link frequency (MHz) • SGL Gateway EIRP (dBW) • SGL Relay G/T (dB/K) • SGL Forward Link Bandwidth (dB-Hz) • User Terminal C/1 (dB) • Forward Link Implementation Loss (dB) • Forward Link Required Eb/No (dB) • Forward Link Frequency Band (MHz) Spectrum Regulatory Status – Fwd Link Frequency
Gateway Cluster	Number of ground terminal locations, geographic location, and data distribution

9.2 DTE System Information Structure

The DTE Library Structure has four subcategories: the station location definition, the antenna definition, the frequency band properties, and the modulation / demodulation properties. As seen in Figure 9-7, using the Near Space Network as an example, the set of associated locations and antennas is displayed in an expandable list view at the left.

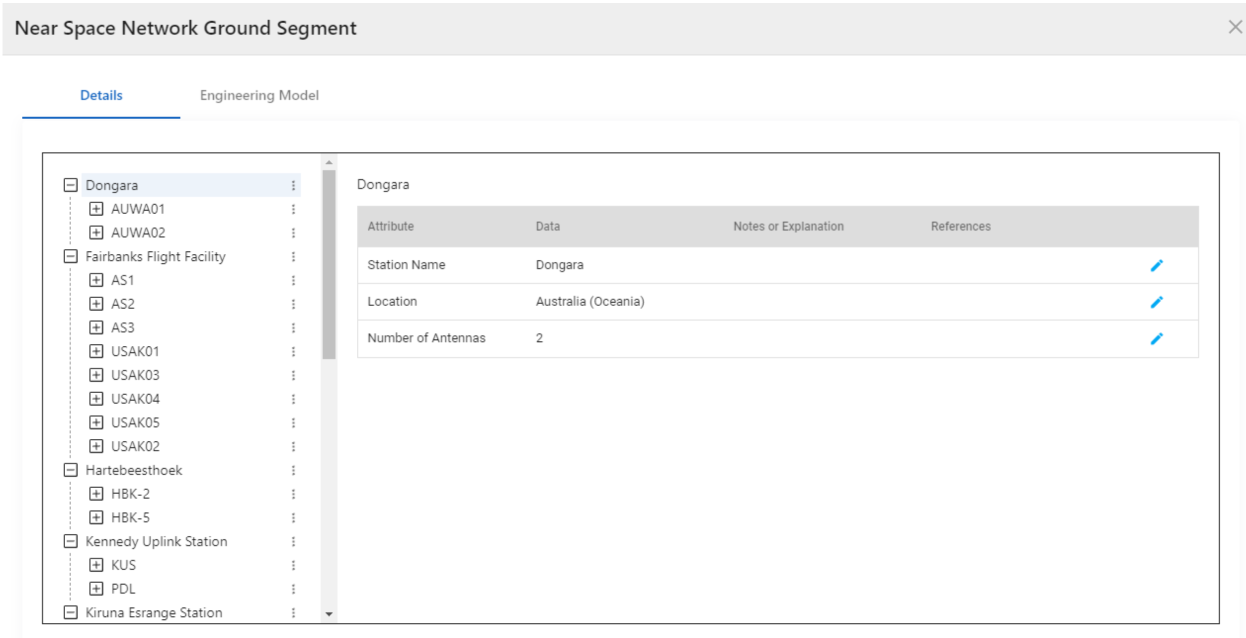


Figure 9-7: Library Page - NSN Network Ground Segment

The sidebar menu allows the user to navigate through and expand the available desired network information. The first level of the DTE library structure is the Ground Station Location Information. This section includes the facility name, the global location name, and the number of antennas at that location (the example for White Sands is shown in Figure 9-8).

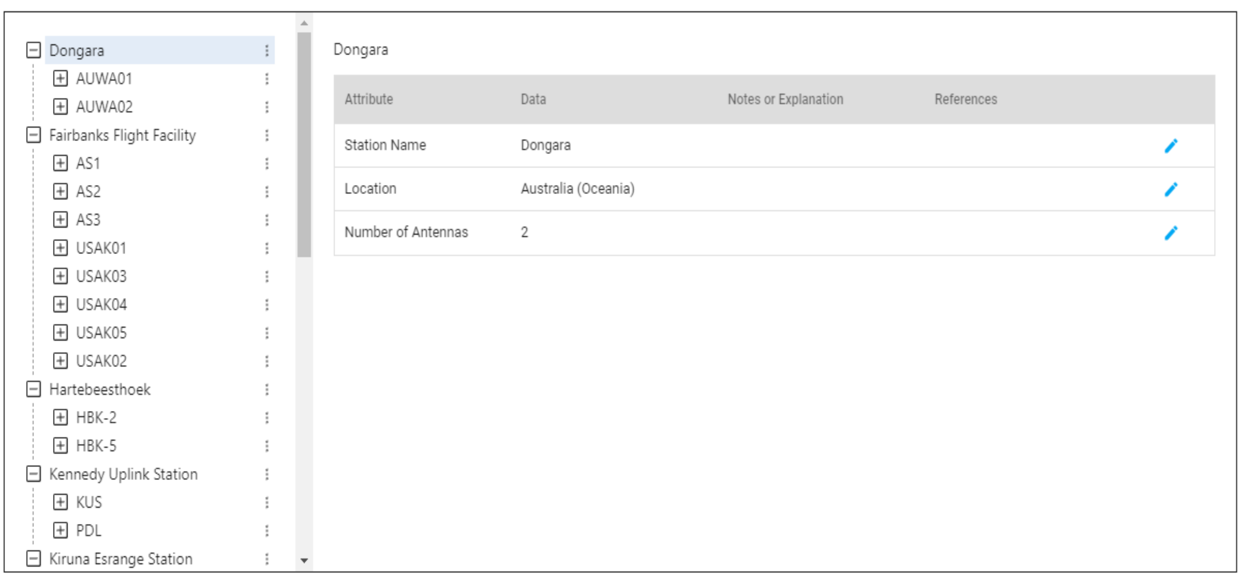


Figure 9-8: DTE Ground Station Location

The second level in the DTE library structure is the antenna information subcategory. This section contains the geographic latitude and longitude, the associated frequency bands, and the diameter of the antenna (Figure 9-9).

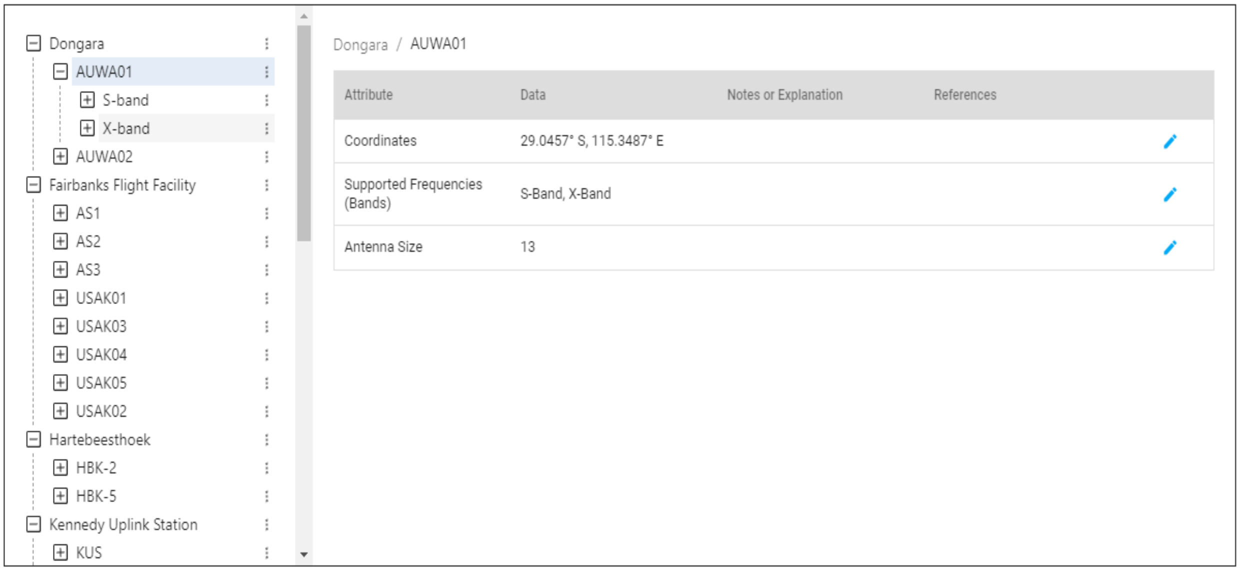


Figure 9-9: DTE Ground Station Antenna

The third level of the DTE library structure is the frequency band information subcategory. Within this section, the supported frequencies, G/T, Polarization, Beamwidth, Gain, Prorogation Loss, and Miscellaneous Losses are defined (Figure 9-10**Error! Reference source not found.**). Note that some antennas have multiple frequency bands associated with them and are not isolated to one individual band.

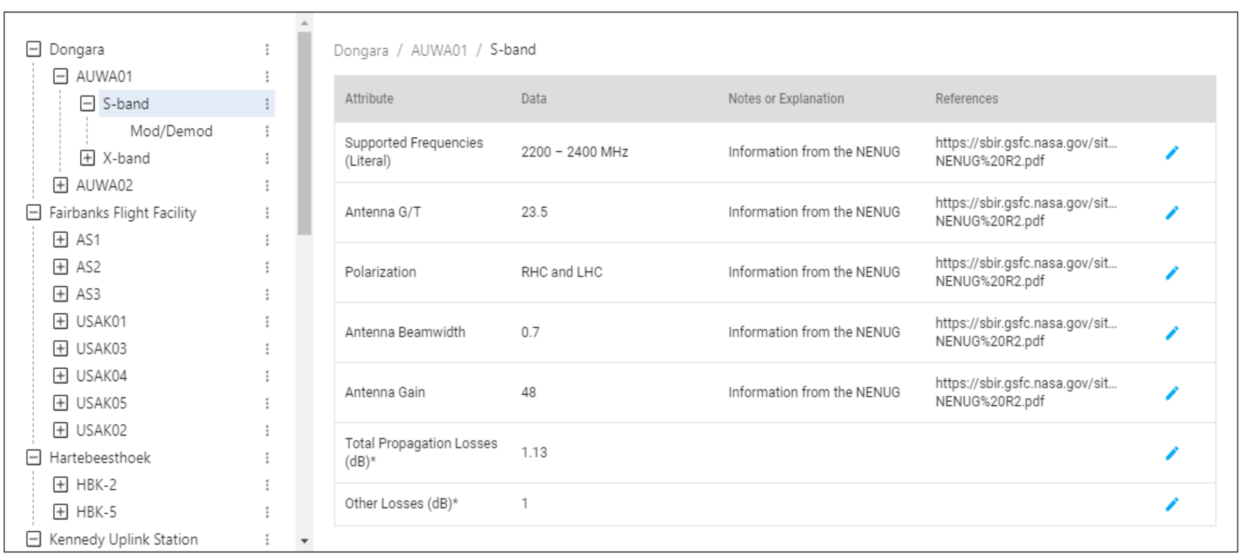


Figure 9-10: DTE Ground Station Frequency Band

The final level of the DTE Library structure is the Modulation / Demodulation subcategory. Within this section, the Supported Modulations, Supported Carrier Data Rates, Data Format, Subcarrier Frequency, Subcarrier Modulation, Subcarrier Data Rate, Subcarrier Format, Decoding, and Max Data Rate (kbps) are defined (Figure 9-11).

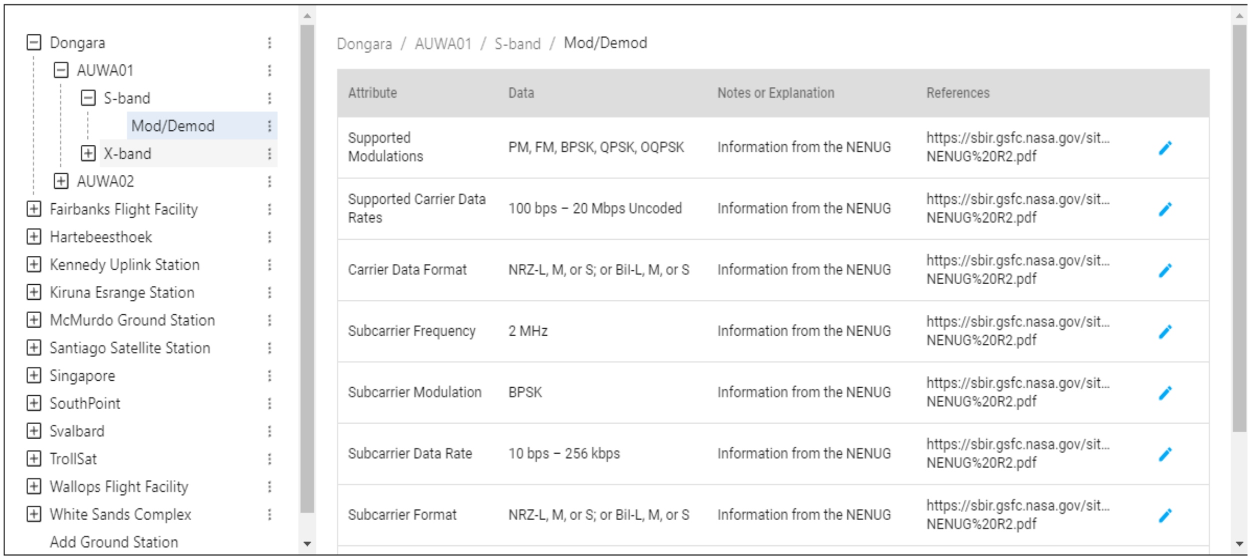


Figure 9-11: DTE Ground Station Modulation/Demodulation

9.3 Accessing Engineering Models

The Engineering Models contain the file structure and all Systems Tool Kit (STK®) reference models for both relay networks and DTE networks. To access the engineering models for all systems, right-click and select "View Network Details" for any relay or DTE network, then click on the Engineering Models tab located on the top right side next to Details depicted in Figure 9-12. Users with a registered CoSMOS account will have access to all available engineering models.

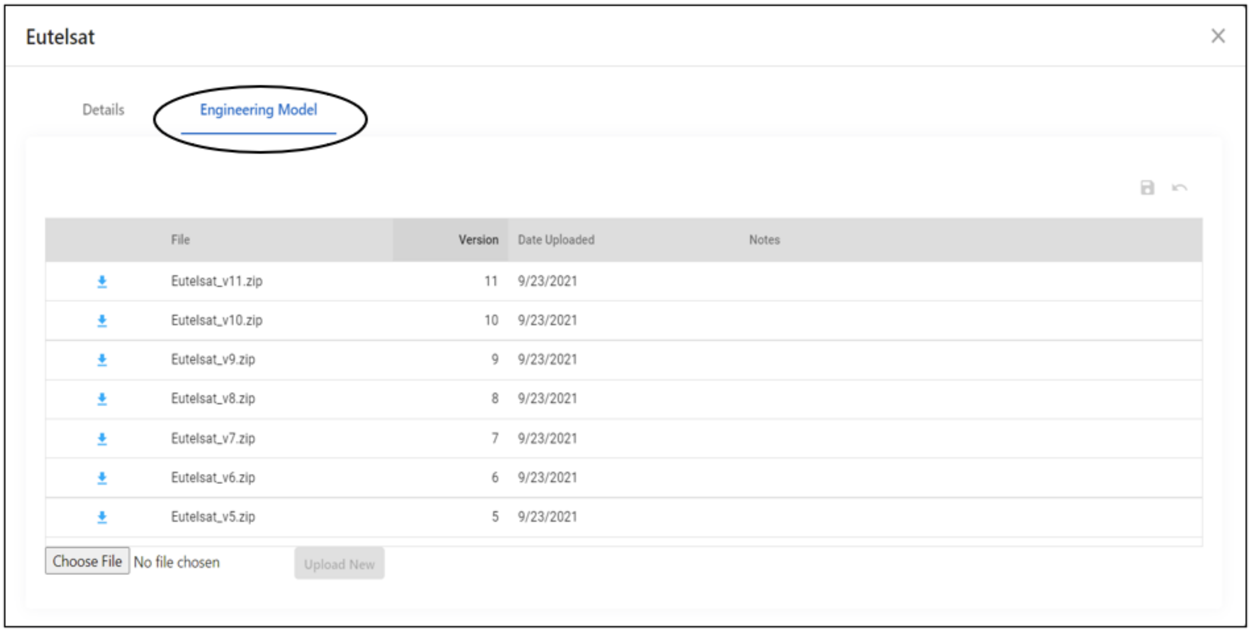


Figure 9-12: Engineering Models - File Structure for Eutelsat

9.4 Administrator Privileges - How to Create a New DTE entry

Administrative privileges include being able to create and delete a new Ground Station or relay network, the creation of a new DTE location [**Future release**], a new antenna attached to the location, a new frequency band attached to the antenna, and the modulation/demodulation of the antenna. All these features can be added or deleted by the administrator. The administrative privileges are limited at this time to the CoSMOS Development Team. To add a new network, the administrator would click on the “New” button on the top right of the network library. The admin would enter in the network name, choose the DTE option (for example), then click “Submit.”

To add a new Ground Station, click on the “Add Ground Station” link. Inside of the dialog box enter in the name of the Ground Station and then click submit (Figure 9-13), then click on the station name and populate the Station Name, Location, and Number of Antennas fields.

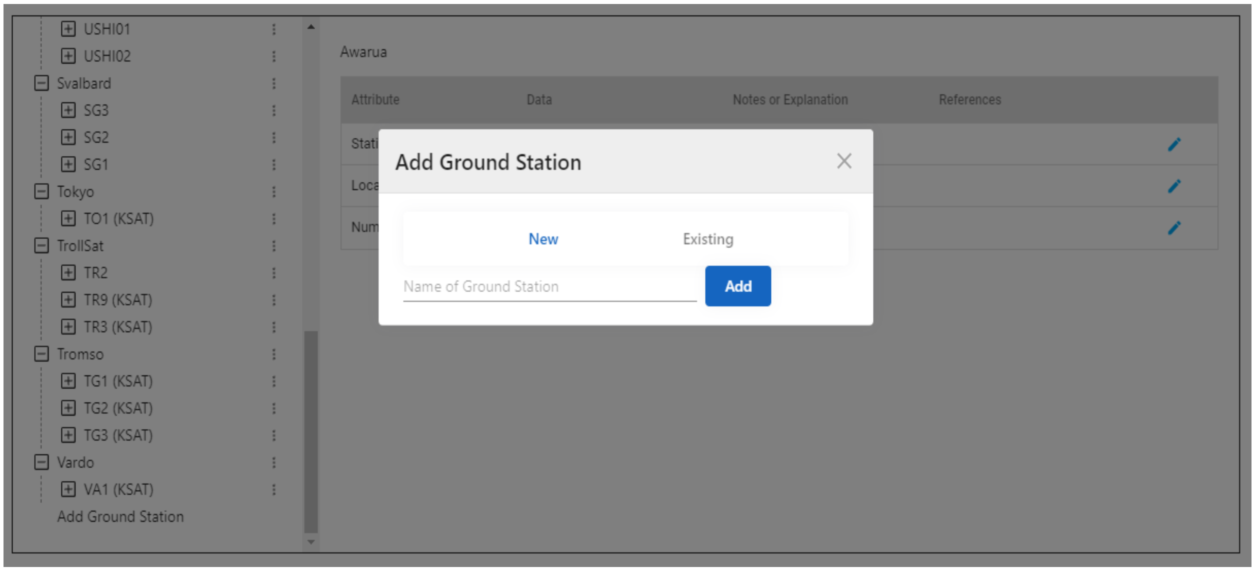


Figure 9-13: Add New Ground System

To add an antenna, click on the three vertical dots beside the new Ground Station Name (Figure 9-14). Inside of the dialog box, select the "Add Antenna" option. Inside of the dialog box, type in the antenna name and click "Submit." Once created, populate the Coordinates, Supported Frequencies, and Antenna Size Fields. If the user would like to remove the Ground Station, they can simply click on the "Remove Ground Station" option.

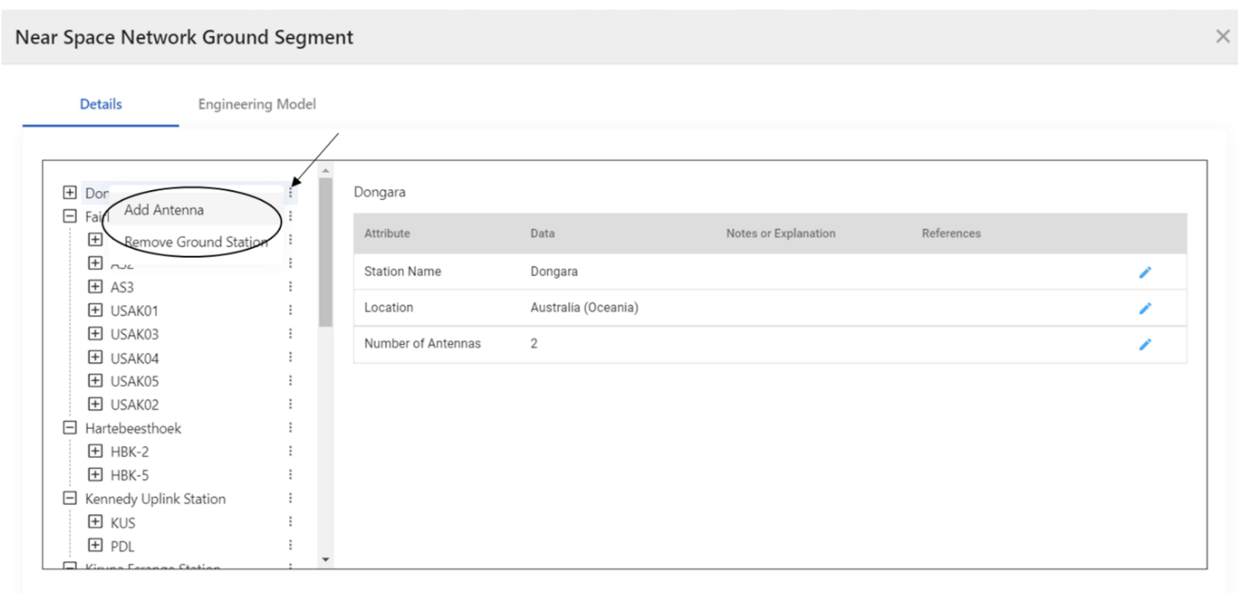


Figure 9-14: Add Antenna/Remove Ground Station

To add a frequency band, click on the three vertical dots beside the antenna name and click on the "Add Frequency Band" option (Figure 9-15**Error! Reference source not found.**). Inside of the dialog box, enter the desired frequency band designation and click the "Submit" button. Once created, populate the Supported

Frequencies (Literal), Antenna G/T, Polarization, Antenna Beamwidth, and Antenna Gain fields. If the user would like to remove an antenna, simply click on the "Remove Antenna" option.

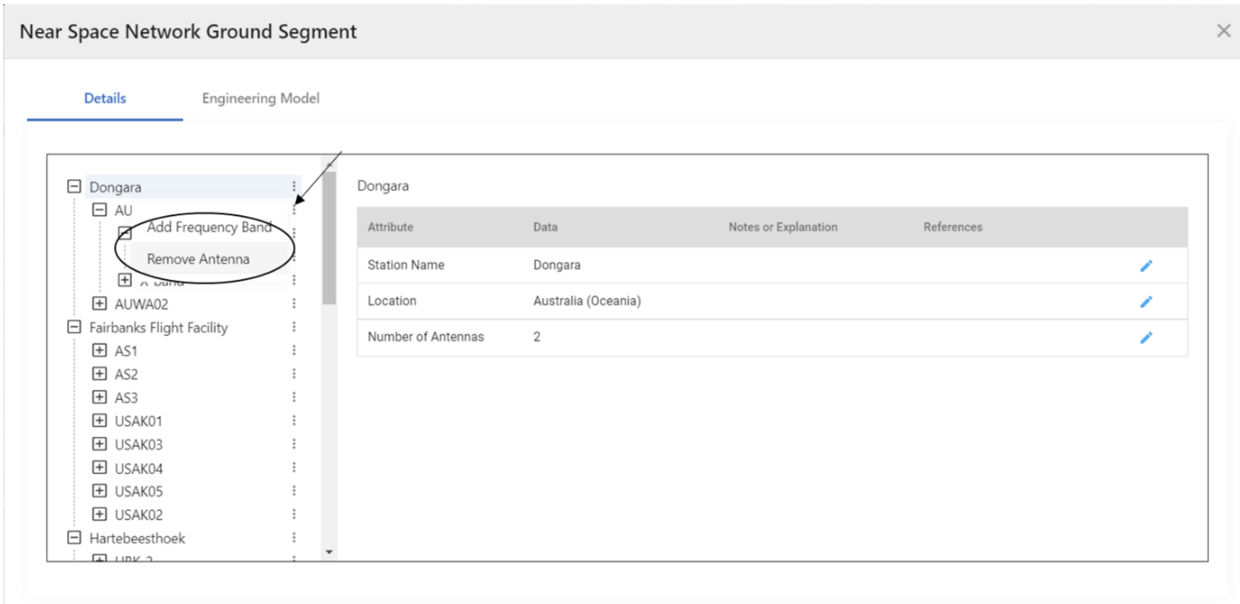


Figure 9-15: Add Frequency Band/Remove Antenna

To add modulations and demodulations, click on the three vertical dots on the right of the frequency band and click on the "Add Mod/Demod" option (Figure 9-16). Inside of the dialog box enter the modulation name and click on the "Submit" button. Once created, populate the Supported Modulations, Supported Carrier Data Rates, Carrier Data Format, Subcarrier Frequency, Subcarrier Modulation, and Maximum Data Rate. To remove a frequency band, simply click on the "Remove Frequency Band" option.

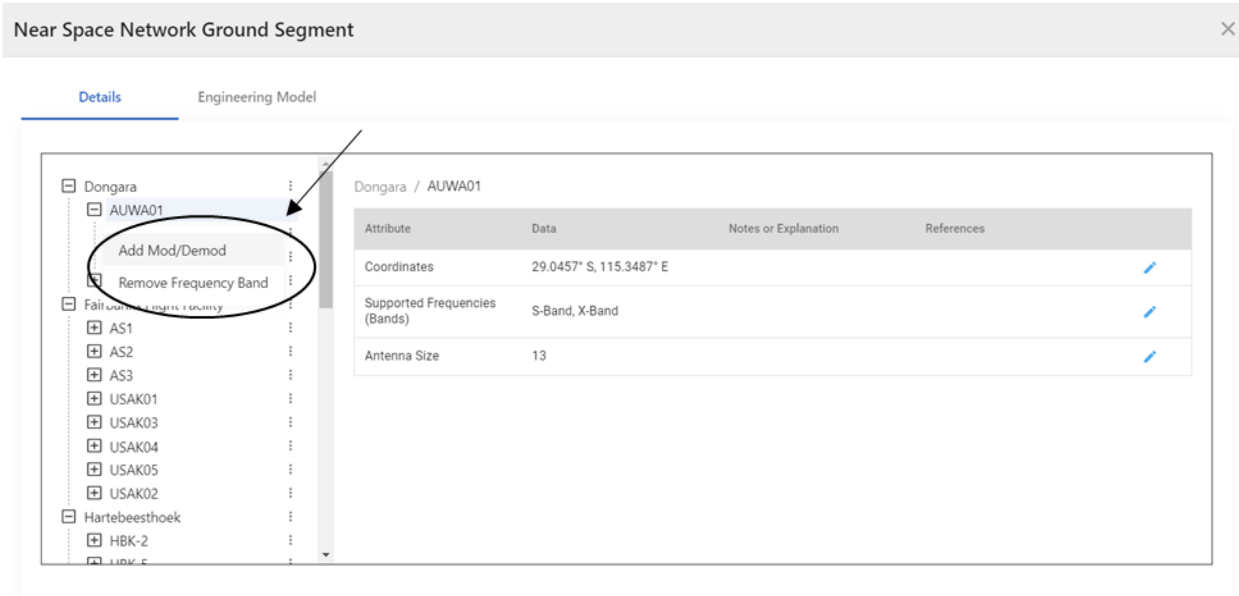


Figure 9-16: Add Modulations/Demodulations / Remove Frequency Band

To remove a modulation or demodulation, click on the three vertical dots on the right side of the modulation name. Inside of the dialog box, click on the "Remove Mod/Demod" option and the modulation will be deleted.

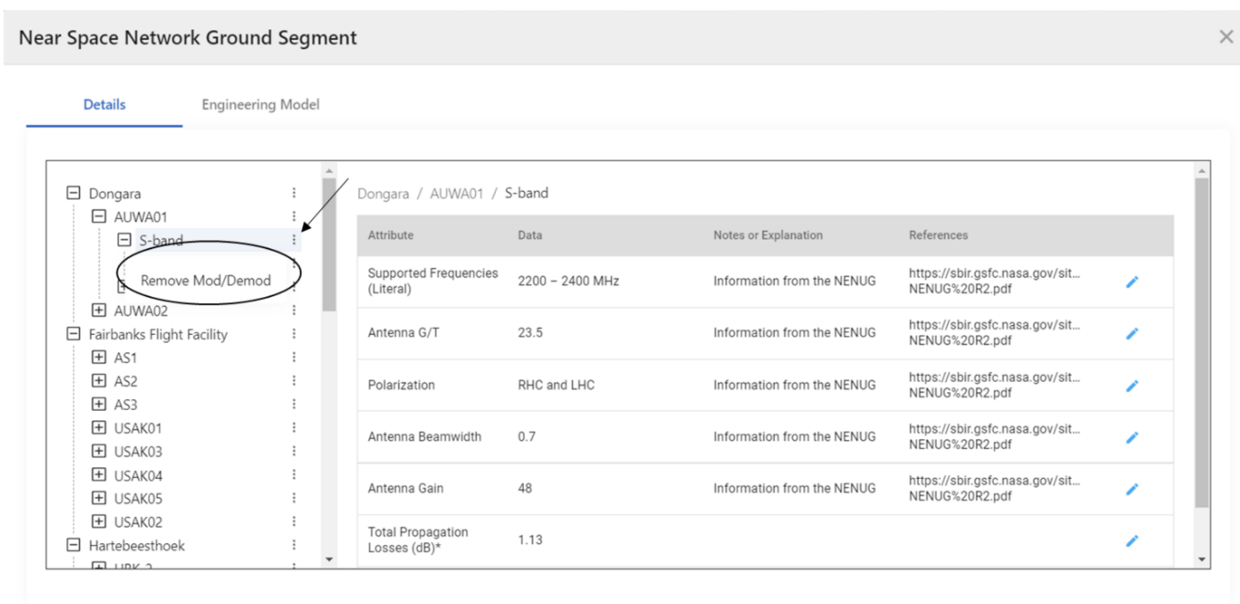


Figure 9-17: Remove Modulations/Demodulations

The administrator can also edit all parameters for all fields in DTE and Relay networks. Relay updates for commercial systems are based on FCC filings and the Space Network Users Guide (SNUG) for NASA owned systems. For the NASA operated Near Earth Network, *NEN: The Near-Earth Network User Guide* (2019 release) was used, and all Commercial DTE network information was obtained using open-source information—primarily through company websites. Admins monitor FCC filings, commercial company websites, and NASA User Guides for updates.

10.0 RESULTS PANEL

The results panel has four main tabs:

- Network Selection Tab
- Analytics Tab
- Performance Tab
- Comparison Tab

The analytics, performance, and comparison tabs cannot be accessed until a network is selected and run for analyses.

10.1 Network Selection Tab

Analysis begins with a user selecting a network from the Network Options Panel, which places the network into the Network Selection Tab. Relay networks *or* any combination of ground networks and stations may be selected. The Network Selection tab also provides the user the ability to either let CoSMOS optimize their modulation and coding options – or specify which modulation and coding option they would like to use for analysis. The following subsections provide further detail on interacting with the network selection tab.

Network Selection

At the top of the screen, inside of the Network Selection Tab, there is an empty box. The user can right-click and select any of the Network options from the Network Option Panel, which populates the selection in the tab. Relay and DTE networks are not available to be combined in this view. The user will only be able to select an individual relay network, individual DTE Network, or a combination of DTE Ground Station Locations. When the desired selection has been made, the configuration can be saved for later comparison (Figure 10-1), and analyses can be initiated by clicking the "Run Analysis" button (Figure 10-2).

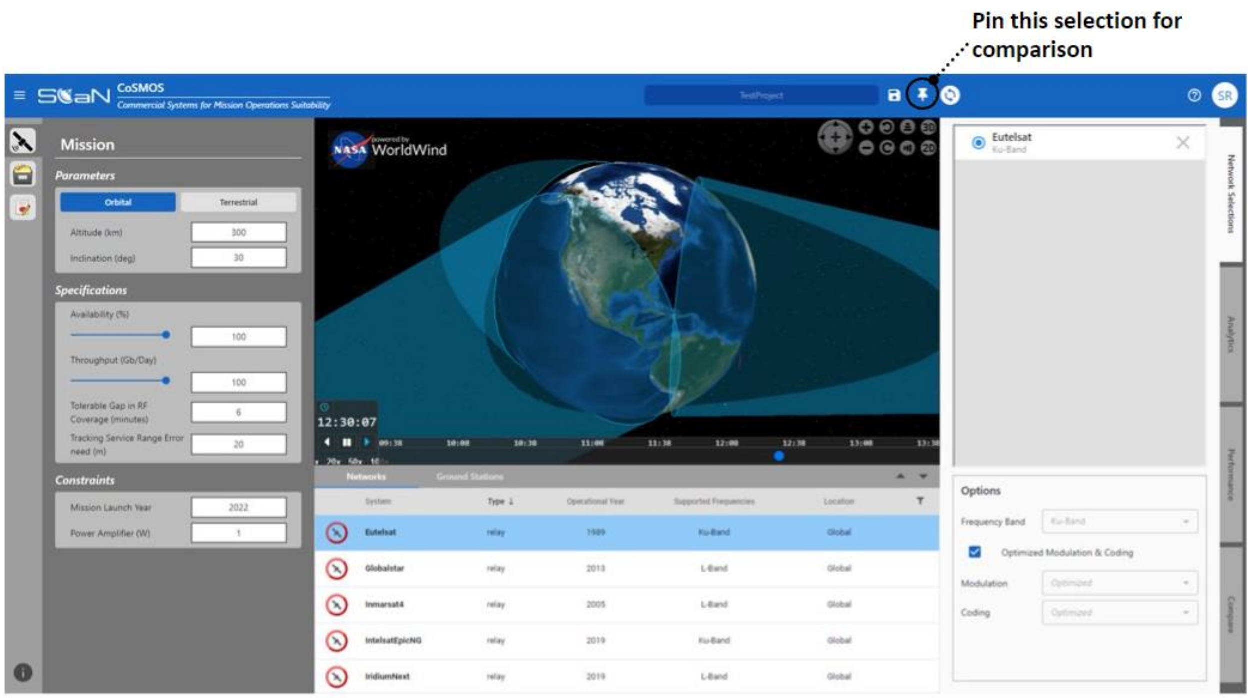


Figure 10-1: Save for Comparison Button

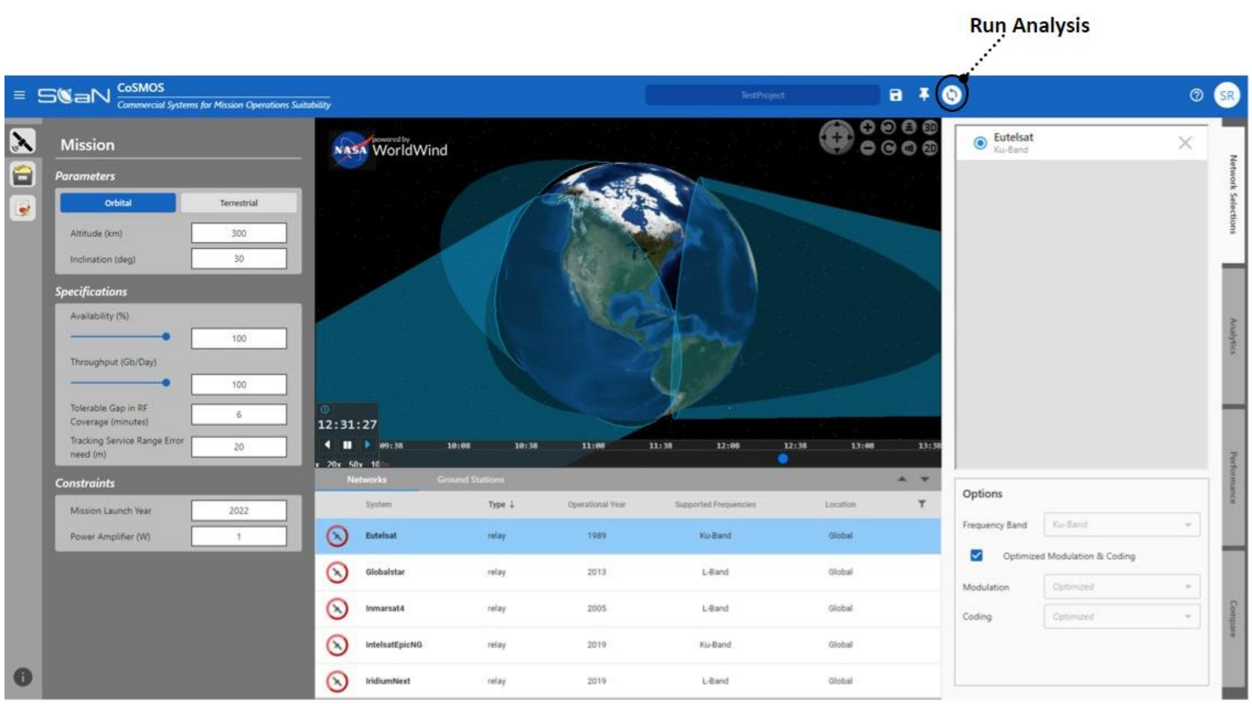


Figure 10-2: Run Analysis Button

Options Selection

The Options dialog at the bottom of the Network Selection panel has three selections: optimized modulation and coding check box, modulation selection, and coding selection. By default, if the user does not un-check the optimized modulation and coding box, CoSMOS will employ the modulation and coding that is optimized for the maximum data rate with the lowest EIRP for the user's analysis based on their network selection. For Relay networks, the only modulation and coding options available for user selection are those that were listed in their respective FCC filings.

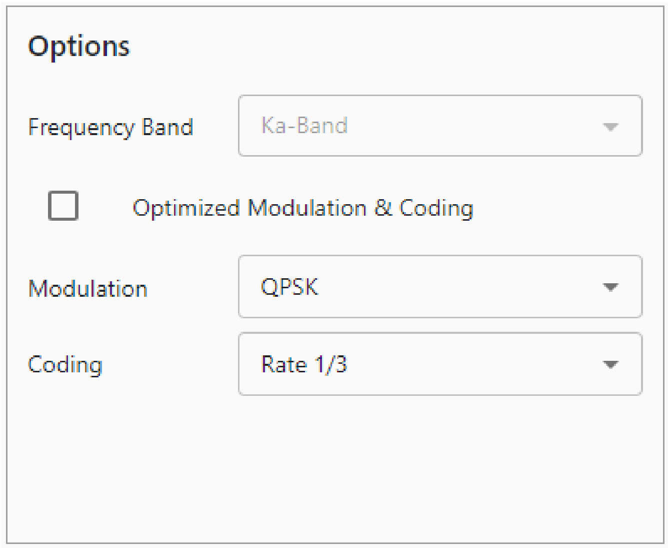


Figure 10-3: Example Relay Modulation and Coding Selection

For a DTE network and/or DTE Ground Station location, the options section will have five selections. Those selections are for the frequency band, antenna, optimized modulation and coding check box, modulation, and coding. The modulation and coding options that are available across all antennas within that network will be the only ones available for selection. An example of this can be seen in Figure 10-4 (below).

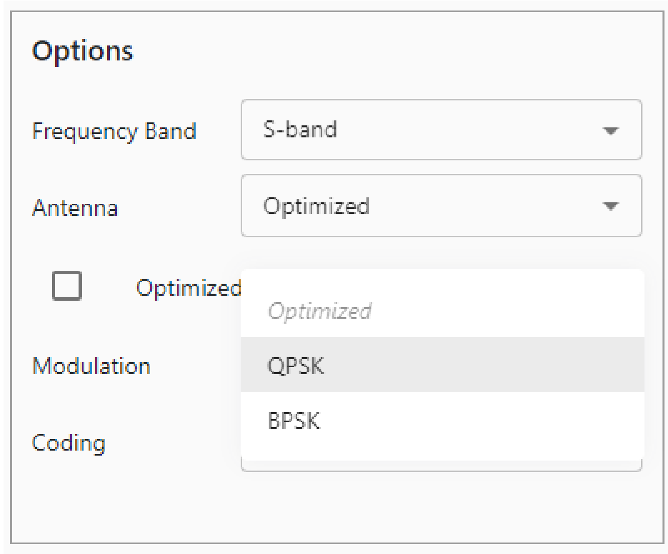


Figure 10-4: Example DTE Modulation and Coding Options Selection

Performing DTE Antenna Selection

If a DTE network and/or DTE Ground Station Location is dropped into the empty network selection pane, the user has the option to select a desired antenna for a particular Ground Station location. To do this, select the "Radio" button next to any Ground Station name, which will then prompt the option to select an antenna from antenna dialog box in the Options section. This can be done for each Ground Station location, if desired (see Figure 10-5). If the user does not select a specific antenna, the CoSMOS default is the antenna with the highest available data rate.

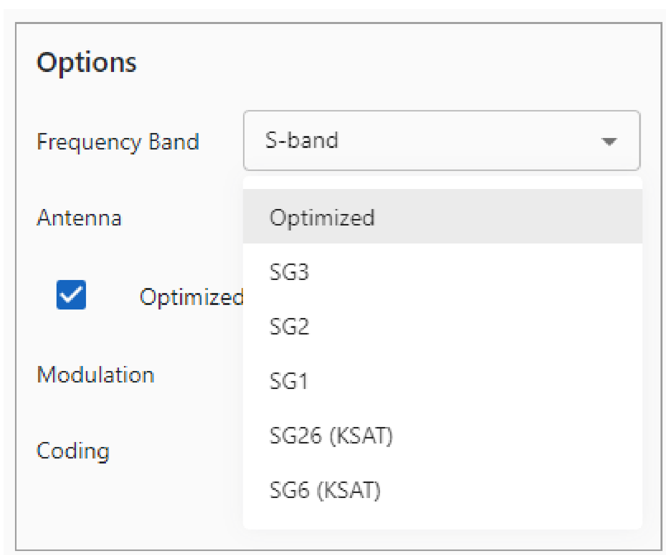


Figure 10-5: DTE Antenna Selection

10.2 Analytics Tab

The Analytics Tab includes a menu at the very top of the screen to choose to see the statistics for RF Coverage or No RF Coverage. If the "RF Coverage" menu option is selected, there will be four RF Coverage metrics displayed in the analytics dialog box. Those metrics are the statistical plots for RF Coverage, Coverage Running Average, Coverage Distribution, and Coverage Statistics. If the "No RF Coverage" menu option is selected, there will be four metrics displayed: statistical plots for Coverage Gaps, Gaps Running Average, Gaps Distribution, and Gaps Statistics.

In both cases, the first regression chart depicts performance across altitude and inclination (for orbital missions); it represents behavior for a range of users and depicts modeled data points with a regression curve overlayed. Selecting an individual modeled point from this first graph, drives the remaining statistical displays. For example, a user at 30-deg inclination and 2,000 km altitude is selected from the RF Coverage regression plot. The modeled data point and its time history for coverage contact durations is depicted in the coverage running average plot. Examples for RF coverage statistics and gap statistics are shown in Figure 10-6 and Figure 10-7.

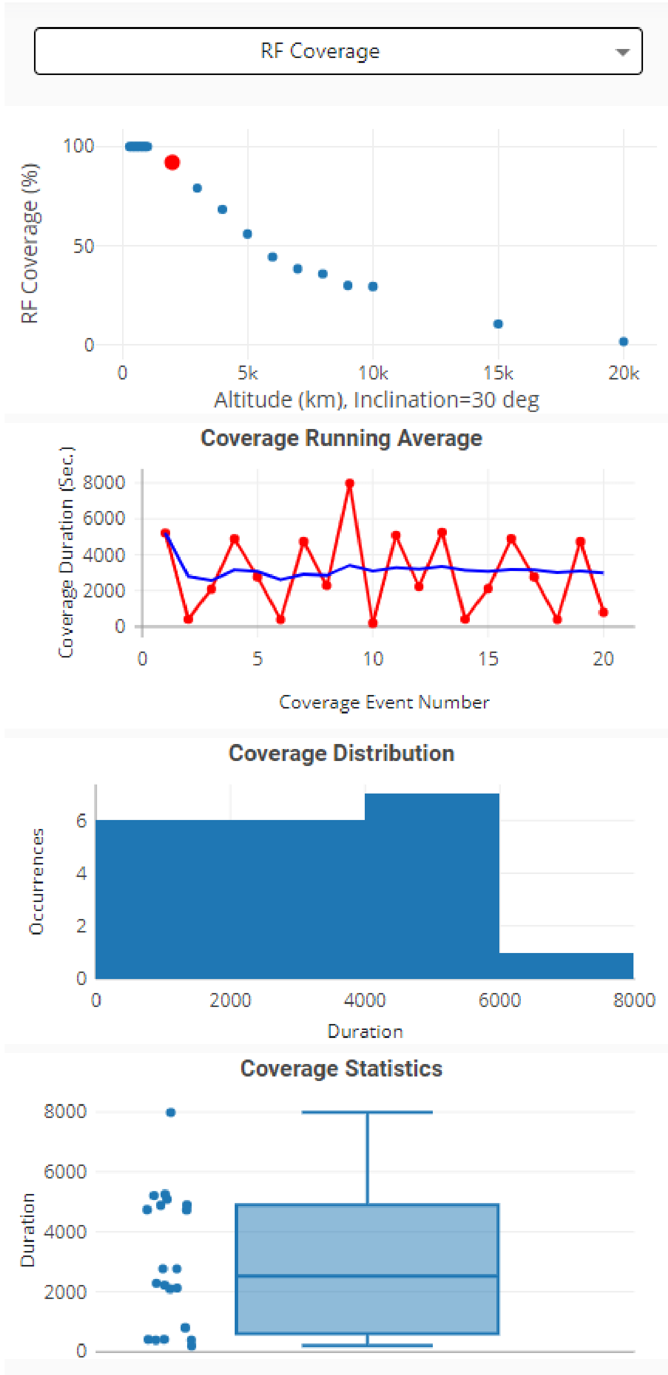


Figure 10-6: RF Coverage Analytical View

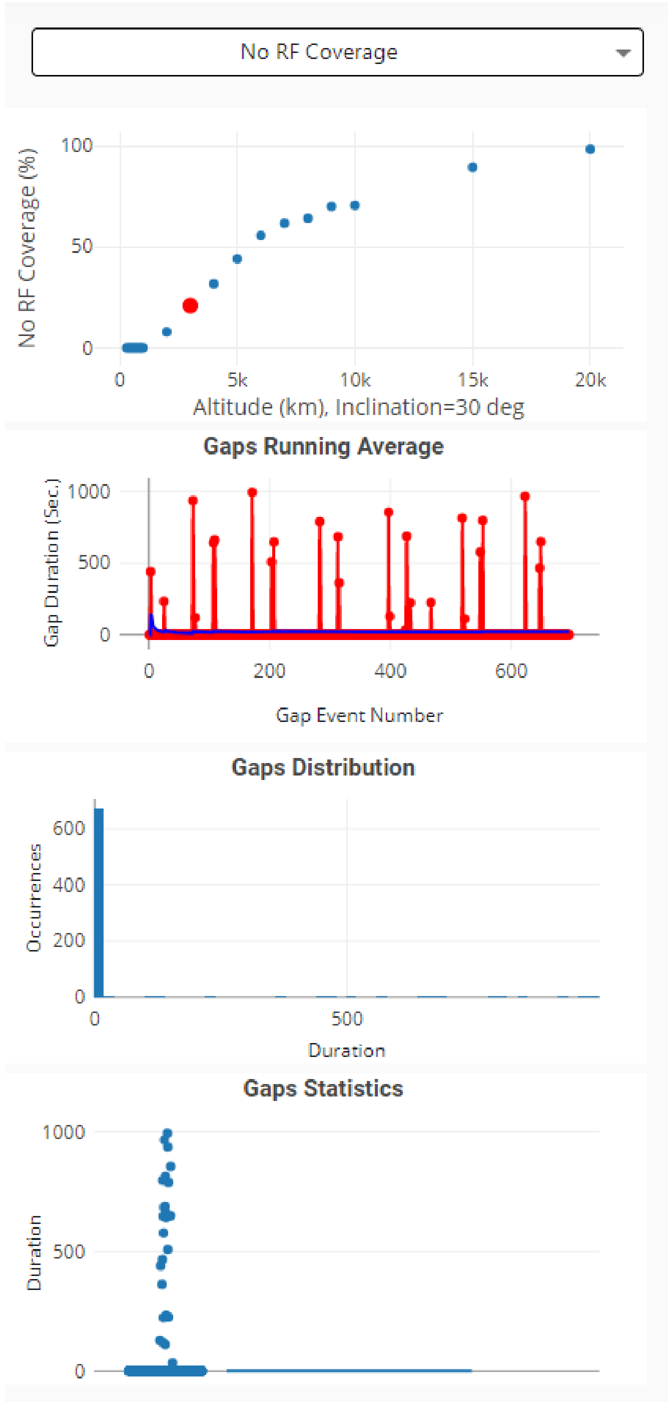


Figure 10-7: No RF Coverage Analytical View

10.3 Performance Tab

The Performance Tab is used to review system performance results (radiofrequency coverage, throughput, etc.) based on the user's specified mission input parameters. There are five main information panels embedded in the Performance tab, which are described further in the subsequent sections:

- Link Analysis
- Performance
- User Burden: Antenna Options
- User Burden: Mission Impacts
- Nav and Tracking

Performance Parameters

The performance section contains nine performance metrics that are output based on the user's mission parameter input selections. Relay systems are listed in Table 10-1. The performance metrics for DTE systems have a slight difference in their representation and are listed in Table 10-2.

Table 10-1: Relay Performance Metric Information

Relay Information Type	Relay Attributes
RF Coverage (%)	RF Coverage is captured as a percentage, representing the duration that the user satellite has enough signal power to close the communications link with the commercial communications system, over a defined period.
Mean Number of Contacts Per Orbit	Mean Number of Contacts Per Orbit is representative of how many network contacts a user would experience per orbit based on user orbit relative to the commercial system's configuration.
Mean RF Contact Duration (seconds)	The average duration of an individual RF coverage contact event, measured in seconds.
Average RF Coverage Gap (minutes)	The average gap in RF coverage the user will experience, measured in minutes.
Max RF Coverage Gap (minutes)	The maximum gap in RF coverage the user will experience, measured in minutes.
Mean Response Time (seconds)	Mean response time measures, on average, how long a user might have to wait for the next RF coverage connection, based on the distribution of gap durations in the observed scenario.
Effective Comms Time (%)	Percentage of time that the user can communicate with the network.
Throughput (Gb/Day)	Potential data volume transmitted in Gb/Day.
Data Rate (kbps)	Potential data rate available for a given user orbit and inclination in kbps.

Table 10-2: DTE Performance Metric Information

DTE Information Type	DTE Attributes
RF Coverage (minutes/day)	RF Coverage is captured in minutes/day, representing the amount of time each day that the user satellite has enough signal power to close the communications link with the selected DTE Ground Station locations.
Number of Contacts Per Day	Number of Contacts Per Day is representative of how many network contacts a user would experience per day based on user orbit relative to the ground network antenna's visibility.

Average Contact Duration (minutes)	The average duration of an individual RF coverage contact event, measured in minutes.
Max RF Coverage Gap (minutes)	The maximum gap in RF coverage the user will experience, measured in minutes.
Average RF Coverage Gap (minutes)	The average gap in RF coverage the user will experience, measured in minutes.
Mean Response Time (seconds)	Mean response time measures, on average, how long a user might have to wait for the next RF coverage connection, based on the distribution of gap durations in the observed scenario.
Data Rate (kbps)	Potential data rate available for a given user orbit in kbps.
Throughput (Gb/Day)	Potential data volume transmitted in Gb/Day.

The tab lists the individual result, e.g., 99.56% coverage; however, clicking on the downward facing arrow on the right-hand side of the metric (Figure 10-8) opens the associated regression plot, which depicts the predicted performance point in context with users at different altitudes.

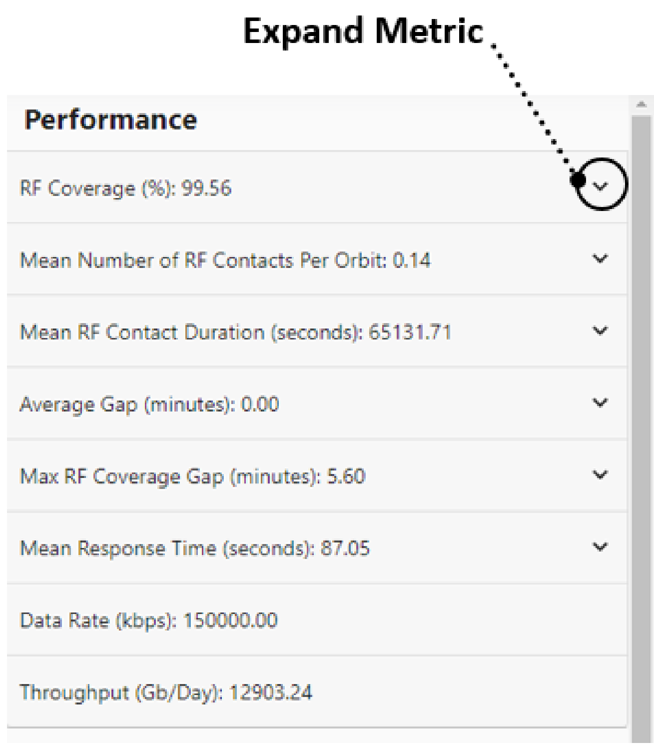


Figure 10-8: Exposing a Performance Regression Plot

To expand the regression plot for better visualization, click on the pop-out button on the top right of the regression plot (Figure 10-9). Each regression plot within CoSMOS can be viewed in 2-D or 3-D feature space; users can simply click on the 2-D or 3-D buttons on the top of the plot to change the view (Figure 10-10). While inside of the expanded regression plot dialog box, there are two additional check boxes where the user can re-select or de-select the option to either show the regression model surface and/or show the underlying data that CoSMOS bases its regression surface on.

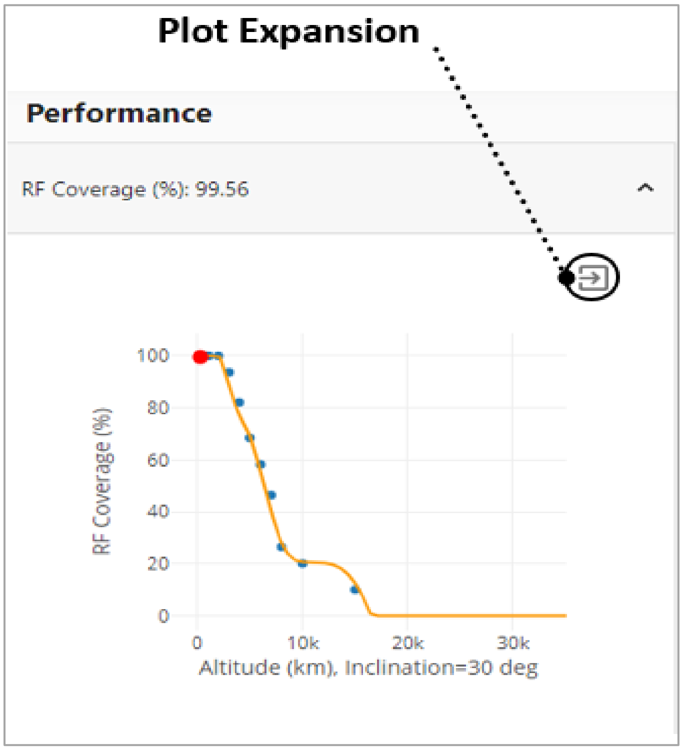


Figure 10-9: Expanding a Performance Regression Plot

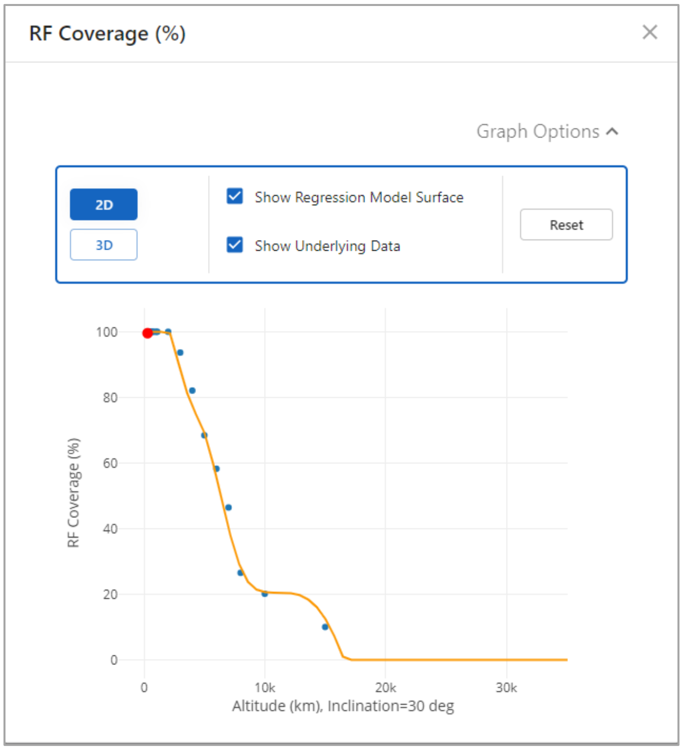


Figure 10-10: 2-D Visualization

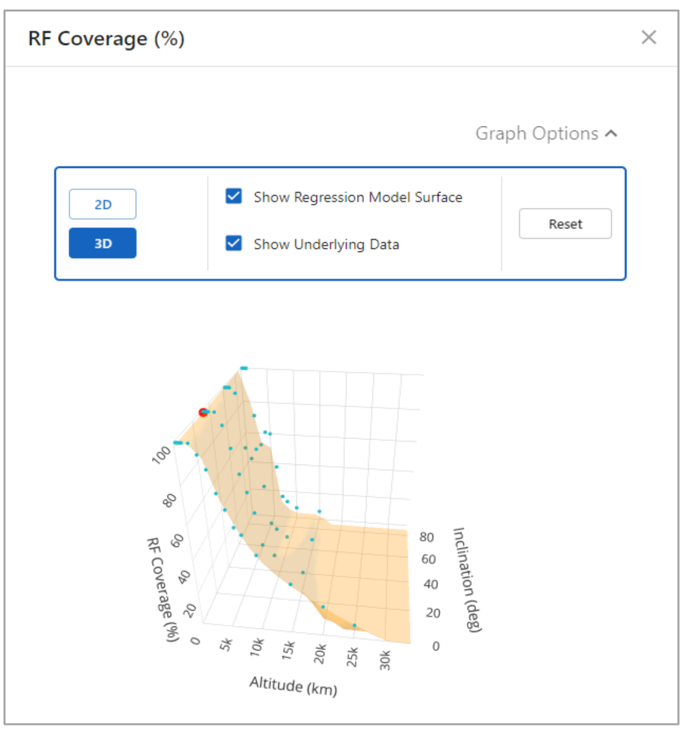


Figure 10-11: 3-D Visualization

[Future release] For the data rate metric, the expanded visualization will show the Data Rate versus Power Received (P_{rec}) plot. Clicking on the "EIRP" button within the data rate versus P_{rec} dialog box will display the Data Rate versus EIRP plot. The system throughput can also be adjusted with the slider at the bottom of the dialog box to visualize the effect of network throughput on the P_{rec} and EIRP real time. See Figure 10-12 and Figure 10-13 for reference.

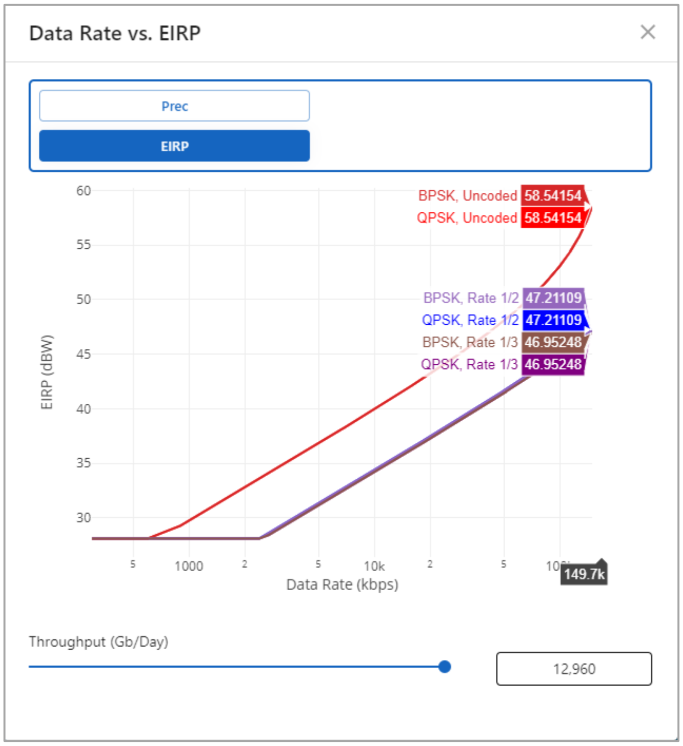


Figure 10-12: Date Rate vs. EIRP for Supported Modulation/Demodulation

Figure 10-13: Date Rate vs. Prec for Supported Modulation/Demodulation

User Burden: Antenna Options

The User Burden Antenna Options section contains seven burden metrics, as seen in Table 10-3. There are two separate calculators within this view: the Electronically Steerable Antenna Size, and Patch Antenna Size. To access any of these calculators, click on the underlined burden metric and the calculator dialog box will pop up in the middle of the screen.

Table 10-3: User Burden: Antenna Options Metric Information

Antenna Options Information Type	Antenna Options Attributes
EIRP (dBW)	The user Effective Isotropic Radiated Power in dBW. A user's EIRP is calculated based on the relay service. Prec requirements and the user orbital characteristics.
Parabolic Antenna Diameter (m)	The parabolic antenna size is calculated based on the gain required to meet the EIRP for a specific mission. A 60% efficiency is assumed for the antenna.
Parabolic Antenna Mass (kg)	The parabolic antenna mass is calculated based on a common/industry mass-estimating relationship driven by antenna diameter.
Electronically Steerable Antenna Size (m^2)	It is assumed the antenna is rectangular and the number of antenna elements are on the order of n^2. The number of elements is calculated based on the antenna's required gain, assuming a conventional patch antenna with the size of $\lambda/2$ represents the elements, and the distance between the elements are $\lambda/2$.
Helical Antenna Height (m)	The Helix antenna height is calculated based on the gain formula for a conventional helix antenna.

Patch Antenna Size (m^2)	An FR4 substrate with a dielectric constant of 4.4 is considered for the antenna. It is assumed the length and the width of the patch antenna are equal.
Dipole Antenna Size (m)	The length of the dipole antenna was considered based on two options (i.e., L = 0.5 of λ, and L = 1.25 of λ).

Link Analysis

The user can visualize the return link budget for any type of network by clicking on the underlined EIRP value in the User Burden: Antenna Options dialog box. Once the user clicks on the underlined EIRP value, the return link budget for the DTE or Relay System they chose for analysis is displayed in the middle of the screen. Inside of the return link budget for both DTE and Relay systems, there is a user editable field called "miscellaneous losses." This field is unique to each user and can be changed to account for variance in link margin and other losses that are not yet accounted for by CoSMOS.

For Relay Networks, there are two different forms of the Return Link Budget. For bent pipe networks, there is a section of calculations for the space-to-ground return link, as seen in Figure 10-14 below. The following networks are bent pipe:

- TDRS KaSA
- TDRS SSA
- Viasat
- Inmarsat-4
- Inmarsat-5
- Globalstar
- OneWeb MEO
- Eutelsat
- Intelsat
- O3b mPower
- O3b Legacy
- Telesat

For regenerative transponder networks, there is no space-to-ground link calculations shown in their return link budgets, as seen in Figure 10-15 below. The following networks are regenerative transponder:

- IridiumNext
- SpaceX 1110

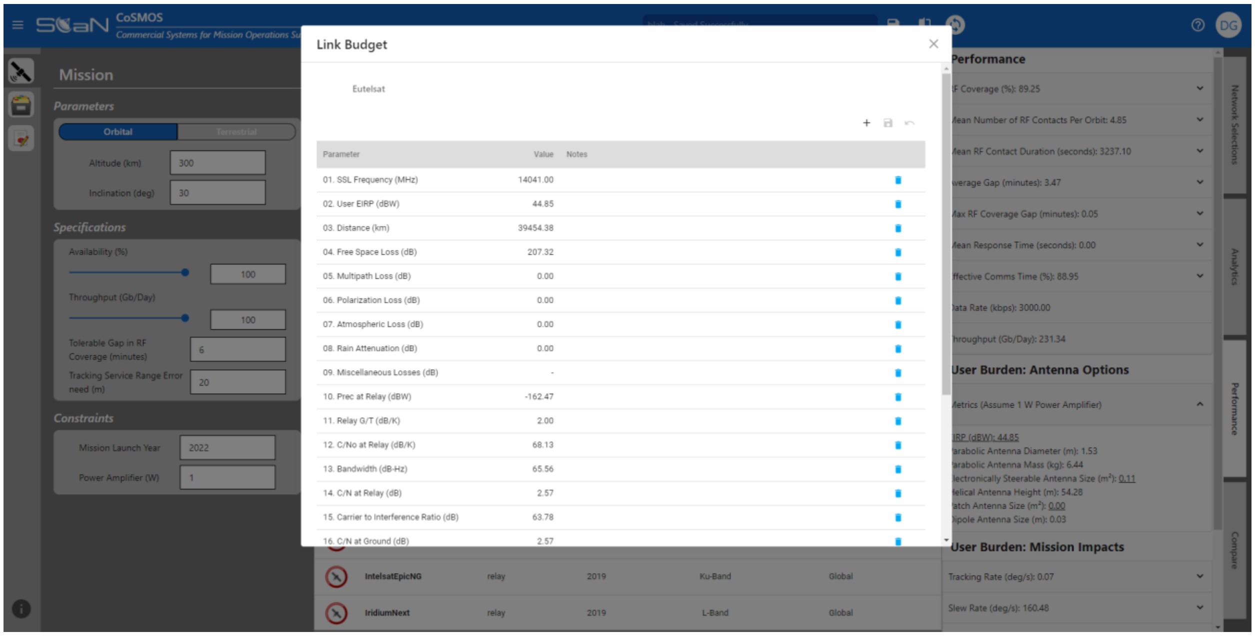


Figure 10-14: Example of Bent Pipe Return Link Budget

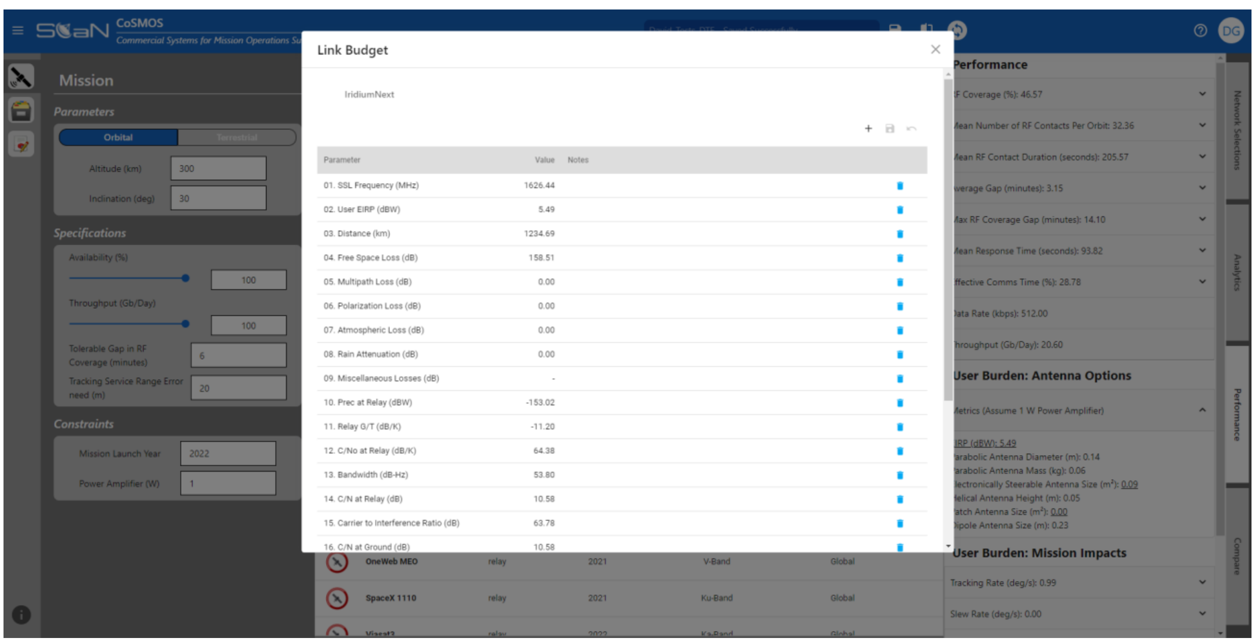


Figure 10-15: Example of Regenerative Transponder Return Link Budget

User Burden: Mission Impacts

The User Burden Mission Impacts section contains five separate metrics that are listed in the User Burden: Mission Impacts Metric Information Table below. Only three metrics within this dialog box have regression plots associated with them.

Table 10-4: User Burden: Mission Impacts Metric Information

Mission Impacts Information Type	Mission Impacts Attributes
Tracking Rate (deg/s)	The Tracking Rate is the Angular Adjustment rate required for a user antenna to maintain RF coverage with the current servicing relay satellite.
Slew Rate (deg/s)	Angular adjustment rate required for the user antenna to reorient in preparation for the next satellite. Can be considered the necessary angular speed to change between relay satellites without losing service.
Pointing-Adjusted RF Coverage (%)	The percent RF coverage available if the user cannot exceed the pointing rate reference threshold. *The approach for this metric is under further development and will be revised.*
Body Pointing Feasibility	Based on the tracking rate, the feasibility of the spacecraft accommodating those rates through body pointing.
Mechanical Pointing Feasibility	Based on the tracking rate, the feasibility of the spacecraft accommodating those rates using a mechanism (gimbal, etc.)

Navigation and Tracking

Navigation and Tracking is the final section within the performance tab. It contains two metrics, Tracking Accuracy and Global Navigation Satellite System (GNSS) Availability. The definitions for each can be seen in Table 10-5.

Table 10-5: Navigation and Tracking Metric Information

Navigation and Tracking Information Type	Navigation and Tracking Attributes
Tracking Accuracy (m)	Denotes the available service provided by the commercial system if the information is available.
GNSS Availability	If the commercial system cannot meet the accuracy need, the user may need to rely on GNSS solutions, although this is not the only option. Output is based on the user altitude relative to the space service volume and GNSS usage feasibility.

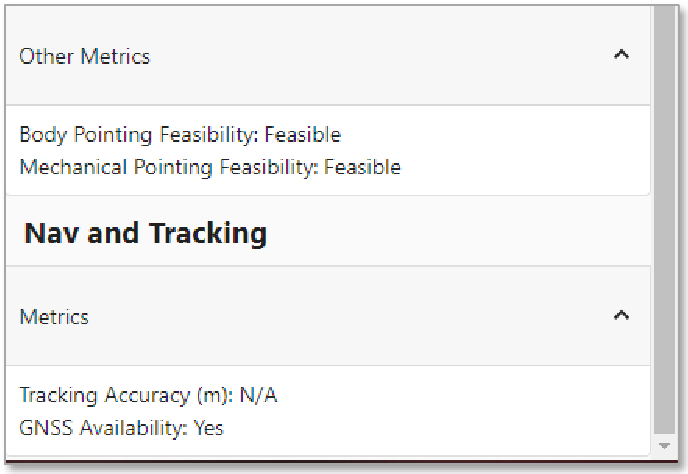


Figure 10-16: Burden Metrics Associated with Pointing, and Nav and Tracking Related Metrics

10.4 Comparison Tab

Based on the selections made by the user during analyses, and which systems were saved for comparison, when the Comparison Tab is selected, the results from each system or Ground Station will be displayed side by side. Currently, only DTE options, or relay options, may be compared to each other; DTE and relay options cannot be compared side by side. Within the Comparison tab, the performance metrics, user burden antenna options, user burden mission impacts, and navigation and tracking options will all be visible. To view the regression plots for any metric, simply click on the unlined metric value and the regression plot will appear in the center of the screen.

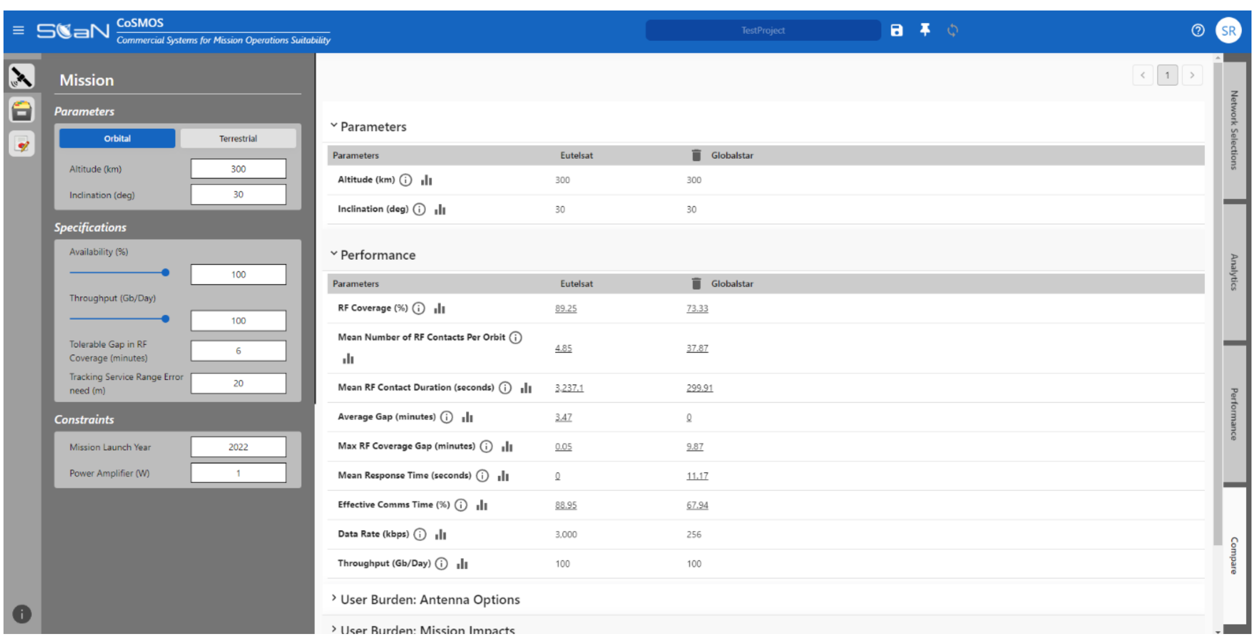


Figure 10-17: Comparison View with Two Relay Systems

The Engineering Models module contains the file structure and all Systems Tool Kit (STK®) reference models for both relay networks and DTE networks. Users can select a particular model from a drop-down menu and view each model's characteristics; the engineering models link provides for external reference models, as shown in Figure 10-18. Intended for the user to do their own experimentation rather than rely on CoSMOS's preprocessed analytical data. To access the engineering models for all systems, right-click and select View Network Details for any relay or DTE network, and then click on the Engineering Models tab, located on the top-right side of the screen, next to Details.

Users with a registered CoSMOS account will have access to all available engineering models. Accounts can be requested at cosmoshelp@teltrium.com.

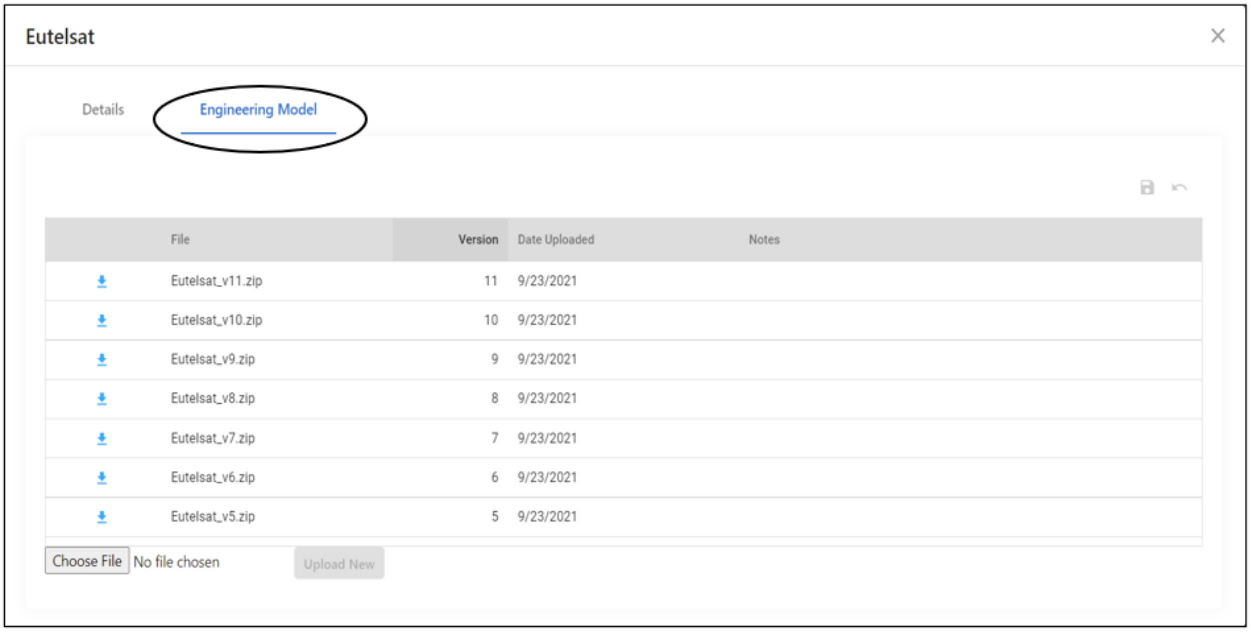


Figure 10-18: Engineering Models - File Structure for Eutelsat

11.0 HELP MENU

To access the help menu for CoSMOS, click on the question mark on the right of the title bar. The user is then prompted with a dialog box to contact the email CoSMOSHelp@teltrium.com for assistance with the tool. Click the "Okay" button when finished to exit back to the main window.

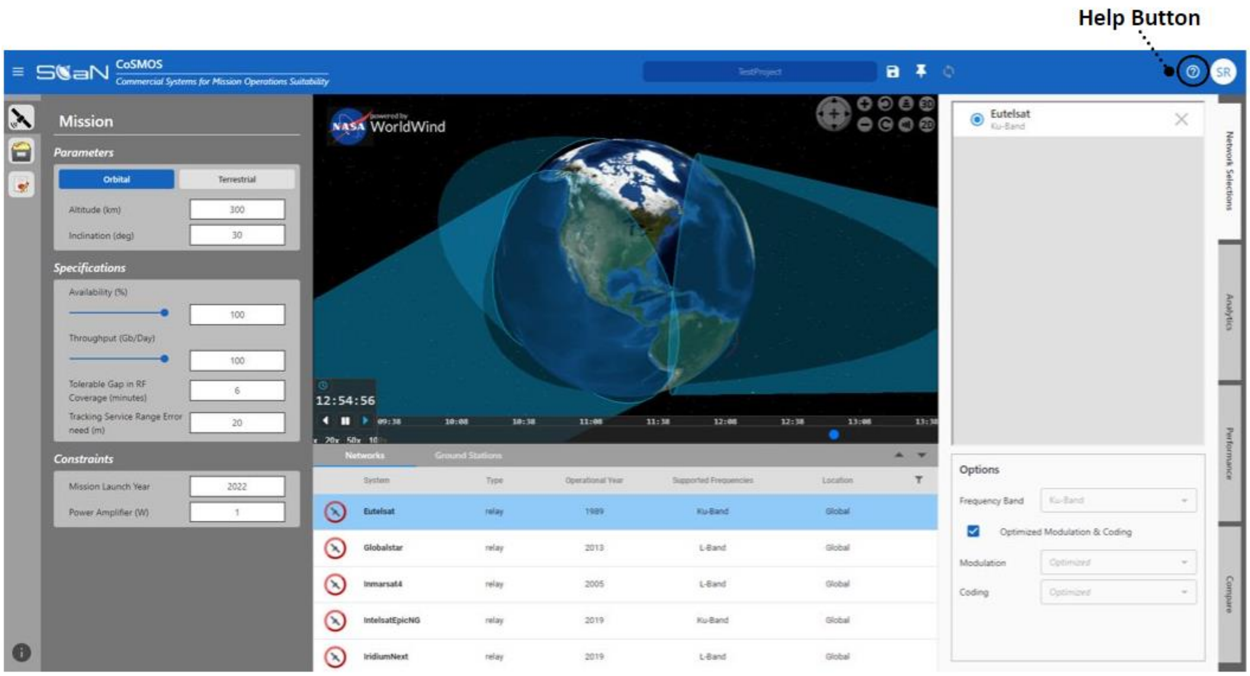


Figure 11-1: Help Menu Location

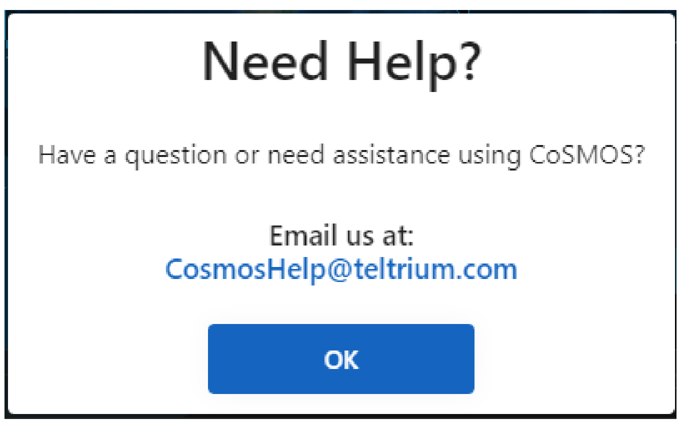


Figure 11-2: Help Menu

12.0 ACCOUNT MANAGEMENT MENU

The account management menu, accessed from the far right corner of the title bar, contains links to three components of CoSMOS: the Account Settings Menu, Log Out Menu, and the Engineering Dashboard. The Engineering Dashboard is a functionality that only individuals with the role of “Engineer” have access to, a nominal user of CoSMOS will not be able to access this component. The functionality of each of these components can be seen in Table 12-1: Account Management Menu Components.

Table 12-1: Account Management Menu Components

Component	Functional Description
Account Settings Menu	Manage User Password, Phone Number, System Role, Email Address, & **User Management Access (Administrative Access Only)**
Log Out Menu	Log out of user account
Engineering Dashboard	**Upload Processed STK Files, Upload Raw DTE files, Process Raw DTE files, Transfer files between data bases, Upload regression files, Visualize raw data and regression changes (All Administrative Use Only)**

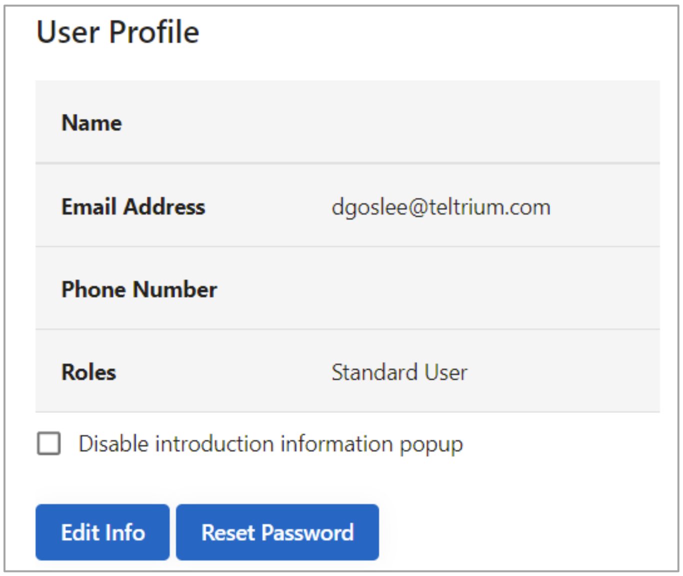


Figure 12-1: Account Settings Menu

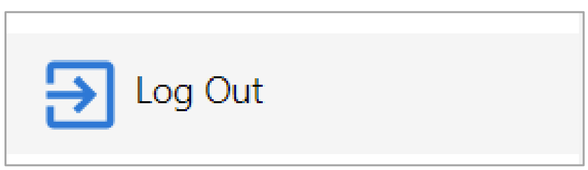


Figure 12-2: Log Out Button

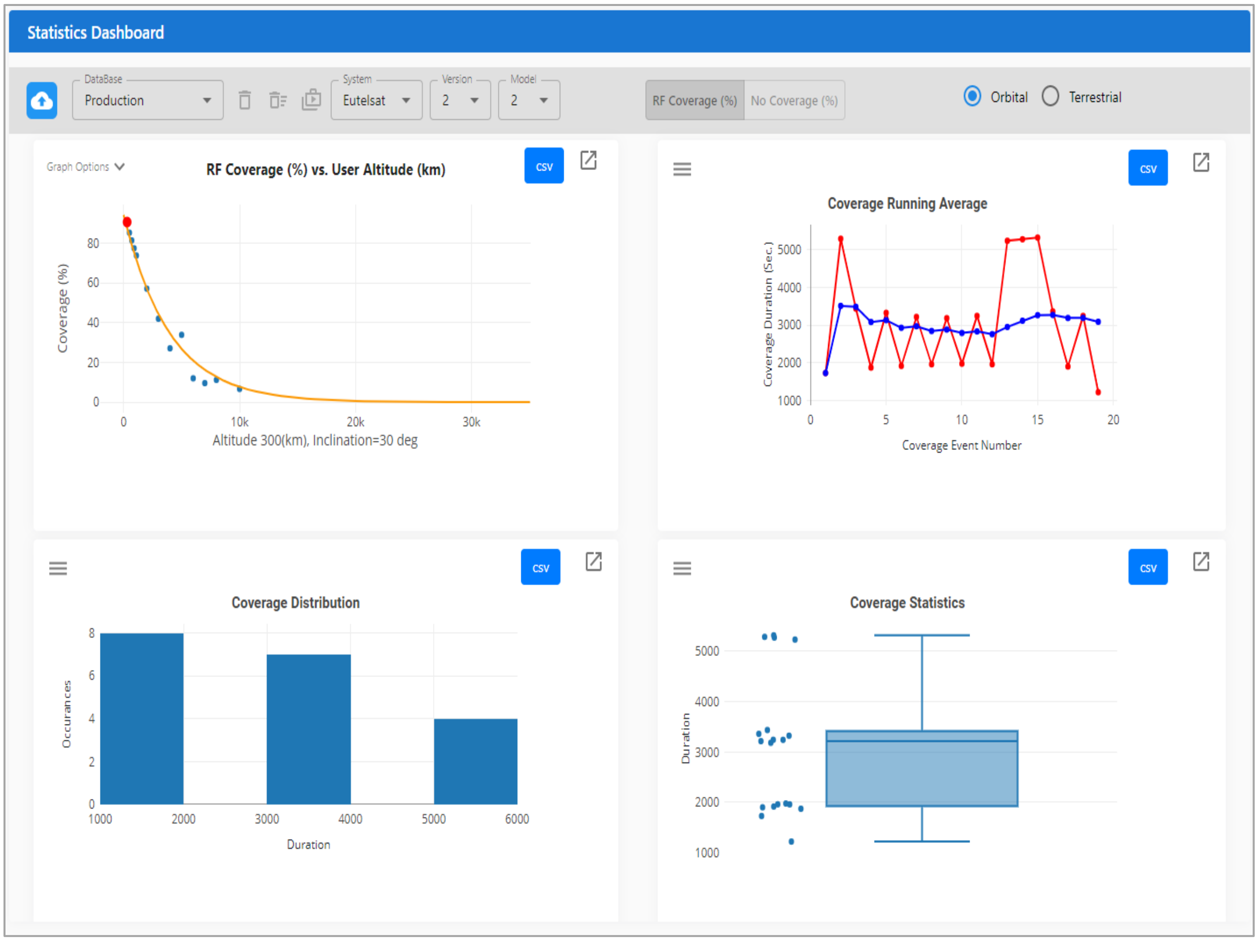


Figure 12-3: Engineering Dashboard

13.0 COSMOS SCENARIO/TUTORIALS

The prior sections established basic introductory elements for CoSMOS. The subsequent sections provide examples of workflows using "real" cases.

13.1 Scenario 1: Small Satellite Commercial Option Identification—DTE and Relay

An astrophysics mission has made first contact with the Near Space Network (NSN). The mission concept involves a single small satellite whose purpose is to detect randomly occurring transient science events and rapidly disseminate low volume data products to the ground. The science mission data need is 100 kbits per transient science event data product with space-ground latency goal to be met as soon as possible and no more than 10 minutes post detection. The average expected number of transient science events is five per day, with the maximum expected rate of transient events being 100 per day at 90% confidence (assuming transient event distribution is normal). For tracking telemetry and command (TT&C), the mission requires 5-minute real-time bi-directional communications event at 32 kbits with average time between contacts of 4 hours. The mission will launch as a secondary payload on a shared launch vehicle and, as a result, the mission must be designed to meet its objectives from any circular orbit, ranging in altitude from 300 km to 850 km, and at any inclination from 0 to 93 degrees.

The mission needs are translated to CoSMOS inputs as shown in Table 13-1, and the targeted outputs that will be used for evaluation are indicated in Table 13-2.

Table 13-1: Scenario 1: Mission Inputs

Input	Scenario 1	
	TT&C	Science Data
User Orbit or Location	Variable	
Availability	5 min/contact	100 contacts/day
Throughput	192 kb/day	0.01 Gb/day
Latency *(Tolerable Gap in RF Coverage)*	240 min	10 min
User Burden: Power Amplifier	-	-
Tracking Service Range Error	-	-
Mission Launch Year	-	-

Table 13-2: Scenario 1: Mission Outputs

Output	Scenario 1	Method
AVAILABILITY METRICS		
RF Coverage (%)		Modeled Statistics
Average RF Contacts Per Orbit		Modeled Statistics
Average RF Contact Duration (sec)	●	Modeled Statistics
Effective Comms Time (%)		Modeled Statistics
THROUGHPUT (Gb/Day)	●	CoSMOS Calculated
LATENCY METRICS		
Average RF Coverage Gap (min)	●	Modeled Statistics
Max RF Coverage Gap (min)	●	Modeled Statistics
Average Response Time (sec)	●	Modeled Statistics
USER BURDEN – ANTENNA OPTION METRICS		
EIRP (dBW)		CoSMOS Calculated
Parabolic Antenna Diam. (m)		CoSMOS Calculated
ESA Size (m^2)		CoSMOS Calculated

Helical Antenna Height (m)		CoSMOS Calculated
Patch Antenna Size (m^2)		CoSMOS Calculated
Dipole Antenna Size (m)		CoSMOS Calculated
MISSION IMPACT METRICS		
Tracking Rate (deg/s)		Modeled Statistics
Slew Rate (deg/s)		Modeled Statistics
Body Pointing Feasibility		CoSMOS Calculated
Mechanical Pointing Feasibility		CoSMOS Calculated
Tracking Service 3-sigma Range Error		Reference
GNSS Availability		Reference
OPERATIONAL YEAR		Reference + CoSMOS

The mission would like to define at least 2 "commercial first" network (or multi-network) solutions that minimize latency for the delivery of data products from space to the ground. The goal is to identify existing or planned commercial Direct-to-Earth and/or space relay providers that could potentially meet these requirements, define what the measures of performance are for those networks, and identify risks and potential mitigations.

For this scenario, the assessment is executed in the following sequence:

Evaluate the performance of DTE service options: (Steps 1-15)

1. Evaluate science latency and the other target metrics, down-select systems as applicable for science data service support
    i. Given the latency requirements, we assess complete networks* as a starting point
2. Identify combinations of Ground Stations that can meet TT&C latency objectives for the potential user orbits
3. Evaluate all target metrics, down-select Ground Station combination options as applicable for TT&C service support,
4. Evaluate additional metrics to make an informed selection / recommendation

Evaluate performance of Relay Networks service options: (Steps 16-23)

1. Evaluate latency and the other target metrics across relay system options for both science and TT&C service support
2. Explore statistics as applicable
3. Evaluate additional metrics to make informed selection / recommendation

Step 1: CoSMOS Login and Project Start

Open the preferred web browser, types in the web address https://cosmos.teltrium.com and press enter. When CoSMOS loads, click on the “New Project” button.

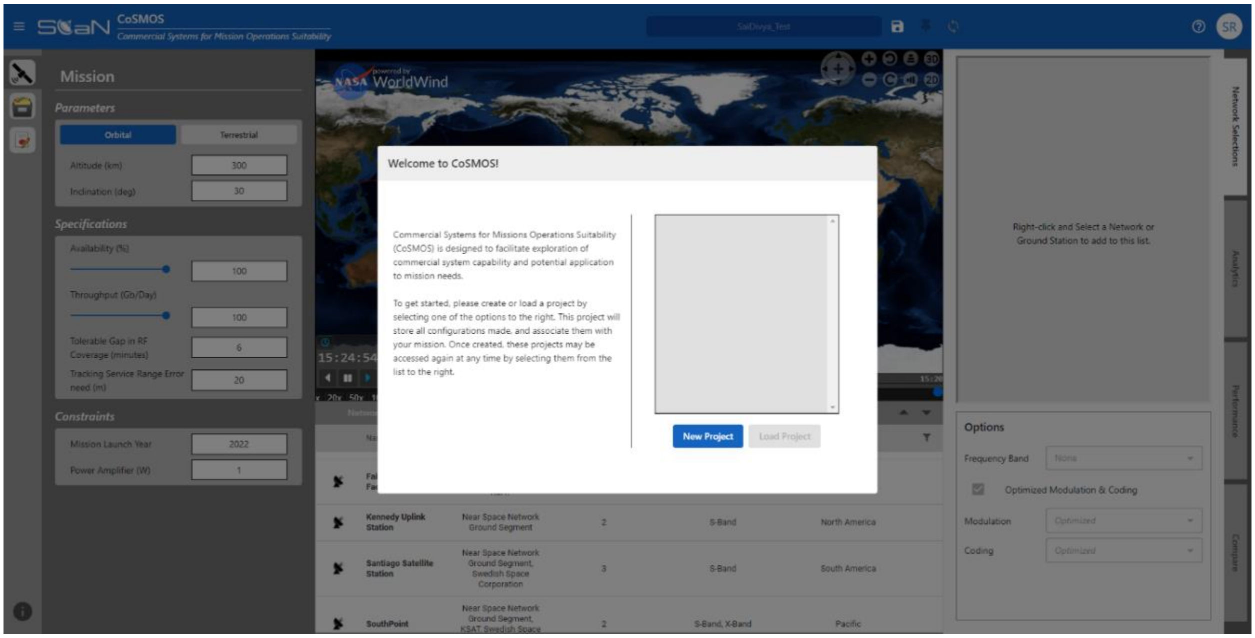


Figure 13-1: New Project Dialog Box

Step 2: Enter Project Name

In the CoSMOS Project Details dialog box, enter in the desired project name, mission name, and a general description of the mission, if applicable.

For the project name we will call this Science_Mission_Scenario_1. For this mission, we will name the file Network_Analysis_1. Then, click the “Create” button to start the new project.

Note: *If this is a project that will have multiple scenarios, a suggested project name would be **project_name**_scenario_1.*

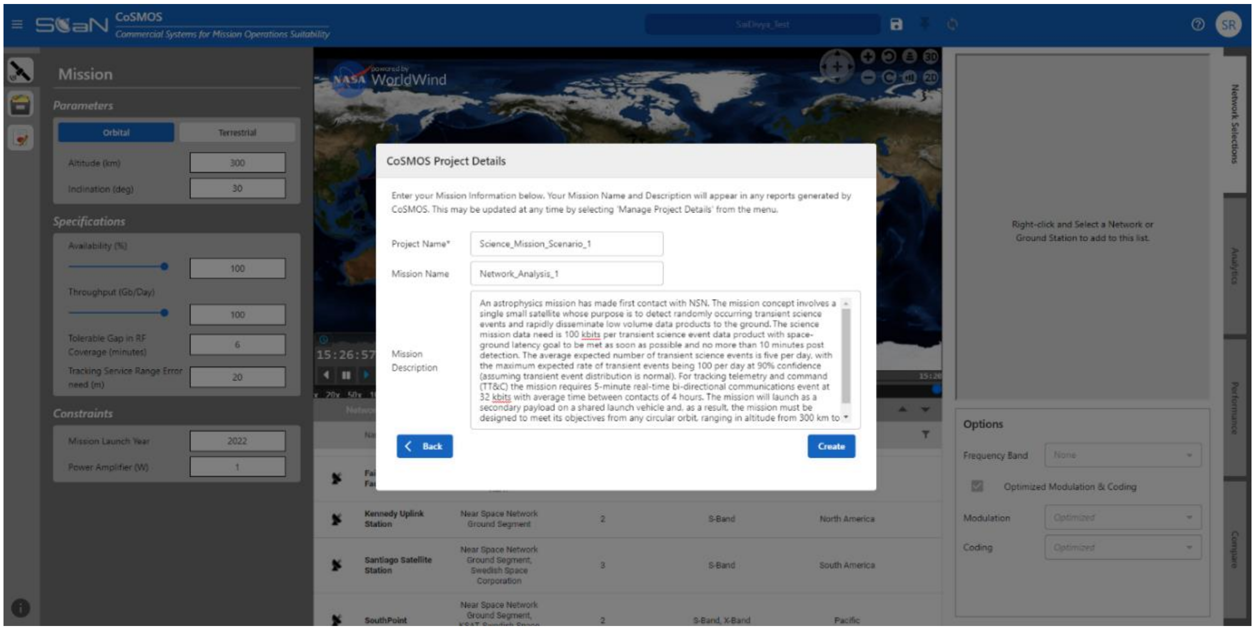


Figure 13-2: New Project Creation Dialog Box

Step 3: Enter Mission Input Parameters

Given the mission can have any number of orbits, a selection of sample cases is explored. Lower altitude orbits are anticipated to have more performance challenges because of ground terminals decreased visibility regions. Further, polar missions have the advantage of repeated passes over sites at extreme latitudes. Therefore, a user altitude of 300 km with an inclination of 0 deg is used as a starting point for a worst-case assessment.

In the Mission Parameters Panel (Figure 13-3), leave the user choice at orbital and enter an altitude of 300 km and an inclination of 0 deg. In the Mission Specifications panel, enter the mission’s desired availability as 100% and enter a throughput of 0.01 Gb/day. Inside of the mission specifications panel, set the tolerable gap in RF coverage to 10 minutes and leave the tracking service range error as the default value. Finally, in the mission constraints panel, leave the mission launch year as the default value of 2022, and the power amplifier as the default value of 1 watt.

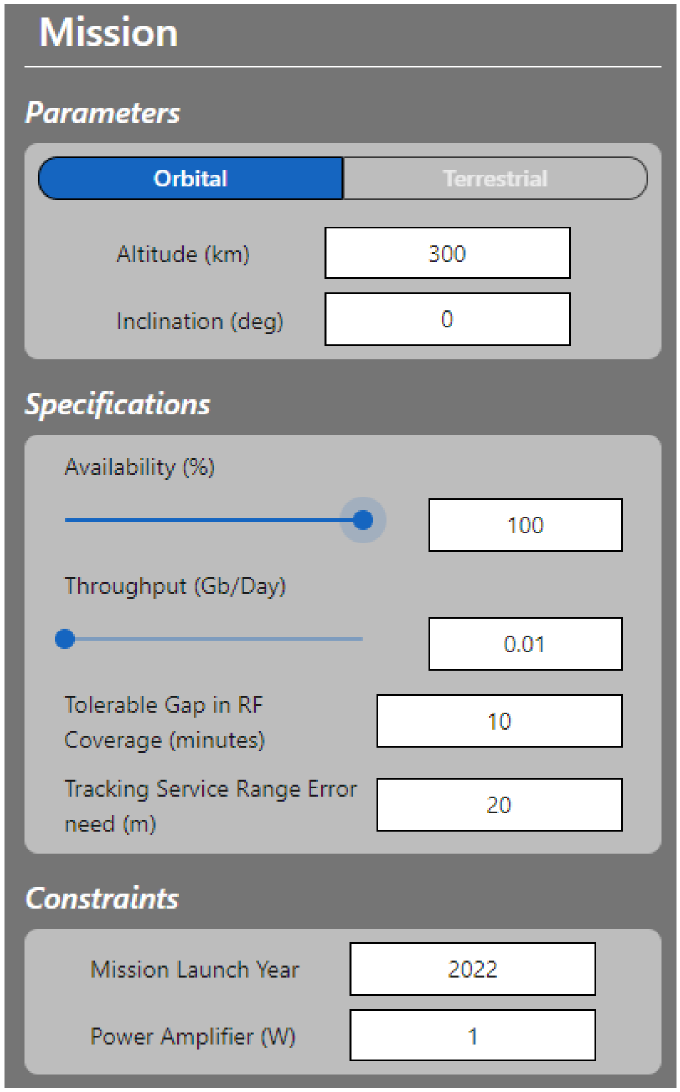


Figure 13-3: Mission Input Panel

Step 4: Select DTE Network Providers

At the bottom of the 3-D visualization of the Earth, the Network Options Panel is visible. Open the Network Selection Tab to display that panel. Given the challenge of meeting the latency requirement we begin by assuming a multi-station solution; right-click and select the entire KSAT Ground Network. This will provide a baseline to see if an entire commercial DTE network can achieve all the mission needs. Finally, choose S-band in the frequency band drop down that is in the Options section (beside the network options panel). S-band is selected based on the very low science data throughput requirements.

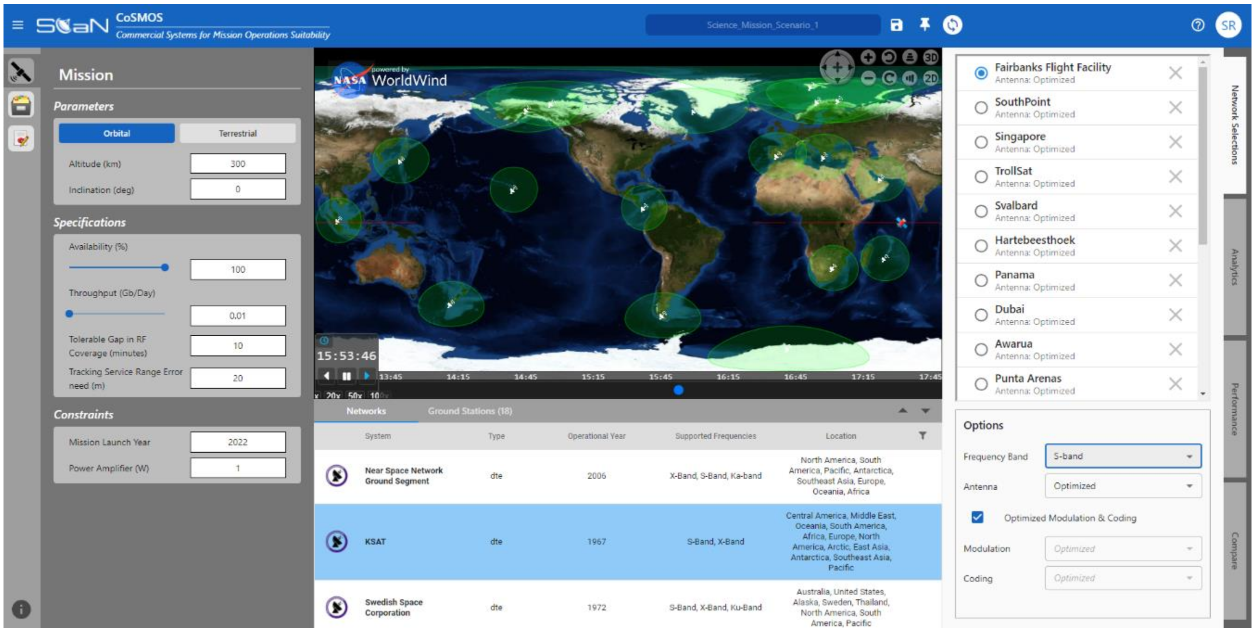


Figure 13-4: Full KSAT Network Selection

Step 5: Run DTE Analysis

Click on the run analyses button on the top right of the title bar (Figure 13-5).

Analysis Notes: *If this combination analysis has not been previously run it will take about 2-3 hours for this to complete. However, if this combination has been run previously it will take about 5 minutes for CoSMOS to retrieve the results.*

Since the mission does not require a specific modulation and coding, CoSMOS will employ its optimization algorithm and automatically choose the antenna with the best visibility, data rate, and modulation & coding.

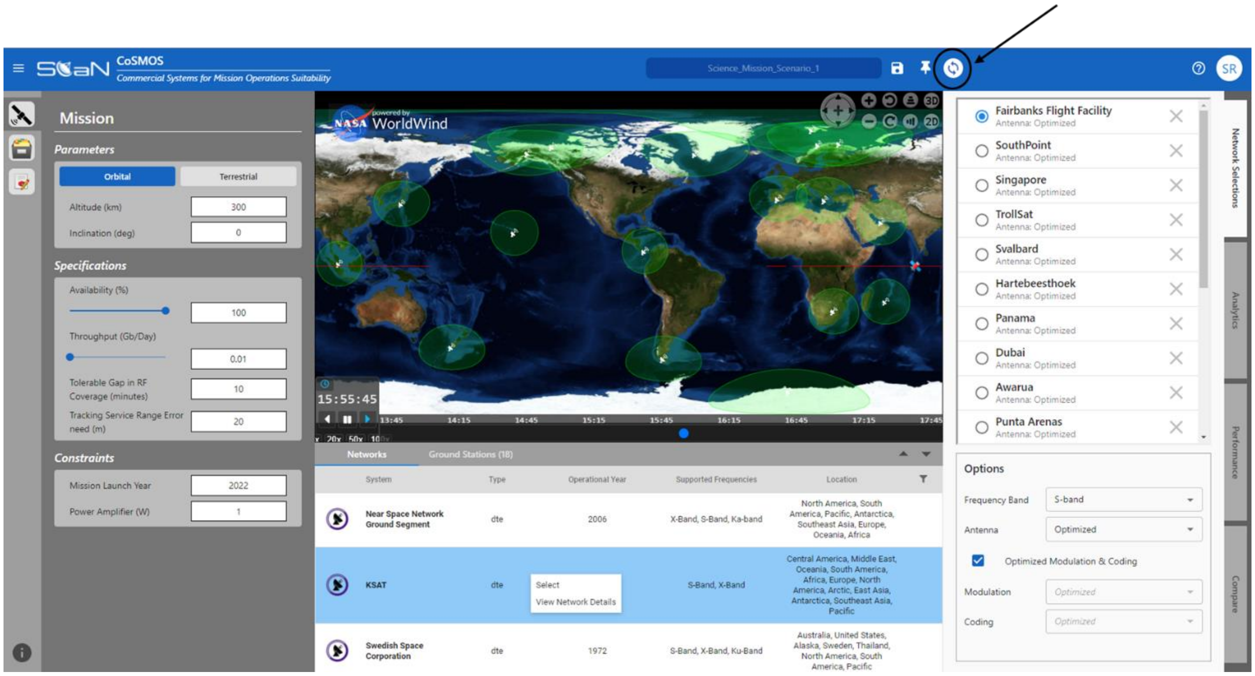


Figure 13-5: Run Full DTE Network Analysis

Step 6: Analyze DTE Performance Parameters

Once the KSAT network combination analysis has been completed, open the performance tab to observe the latency metrics (i.e., Average Gap, Max Gap, and Mean Response Time) for a 300 km / 0 deg user. An example of the visibility regions for a 300 km user can be seen in Figure 13-6 below. The antenna footprints are based on altitude only, and do not consider inclination; this provides the user visibility of all the stations selected, even if the station does not have visibility of the mission based on its inclination.

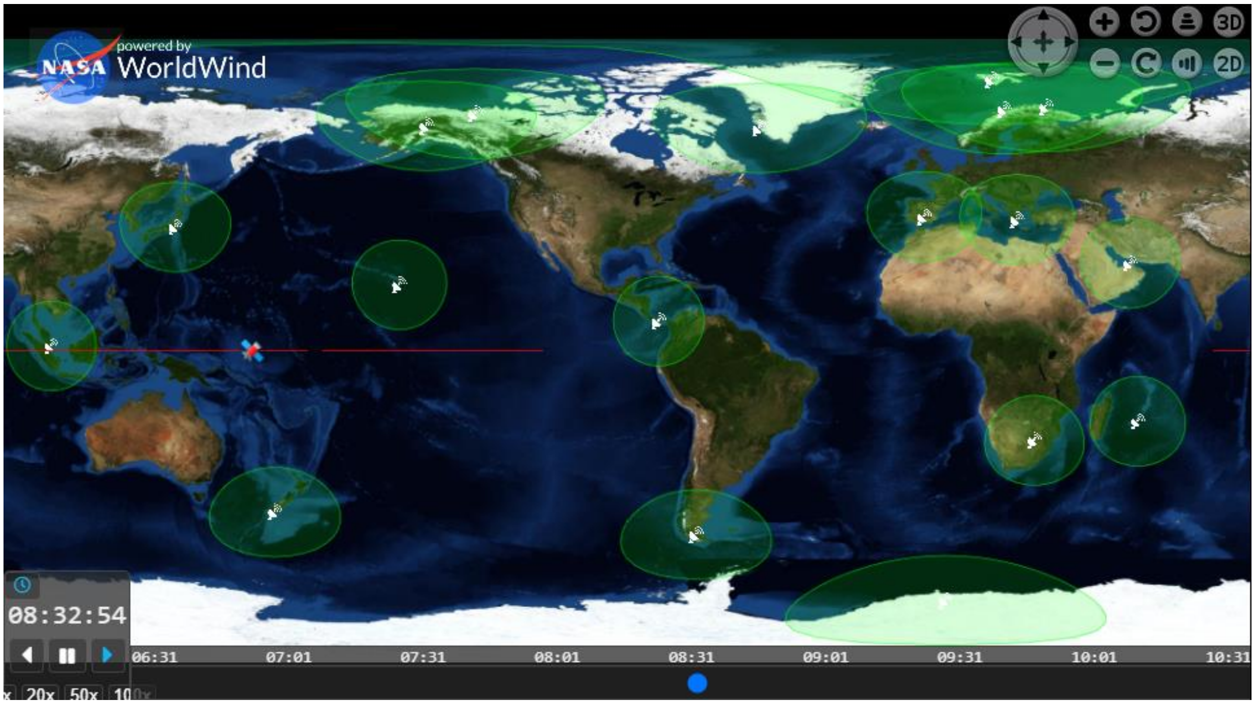


Figure 13-6: KSAT Antenna Visibility for 300 km User

Click on the Average Gap performance metric to expand the regression plot for the 300 km / 0 deg user. Then, click on the on the pop-out button on the top right of that plot and select the 3-D regression plot option. This will give the user visualization of the complete altitude / inclination space for this key latency metric as shown in the figure below. Complete this for the Max Gap and Mean Response Time metrics to observe the overall trend in the latency metrics.

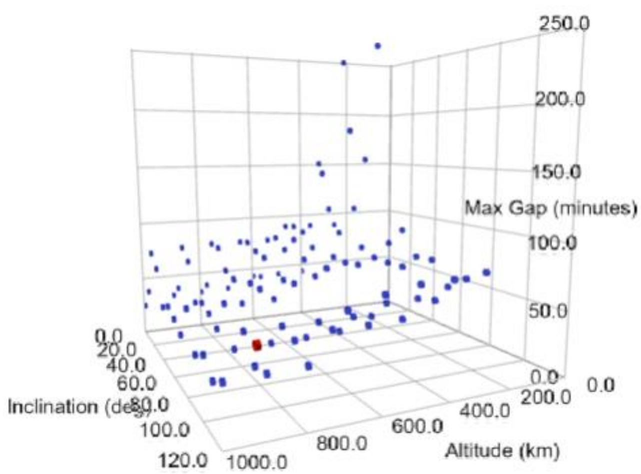


Figure 13-7: 3-D Average Gap Plot for Full KSAT Network Analysis

Analysis Notes: *From observing the 3-D plots for each latency metric higher altitude, users will have increased visibility regions and therefore better overall performance. One of the best high-altitude users is at 850 km / 93 deg and this is used as our best-case user.*

Step 7: Run Multiple Altitude and Inclination Users

The 10-minute science latency objective is challenging to meet even with a complete DTE network. For the best-case user at 850 km / 93 deg inclination, there is an average gap of 9 minutes and a mean response time of 3 minutes. Even the best-case user has a max gap of 39 minutes, which far exceeds the 10-minute latency requirements of the mission. Results for a set of bounding mission altitudes and inclinations, across the target metrics are shown for the complete KSAT network in Table 13-3.

Table 13-3: KSAT Full Network Combination Performance Outputs

User Altitude / Inclination	Max Gap (min)	Average Gap (min)	Mean Response Time (min)	Average Contact Duration (min)	Throughput (Gb/Day) (CoSMOS)[2]
300 km / 0 deg	43.5	42.2	18.5	5.9	84.3
300 km / 30 deg	111.5	27.3	23.1	5.4	131.8
300 km / 60 deg	88	21.2	14.6	5.4	152.9
300 km / 93 deg	80.3	16.4	11.7	5.9	209.9
850 km / 0 deg	32.3	16.8	7.0	11.0	282.8
850 km / 30 deg	78.3	15.2	8.1	13.3	349.6
850 km / 60 deg	48.3	10.8	3.9	14.9	429.4
850 km / 93 deg	39.2	9.4	3.2	15.9	489.3

Analysis Notes: *As expected, meeting the 10-minute science latency requirement for a multi-station DTE solution is not possible as our available station model has gaps that exceed this requirement. The KSAT network (all sites) does not meet the science requirement.*

Step 8: Evaluate TT&C Performance

The next evaluation is the ability to meet the 4-hour average time between contacts for TT&C – a far less demanding objective than the 10-minute science data latency threshold. Enter the worst-case user altitude of 300 km / 0 deg and click on the “Run Analysis” button on the top right-hand side of the main panel beside the status bar . Then, click on the comparison tab to view all KSAT Ground Stations and their performance metrics side by side and observe the stations that do and do not have RF coverage for that user. Repeat this same process with a variable altitude for the bounding mission orbits. The results are summarized in Table 13-4.

Table 13-4: KSAT Individual Station Variable User RF Coverage Outputs

User Altitude / Inclination	# of Sites with Coverage	Worst Site – Minutes Per Day	Best Site – Minutes Per Day
300 km / 0 deg	2	Panama – 75	Singapore – 103
300 km / 30 deg	9	Tokyo – 11	Mauritius – 39
300 km / 60 deg	17	Trollsat – 5.4	Punta Arenas – 37
300 km / 93 deg	18	Panama - 12	Svalbard – 68
850 km / 0 deg	4	Mauritius - 97	Panama – 174
850 km / 30 deg	14	Inuvik - 28	Panama – 97
850 km / 60 deg	18	Inuvik – 25	Awarua – 85
850 km / 93 deg	18	Nemea - 27	Trollsat – 149

Step 9: Create Other DTE Network Configurations

Navigate back to the network selection tab and observe the Ground Stations that are part of KSAT's network. Based on individual performance, a set of combined station configurations were selected to illustrate the analyses process: a minimal combination of 2 sites maximizing performance for high (A) and low (B) inclinations; two 3-site configurations blending high and low inclination capability (C, D); and a configuration combining high and low inclination support stations with mid-latitude options (E). A visualization for combination E can be seen in Figure 13-9.

- (A) → TrollSat; Svalbard
- (B) → Panama; Singapore
- (C) → TrollSat; Svalbard; Panama
- (D) → Svalbard; Punta Arenas; Singapore
- (E) → TrollSat; Svalbard; Punta Arenas; Tokyo; Panama; Singapore

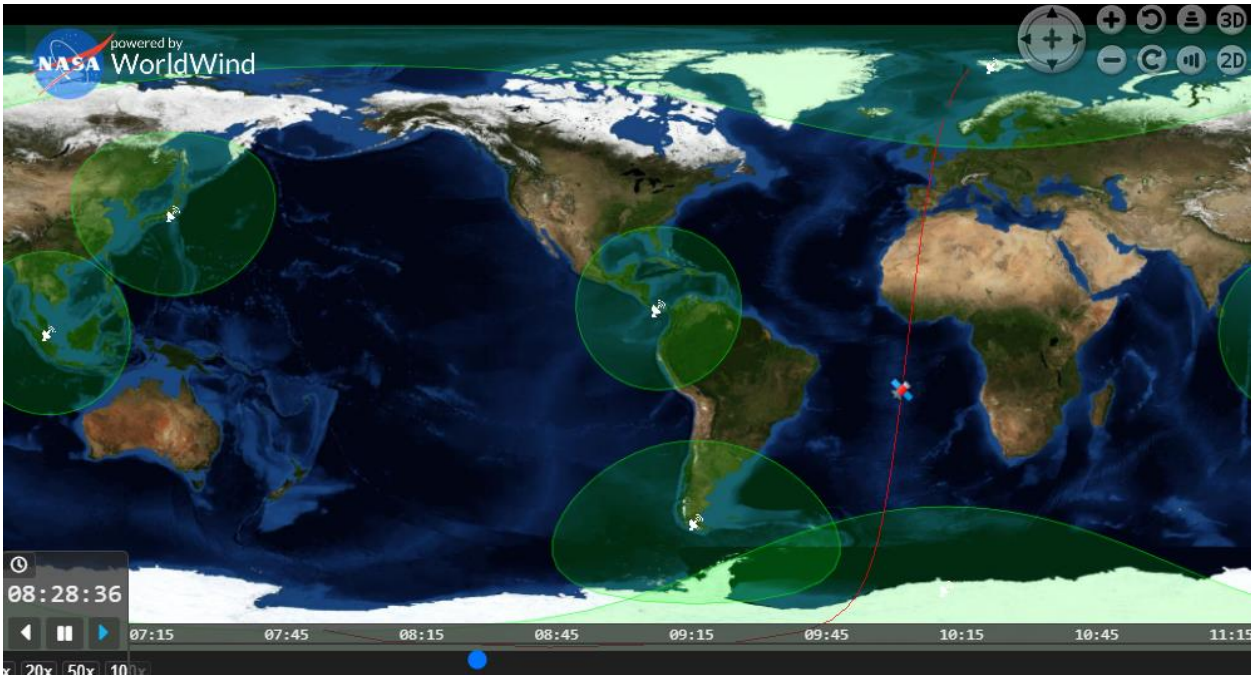


Figure 13-8: DTE Combination E Antenna Visibility

Step 10: Run Analysis on Other DTE Network Configurations

To run the first combination, delete all Ground Stations in the network selection tab, except for Svalbard and TrollSat by clicking the *"X"* beside the station name. In the mission parameters dialog box, enter a user altitude of 300 km and an inclination of 0 degrees, then click on the "Run Analysis" button. Once the analysis has been completed, click the "Save" for comparison button, and open the performance tab to review the TT&C performance metrics.

Analysis Notes: *Because these are polar stations and the user altitude / inclination entered was equatorial, there are no outputs for most of the performance metrics.*

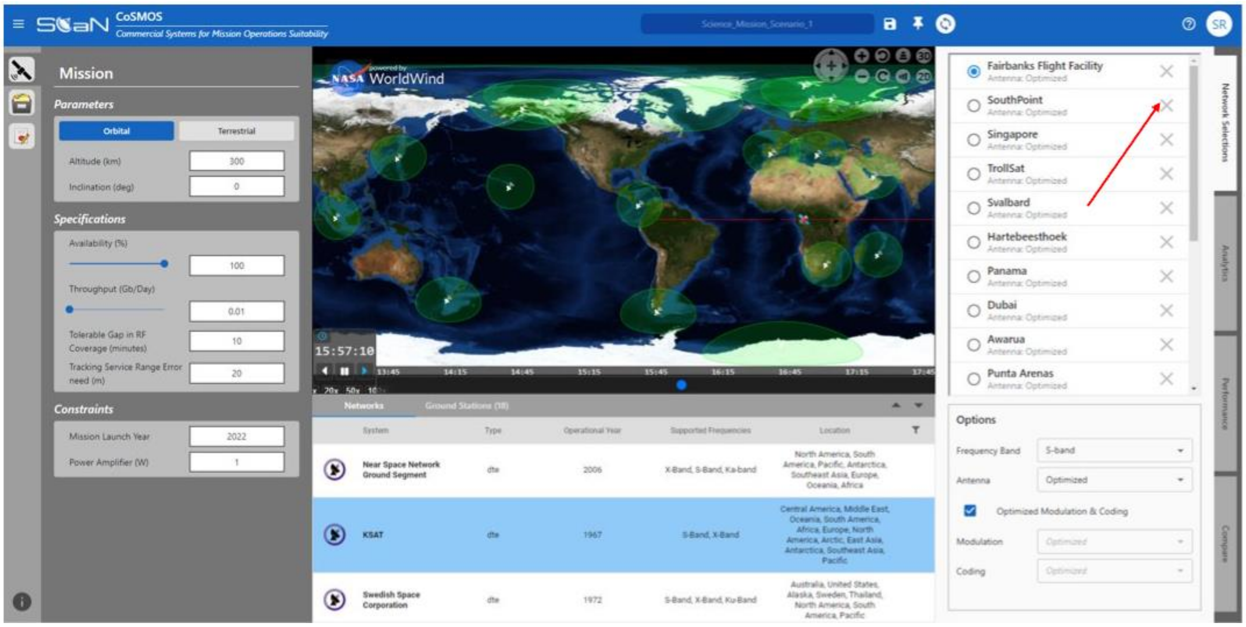


Figure 13-9: Deletion of Ground Stations

Step 11: Run Analysis on Other DTE Network Configurations (Cont.)

Once the analysis of the first combination has been completed for the desired range of users, open the Network Selection tab, and delete the Svalbard and TrollSat Ground Stations. Navigate back to the Network Library and click on the Ground Stations filter option to display all of the available DTE Ground Stations. Locate Panama and Singapore, then right-click and select each of those, so they appear in the network Selection Dialog box. If the user altitude and inclination has been changed from the original worst-case user, then, in the mission parameters dialog box, enter a user altitude of 300 km and an inclination of 0 deg, then click on the "Run Analysis" button and save the combination for comparison.

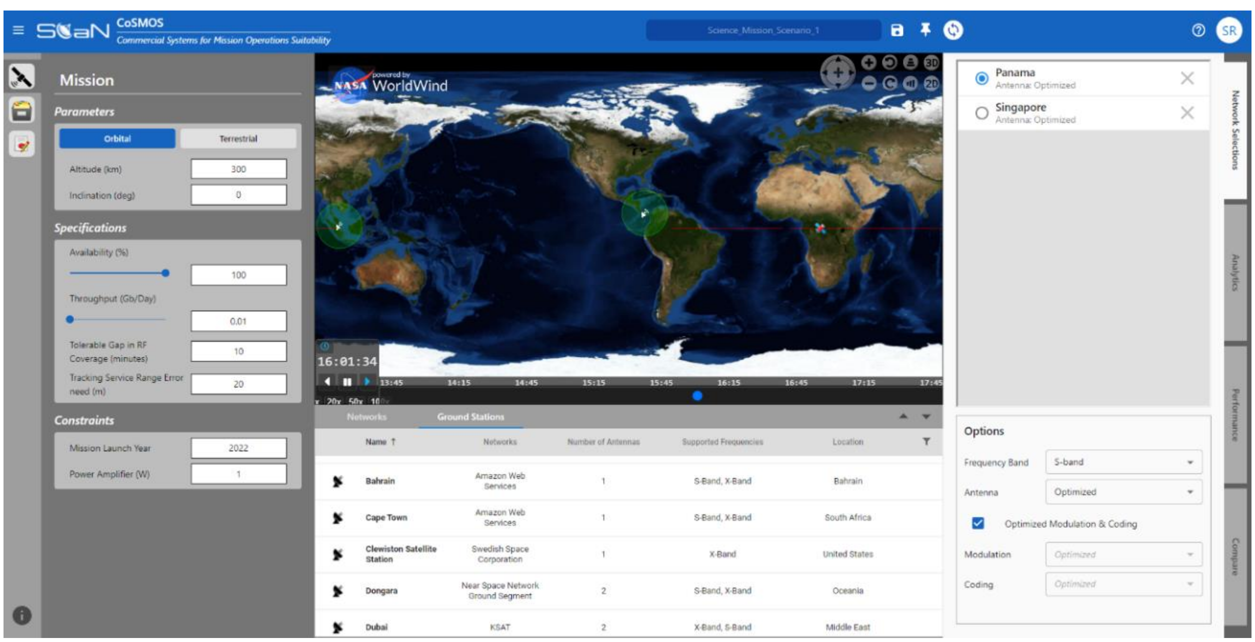


Figure 13-10: DTE Combination B

Step 12: Observe DTE Performance Parameters for Other Networks Configurations

Once the analysis is complete, open the performance tab and observe the TT&C performance metrics. Complete the same analysis for the desired range of users for this station combination, and repeat the same process denoted in **Steps 10-11** for the remaining Ground Station combinations.

Analysis Notes: *These configurations were used to assess metrics across the range of user cases – two examples for the completed analysis of station combinations A through E are shown in Table 13-5 and Table 13-6 below.*

Table 13-5: Assessment for Mission Configuration 300 km / 0 deg

	Network Ground Station Configuration	Max Gap (min)	Average Gap (min)	Mean Response Time (min)	Average Contact Duration (min)	Throughput (Gb/Day)
A	Trollsat, Svalbard	43200.0	43200.0	43200.0	0.0	0.0
B	Panama, Singapore	43.5	42.2	18.5	5.9	84.3
C	Trollsat, Svalbard, Panama	91.5	91.2	43.3	5.0	22.5
D	Svalbard, PA, Singapore	89.5	89.1	41.5	6.9	61.8
E	Trollsat, Svalbard, PA, Tokyo, Panama, Singapore	43.5	42.2	18.5	5.9	84.3

Table 13-6: Assessment for Mission Configuration 850 km / 93 deg

	Network Ground Station Configuration	Max Gap (min)	Average Gap (min)	Mean Response Time (min)	Average Contact Duration (min)	Throughput (Gb/Day)
A	Trollsat, Svalbard	57.1	40.9	17.2	11.9	200.3
B	Panama, Singapore	598.1	180.6	228.9	13.6	35.7
C	Trollsat, Svalbard, PA	55.3	33.8	14.5	11.8	212.1
D	Svalbard, PA, Singapore	83.5	46.8	25.7	11.6	172.2
E	Trollsat, Svalbard, PA, Tokyo, Panama, Singapore	55.3	21.9	10.3	12.3	283.7

Step 13: Observe Performance Parameters for DTE Case E

Leave the Ground Stations for combination E in the network selection panel; do not delete these, as they are used for a further assessment in **Step 16**. The 4-hour average (240 minute) latency is met by Combinations B, C, D, and E, using the mean response time metric as the discriminator. The 5-minute contact durations are met except for combination A for an equatorial orbiting user. Finally, the TT&C throughput objective (max 0.192 Mb/day) is very low and can be met across all sample cases. However, upon review of the complete set of mission user test points, only Configuration E meets the latency, contact and throughput objectives.

Step 14: Observe User Burden: Antenna Options for DTE Combination E

In the mission parameters panel, enter in a user altitude of 300 km and an inclination of 0 deg and click on the "Run Analysis" button. When the analysis is complete, click on the Performance tab and open the *User Burden: Antenna Options Dialog Box* to review the user burden metrics for configuration E. Observe the calculated EIRP, Parabolic Antenna Diameter, Helical Antenna Height, Path Antenna Size, etc. Repeat the same process for the desired range of users. Examples of output from CoSMOS can be seen in Table 13-7 and Table 13-8.

Table 13-7: Assessment for Mission Configuration 300 km / 0 deg

Network Ground Station Configuration	EIRP (dBW)	Parabolic Antenna Diameter (m)	Helical Antenna Height (m)	Patch Antenna Size (m^2)	Dipole Antenna Size (m)	Operational Year
Trollsat, Svalbard; PA, Tokyo; Panama, Singapore	7.95	0.13	0.07	0.002	0.16	1967

Table 13-8: Assessment for Mission Configuration 850 km / 93 deg

Network Ground Station Configuration	EIRP (dBW)	Parabolic Antenna Diameter (m)	Helical Antenna Height (m)	Patch Antenna Size (m^2)	Dipole Antenna Size (m)	Operational Year
Trollsat, Svalbard; PA, Tokyo; Panama, Singapore	13.65	0.26	0.25	0.002	0.16	1967

A parabolic antenna is not a practical solution because of its small size (0.13 meter for 300 km / 0 deg orbit and 0.26 meter for 850 km / 93 deg orbit). A patch antenna is also not practical (0.002-meter square for both 300 km / 0 deg orbit and for 850 km / 93 deg orbit).

Analysis Notes: *A helical or a dipole antenna are practical options for TT&C service via our ground terminal service configuration.*

Step 15: Delete All Remaining DTE Ground Stations

Like DTE Networks, for Commercial Relay networks, it's anticipated that the science latency requirement of 10-minutes is the most challenging requirement. Max gap, average gap, and mean response time are evaluated, with max gap as the discriminator. To start the relay analysis, click on the Network Selection Panel and delete all remaining Ground Stations from combination E. Once this has been completed, navigate back to the Network Library Panel in the center of the screen and select the Networks Filtering tab.

Step 16: Select Relay Networks

Scroll through the network library, highlight each commercial network individually, and click on the "Save for Comparison" button to save the first ten commercial relay networks. When the eleventh relay network has been selected, right-click and select the network so that it appears in the network selection panel, and then proceed to Step 17.

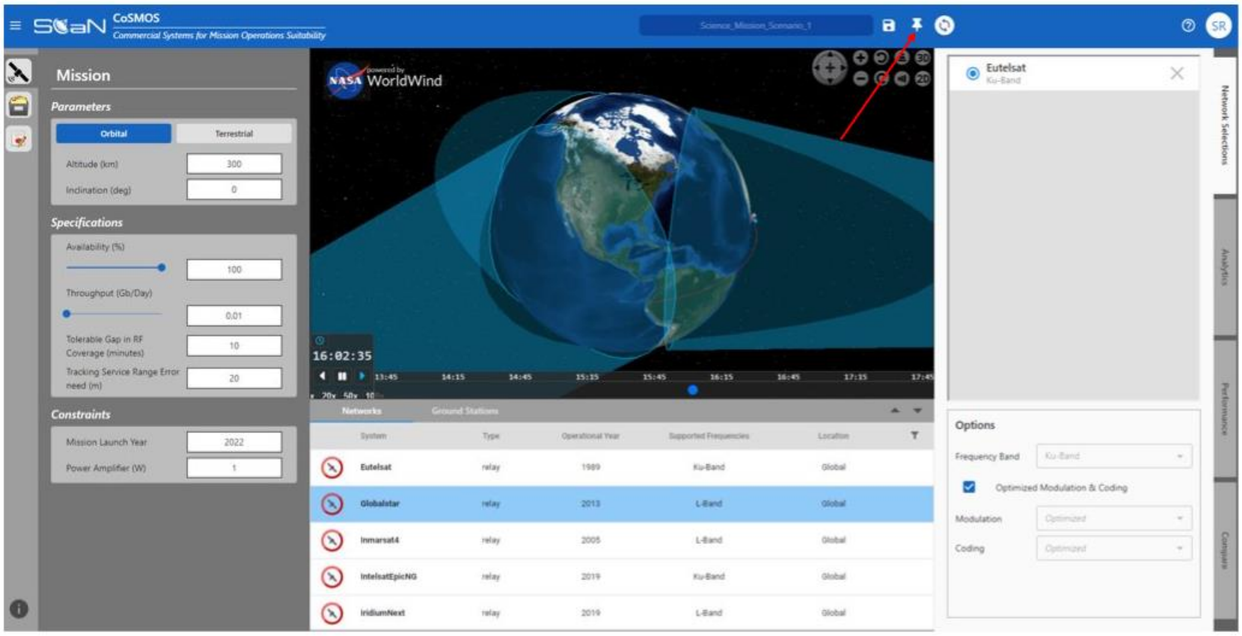


Figure 13-11: Saving Relay Systems for Comparison

Step 17: Enter Relay Mission User Parameters

Once all commercial relay networks have been added to the network selection panel, navigate back to the Mission Parameters dialog box and enter in the mission altitude of 300 km at an inclination of 0 deg. Do not change any of the other input parameters, and then click on the "Run Analysis" button. This sample mission point at the lowest inclination will represent the most challenging link closure case for the relay networks, and the 0-deg inclination means we can anticipate good visibility from most relays, as opposed to polar orbiting missions, which may not receive coverage from relay constellations in low inclinations or in geosynchronous orbit.

Step 18: Observe Relay Performance Parameters for all Networks

When the analysis has been completed, open the Performance tab and observe the Max Gap, Average Gap, Mean Response Time, Average Contact Duration, and Throughput for each relay system. Repeat prior steps for a challenging mission user at an altitude of 850 km and an inclination of 93 deg. The performance results for the specified metrics of these two users can be observed in Table 13-9 and Table 13-10; the systems that passed all mission requirements are highlighted in green.

Table 13-9: Target Metrics for 300 km / 0 deg User

Relay Networks	Max Gap (min)	Average Gap (min)	Mean Response Time (min)	Average Contact Duration (min)	Throughput (Gb/Day)
Eutelsat	7.5	7.4	16.9	57.4	235.0
Globalstar	0.0	0.0	0.0	4.3	14.0
Inmarsat-4	0.0	0.0	0.0	1,079.6	42.5
IntelsatEpicNG	0.0	0.0	0.0	5.4	3000.0
IridiumNext	18.2	2.2	1.2	2.3	18.0
O3b mPOWER	0.0	0.0	0.0	943.7	8,444.0
OneWeb MEO	0.0	0.0	0.0	41.7	2,089.0
SpaceX 1110	0.0	0.0	0.0	1,221.5	86,201.0
Viasat3	0.0	0.0	0.0	860.9	8,640.0
O3b Legacy	0.0	0.0	0.0	1,052.2	8,640.0
Inmarsat-5	0.0	0.0	0.0	1,076.7	430.7

Table 13-10: Target Metrics for 850 km / 93 deg User

Relay Networks	Max Gap (min)	Average Gap (min)	Mean Response Time (min)	Average Contact Duration (min)	Throughput (Gb/Day)
Eutelsat	57.4	30.1	6.7	82.9	5,081.0
Globalstar	33.9	14.6	12.0	0.95	1.7
Inmarsat-4	8.9	0.0	0.0	9.1	31.3
IntelsatEpicNG	126.5	20.0	32.7	3.4	1,068.0
IridiumNext	*N/A	*N/A	*N/A	*N/A	*N/A
O3b mPOWER	49.3	35.8	18.1	17.6	3,189.0
OneWeb MEO	17.4	9.2	3.2	10.5	1,342.0
SpaceX 1110	20.3	2.7	3.0	6.3	20,164.0
Viasat3	35.9	29.5	6.8	60.3	173.0
O3b Legacy	32.7	31.8	10.1	21.9	3,180.0
Inmarsat-5	0.86	0.0	0.0	154.7	430

* IridiumNext will not have results for 850 km as its constellation orbits at 770 km

Analysis Notes: *For the 300 km / 0 deg user, Eutelsat and Iridium Next do not meet the latency needs. However, the contact durations required for TT&C are easily met, except for Globalstar and IridiumNext. All commercial systems can meet the throughput requirement of 0.01 Gb/Day*

For 850km / 93 deg users, the 10-minute science latency cannot be met, using max gap as not-to-exceed, by any of the networks except for Inmarsat-4 and Inmarsat-5. The 4-hour latency for TT&C is fully supportable by any of the networks, but contact durations are too short for Intelsat and Globalstar. Throughput again is not a challenge for any of the networks.

The Inmarsat-4 mean contact time passes the threshold but is low enough to warrant additional investigation.

Step 19: Delete all Relay Networks That Fail Mission Requirements

Now that we have seen that only Inmarsat-4 and Inmarsat-5 meet all mission requirements, the low average contact time warrants additional investigation into Inmarsat-4's coverage statistics. To do this, navigate back to the network selection panel, delete any commercial relay systems that may be in that panel, then right-click and select Inmarsat-4. Once Inmarsat-4 has been selected, click the "Run Analyses" button. Once the analysis has been refreshed, click on the Analytics tab to observe the coverage statistics for the 850 km / 93 deg user, as seen in Figure 13-12 below.

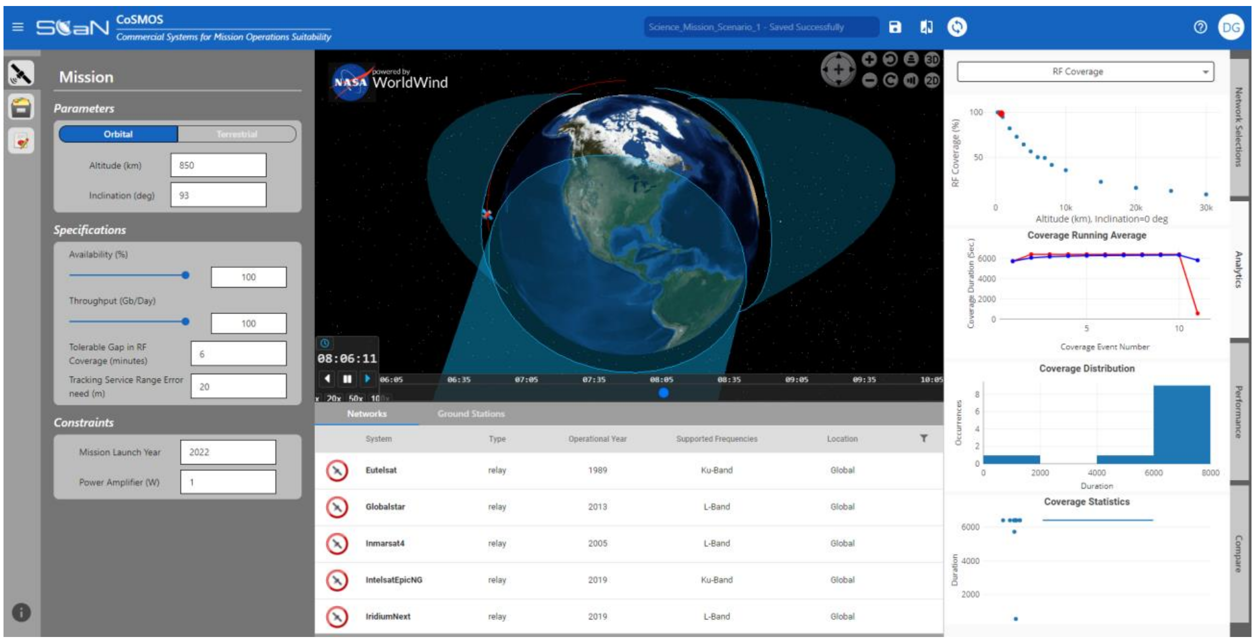


Figure 13-12: Coverage Analytics Visualization

Step 20: Further Analysis of Performance Metrics Using the Analytics Tab

Once the Analytics tab is open, it is key to note that the coverage analytics can only be viewed for modeled data points based on an 18-hour simulation time. If a user does not fall on a modeled point, a nearby point can be selected to assess. For Scenario 1, select an 800 km / 90 deg user to observe the Coverage Running Average plot and the Coverage Statistics plot, as seen in Figure 13-13 below.

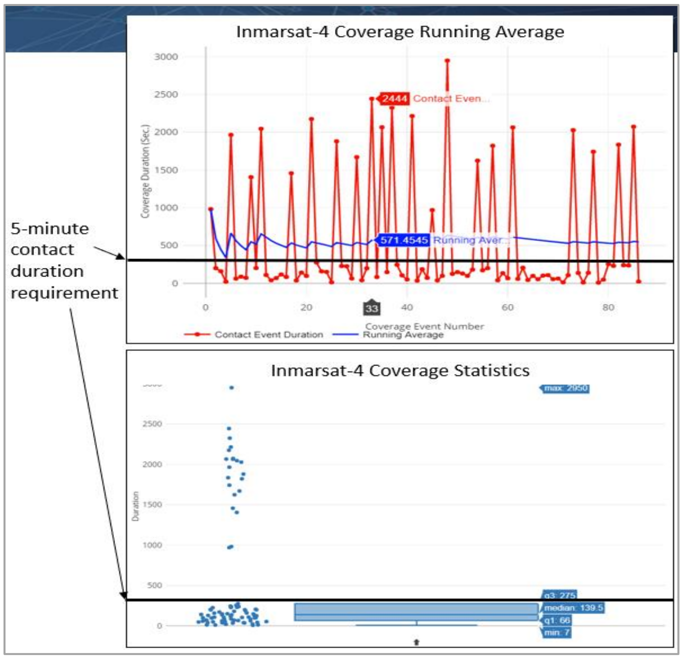


Figure 13-13: Coverage Analytic Visualization for 800 km / 90 deg User

Analysis Notes: *Although mean contact duration appeared satisfactory, the simulation results for a representative user indicate most contacts are less than 5-minutes. However, the periodicity of the longer duration contacts meets the 4-hour latency objective for TT&C and Inmarsat-4 remains a potential mission solution.*

Step 21: De-Select Inmarsat-4

Navigate back to the Network Selection tab and de-select the Inmarsat-4 network. Then in the mission parameters tab enter the mission altitude of 300 km and 0 deg inclination and click on the “Run Analyses” button. Once the analysis has been refreshed, select the Comparison tab.

Step 22: Observe User Burden: Antenna Options for Inmarsat-4 and Inmarsat-5

Once inside the Comparison tab, navigate down to the User Burden: Antenna Options dialog box and open it to view the results for Inmarsat-4 and Inmarsat-5. Observe the EIRP, Parabolic Antenna Diameter, Helical Antenna Height, Patch Antenna Size, etc. Repeat **Step 21** and **Step 22** to view the User Burden results for the 850 km / 93 deg user. The results from these users are compared in Table 13-***12***.

Table 13-11: Best and Worst-Case User Burden Metrics

User Altitude / Inclination	System	EIRP (dBW) [Note 1]	Parabolic Antenna Diameter (m)	Helical Antenna Height (m)	Patch Antenna Size (m2)	Dipole Antenna Size (m)	Operational Year
300 km / 0 deg	Inmarsat-4	8.2	0.29	0.23	0.003	0.23	2006
	Inmarsat-5	11.1	0.37	6.8	0.003	0.005	2014
850 km / 93 deg	Inmarsat-4	8.10	0.29	0.22	0.003	0.09	2006
	Inmarsat-5	10.9	0.37	6.7	0.003	0.005	2014

Analysis Notes: The antenna calculations that are "grayed" out are not optimal solutions for the noted commercial network.

Step 23: Save Mission Project

On the top right-hand side of the main panel, next to the status bar, click on the "Save" button to save this mission configuration. Once the "Save" button has been clicked, ensure that the status bar states, *"Mission_Scenario_1 – Saved Successfully."* ***[Future Release]***

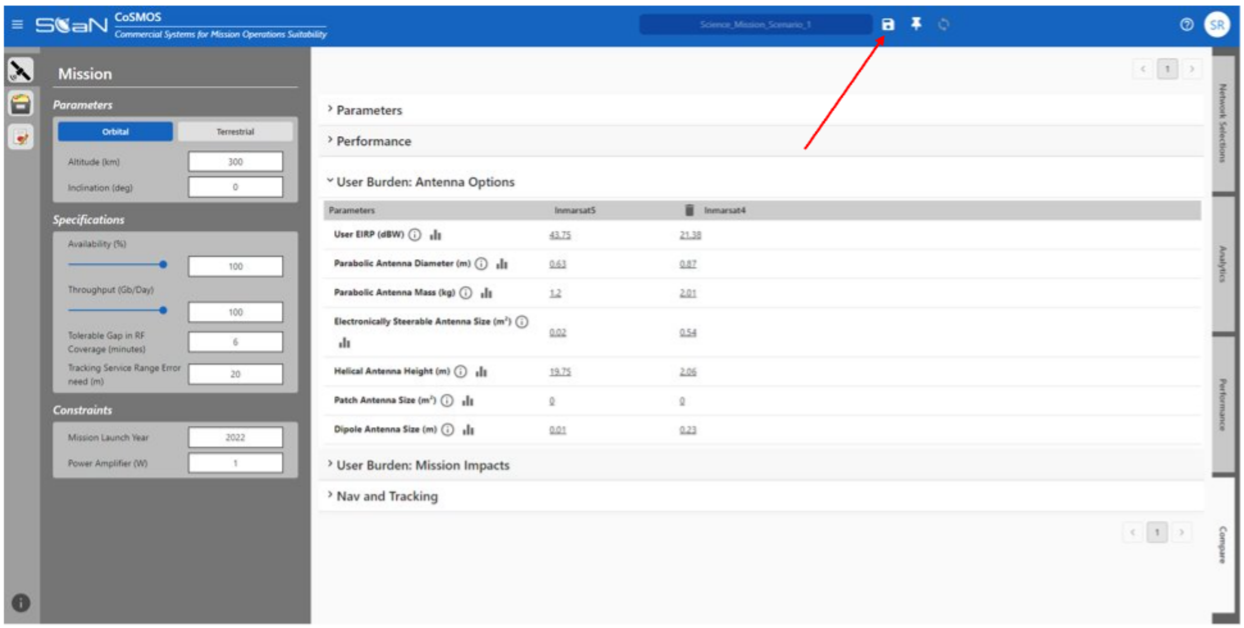


Figure 13-14: Saving Mission Project

Results and Conclusions

TT&C Service Objectives could be met by DTE Ground Station services from combinations of KSAT locations: TrollSat, Svalbard, Punta Arenas, Panama, Tokyo, and Singapore (Combination E). Inmarsat-4 and Inmarsat-5 meet all mission objectives – both science data and TT&C –for the potential span of user orbits. The key performance metrics are summarized in Table 13-***12***.

Table 13-*12*: Performance Metric Comparison for Best / Worst-Case Users

Metrics	300 km / 0 deg			850 km / 93 deg		
	Inmarsat 4	Inmarsat 5	DTE Combo E**	Inmarsat 4	Inmarsat 5	DTE Combo E**
Maximum Gap	0	0	43.5	8.8	0.86	55.3
Average Gap	0	0	42.2	0	0	21.9

Mean Response Time	0	0	18.2	0	0	10.3
Average Contact Duration (min)	1,079.4	1,076.8	5.9	28.6	154.3	12.3
Throughput (Gb/Day)	42.5	430.7	84.3	31.3	430.9	283.7
EIRP (dBW)	11.8	39.2	7.9	11.7	39.05	13.7
Parabolic Antenna Dia. (m)	0.29	0.37	0.13	0.29	0.37	0.26
Operational Year	2006	2014	1967	2006	2014	1967

CoSMOS does not generate risk assessments for any network; however, several observations can be made based on knowledge of the mission and of each of the systems that are in the system library, as summarized in Table 13-13.

Table 13-1313: Risk Summary

	Inmarsat-4	Inmarsat-5	DTE Combo E for TT&C Only
Design Risks	Commercial company, AddValue, has been offering a satellite relay service via Inmarsat-4 – first commercial user contracted with AddValue in late 2020. IDRS user terminals are available. On orbit testing and the subsequent commercial service reduces risk somewhat. GEO system – good coverage, relatively low risk from a dynamics standpoint.	GEO system – good coverage, relatively low risk from a dynamics standpoint. No user terminal available yet.	Relatively high number of Ground Stations to achieve coverage for a wide range of users to achieve TT & C mission requirements
Programmatic Risks	Spectrum use (for space-to-space relay) is currently experimental, non-interference-basis. Use of an IDRS terminal limits the user to that service. Inmarsat is an established entity and Inmarsat-4 is operational—potentially lower risk than newer entrants to the market.	Spectrum use (for space-to-space relay) is currently experimental, non-interference-basis. No user terminal available yet. Inmarsat is an established entity and Inmarsat-5 is operational– potentially lower risk than newer entrants to the market.	Scheduling contact events between multiple Ground Station locations

Mitigations	NASA will be sponsoring funded space act agreements for demonstrations of satellite communications (SATCOM) services. If Inmarsat-4 (or service intermediary like AddValue) is selected, the demonstration may buy down risk by validating capability and performance for NASA use cases.	Wideband terminal development (NASA-sponsored) may address terminal deficit. NASA will be sponsoring funded space act agreements for demonstrations of SATCOM services. If Inmarsat-5 (or service intermediary) is selected, the demonstration may buy down risk by validating capability and performance for NASA use cases.	

13.2 Scenario 2: Mission Exploration of Space-Based Relays

An Earth science mission has made first contact with the Near Space NSN. The mission concept involves a constellation of three satellites in dissimilar circular low Earth orbits:

- Satellite A Orbit: 450 km, 0 deg. inclination
- Satellite B Orbit: 300 km, 93 deg. inclination
- Satellite C Orbit: 600 km, 56 deg. inclination

The mission requires the following:

- Science Mission Data Volume: 100 Mbits daily average
- TT&C: Opportunities to schedule 5-minute real-time bi-directional communications event at 32 kbps with average time between contacts of 4 hours.

To maximize the space available for earth-facing instruments, spacecraft accommodation constraints preclude placement of a DTE antenna on the nadir side. To minimize design variation, the mission would prefer to have a common design for all user terminals. The objective of the scenario is to identify commercial space relay provider(s) that may satisfy the following mission needs, which are summarized in context of CoSMOS inputs in Table 13-14. Target outputs which will be evaluated are identified in Table 13-15.

Table 13-14: Mission Inputs

Input	Scenario 2	
	TT&C	Data
User Orbit or Location	300km/93-Deg, 450km/0deg, 600km/56deg	
Availability	5 min/contact	-
Throughput	192 kb/day	0.1 Gb/day
Latency *(Tolerable Gap in RF Coverage)*	240 min	-
User Burden: Power Amplifier	-	-
Tracking Service Range Error	-	-
Mission Launch Year	-	-

Table 13-15: Mission Outputs

Output	Scenario 2	Method
AVAILABILITY METRICS		
RF Coverage (%)		Modeled Statistics
Average RF Contacts Per Orbit		Modeled Statistics
Average RF Contact Duration (sec)	●	Modeled Statistics
Effective Comms Time (%)		Modeled Statistics

THROUGHPUT (Gb/Day)	●	CoSMOS Calculated
LATENCY METRICS		
Average RF Coverage Gap (min)	●	Modeled Statistics
Max RF Coverage Gap (min)	●	Modeled Statistics
Average Response Time (sec)	●	Modeled Statistics
USER BURDEN – ANTENNA OPTION METRICS		
EIRP (dBW)		CoSMOS Calculated
Parabolic Antenna Diam. (m)		CoSMOS Calculated
ESA Size (m^2)		CoSMOS Calculated
Helical Antenna Height (m)		CoSMOS Calculated
Patch Antenna Size (m^2)		CoSMOS Calculated
Dipole Antenna Size (m)		CoSMOS Calculated
MISSION IMPACT METRICS		
Tracking Rate (deg/s)		Modeled Statistics
Slew Rate (deg/s)		Modeled Statistics
Body Pointing Feasibility		CoSMOS Calculated
Mechanical Pointing Feasibility		CoSMOS Calculated
Tracking Service 3-sigma Range Error		Reference
GNSS Availability		Reference
OPERATIONAL YEAR		Reference + CoSMOS

Step 1: CoSMOS Log In and Project Start

The user navigates to https://cosmos.teltrium.com. When CoSMOS loads, click on the "New Project" button.

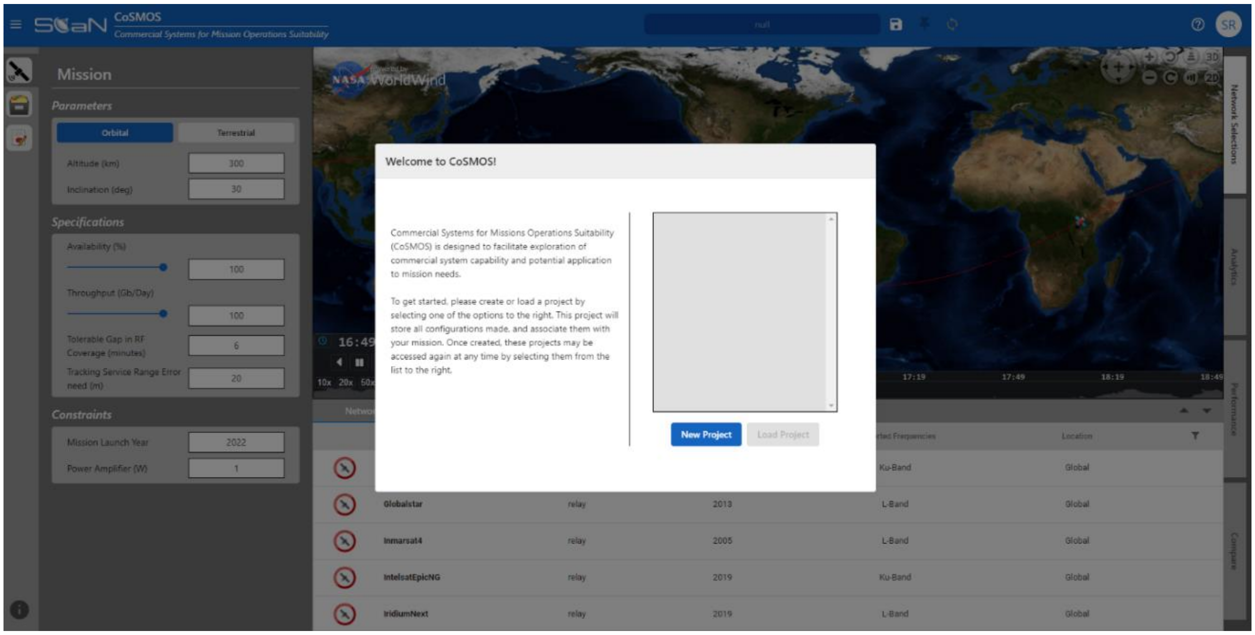


Figure 13-15: New Project Dialog Box

Step 2: Enter Project Name

In the CoSMOS Project Details dialog box, enter in the desired project name, mission name, and a general description of the mission, if applicable.

For the project name, this mission will be called Earth_Science_Mission_Scenario_1.

For this mission, the file will be named Relay_Network_Analysis_1. Then, click the "Create" button to start the new project, as shown in Figure 13-16 below.

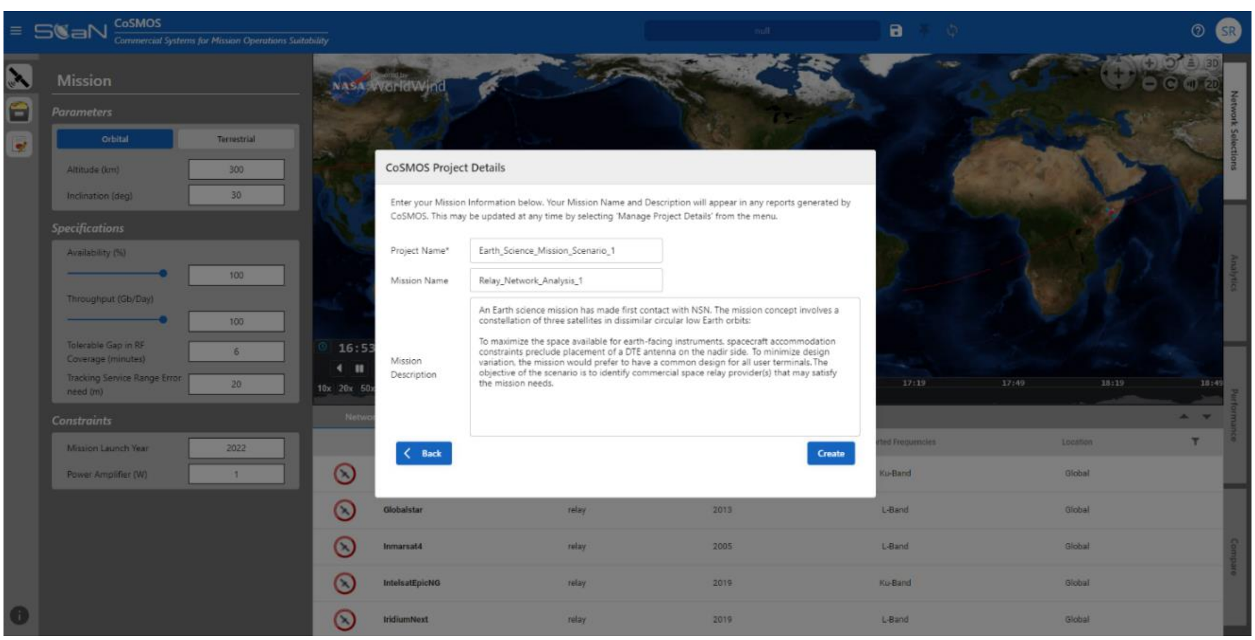


Figure 13-16: New Project Creation Dialog Box

,

Step 3: Enter SAT A Mission Input Parameters

In the Mission Parameters panel, leave the parameter selection at Orbital and enter the altitude of 450 km and an inclination of 0 deg corresponding to Satellite A. In the Mission Specifications panel enter the mission's desired availability as 100 percentage and enter a throughput of 0.1 Gb/day. Inside of the Mission Specifications panel, enter the tolerable gap in RF coverage as 240 minutes and leave the tracking service range error as the default value. Finally, in the Mission Constraints panel, leave the mission launch year as the default value of 2022, and the power amplifier as the default value of 1 Watt, as shown in Figure 13-17 below.

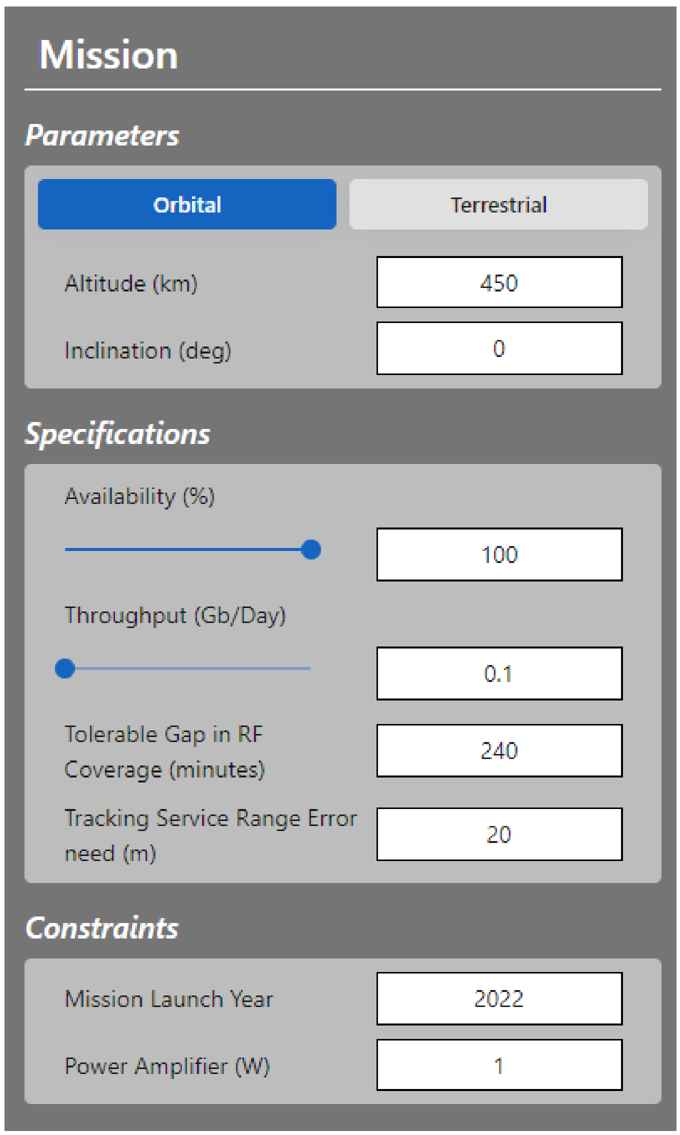


Figure 13-17: Mission Input Panel for SAT A

Step 4: Select Relay Networks

Open the Network Selection tab and then navigate back to the middle of the CoSMOS screen to the Network Library panel. Highlight each commercial relay network individually, then right-click and select that network, and then click on the “Pin this Selection for Comparison” button for each of the first ten networks. For the eleventh (last) commercial network, right-click and select it so that it appears in the Network Selection panel and move on to Step 5.

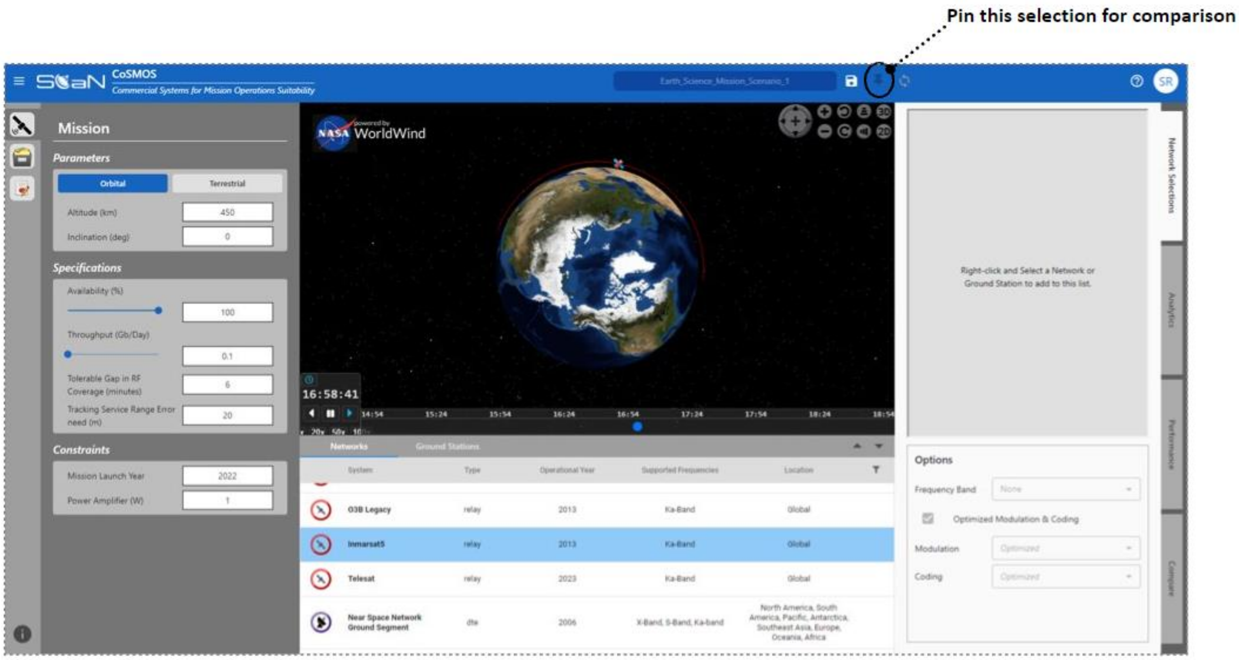


Figure 13-18: Save for comparison button

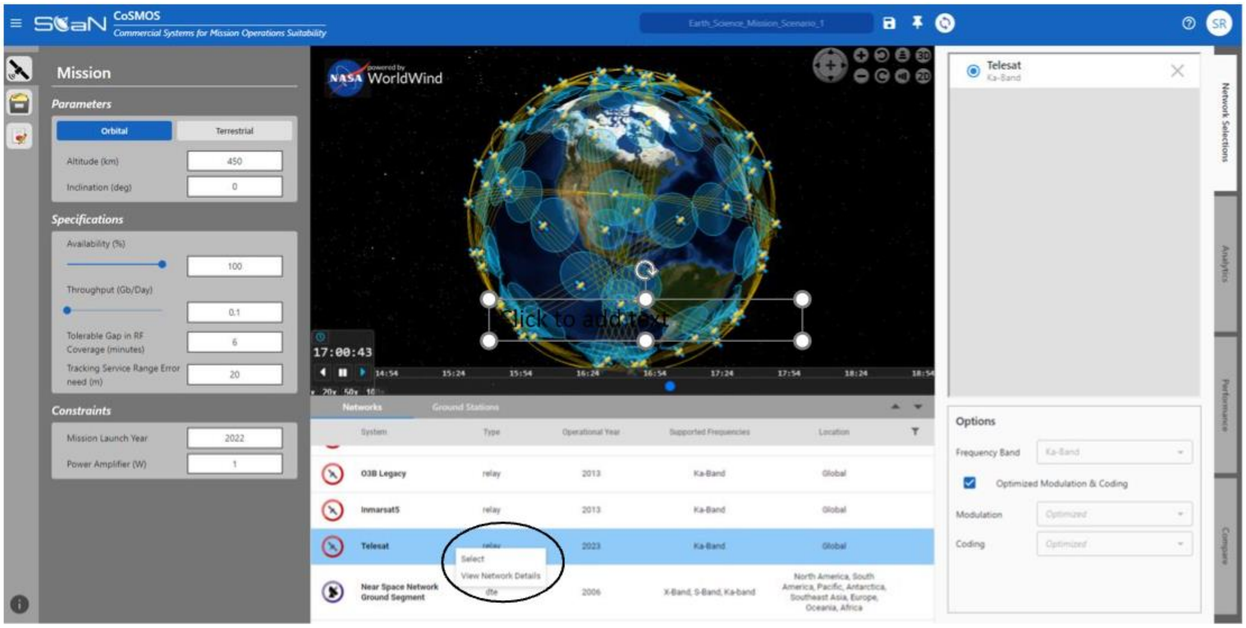


Figure 13-19: Adding Telesat to Network Selection Panel

Step 5: Run Relay Analysis

Once this has been completed, navigate back to the top of the CoSMOS screen and click on the "Refresh Analysis" button show in Figure 13-20 below.

Note: *This may take 5-7 minutes to run so grab another espresso if needed.*

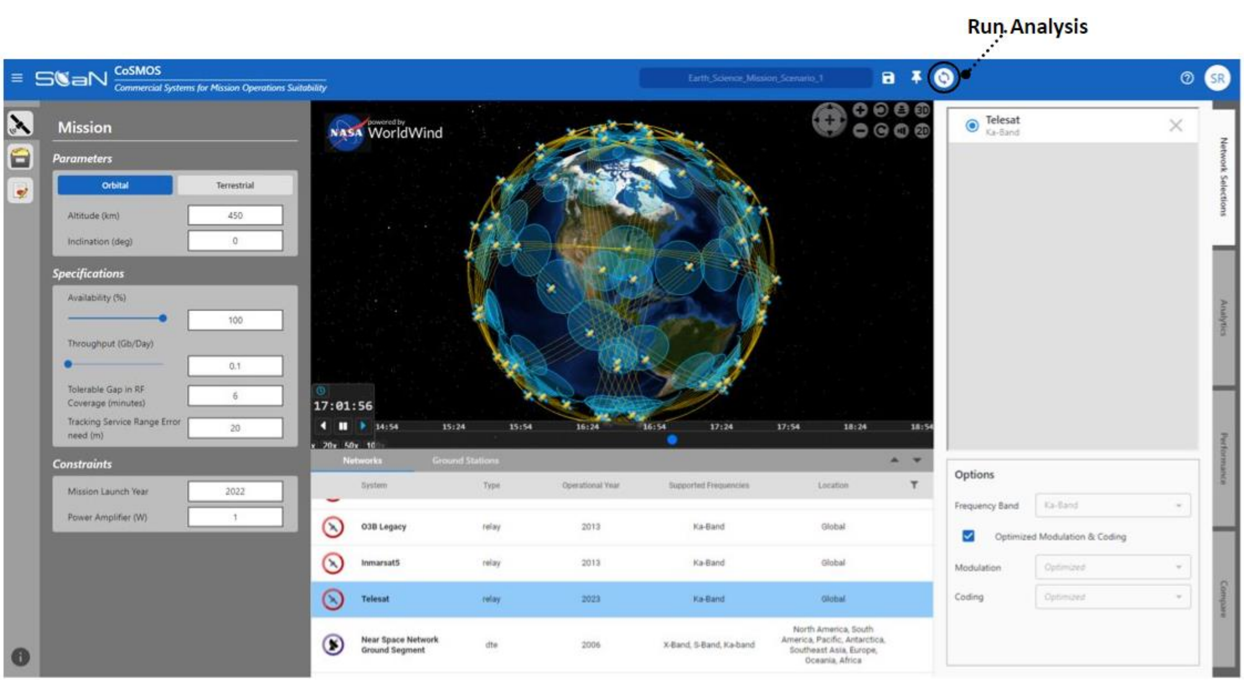


Figure 13-20: Running Mission Analysis

Step 6: Observe SAT A Performance Parameters for all Relay Networks

When the analysis for User A has completed, open the Comparison tab to evaluate the Max Gap, Average Gap, Mean Response Time, Average Contact Duration, and Throughput for each relay system. The performance results for the specified metrics of User A are summarized in Table 13-16 and the systems that passed the mission requirements are highlighted in green.

Table 13-16: Target Metrics for SAT A

Relay Networks	Sat A - 450 km / 0 deg User				
	Max Gap (min)	Average Gap (min)	Mean Response Time (min)	Average Contact Duration (min)	Throughput (Gb/Day)
Eutelsat	8.2	6.5	0.31	52.7	211.0
Globalstar	27.9	6.4	3.7	3.1	16.22
Inmarsat-4	0.0	0.0	0.32	880.4	42.51
IntelsatEpicNG	0.0	0.0	0.0	281.0	2668.9
IridiumNext	45.7	7.8	1.2	4.7	6.79
O3b mPOWER	0.09	0.0	0.0	975.3	8450.1
OneWeb MEO	0.95	0.97	0.0	32.2	1,997.6
SpaceX 1110	0.2	0.0	0.0	480.4	83,571.8
Viasat3	0.0	1.2	0.27	622.8	8,441.2
O3b Legacy	1.4	0.0	0.31	1067.6	8,640.0
Inmarsat-5	0.0	0.0	0.0	1088.9	431.4

Analysis Note: *The 5-minute (300 sec) contact duration objective is not met by:*

- *Globalstar*
- *IntelsatEpicNG*
- *IridiumNext*

A throughput of 0.1 Gb/Day along with the 4-hour (240 minute) latency requirement is satisfied across all systems.

Step 7: Enter SAT B Mission Input Parameters

Navigate back to the Mission Parameters panel leave the parameter selection at orbital and enter the altitude of 300 km and an inclination of 93 deg corresponding to Satellite B. In the Mission Specifications panel, enter the mission's desired availability as 100 percentage and enter a throughput of

0.1 Gb/day. Inside of the mission specifications panel, enter the tolerable gap in RF coverage as 240 minutes and leave the tracking service range error as the default value. Finally, in the mission constraints panel, leave the mission launch year as the default value of 2022, and the power amplifier as the default value of 1 Watt, as shown in Figure 13-21.

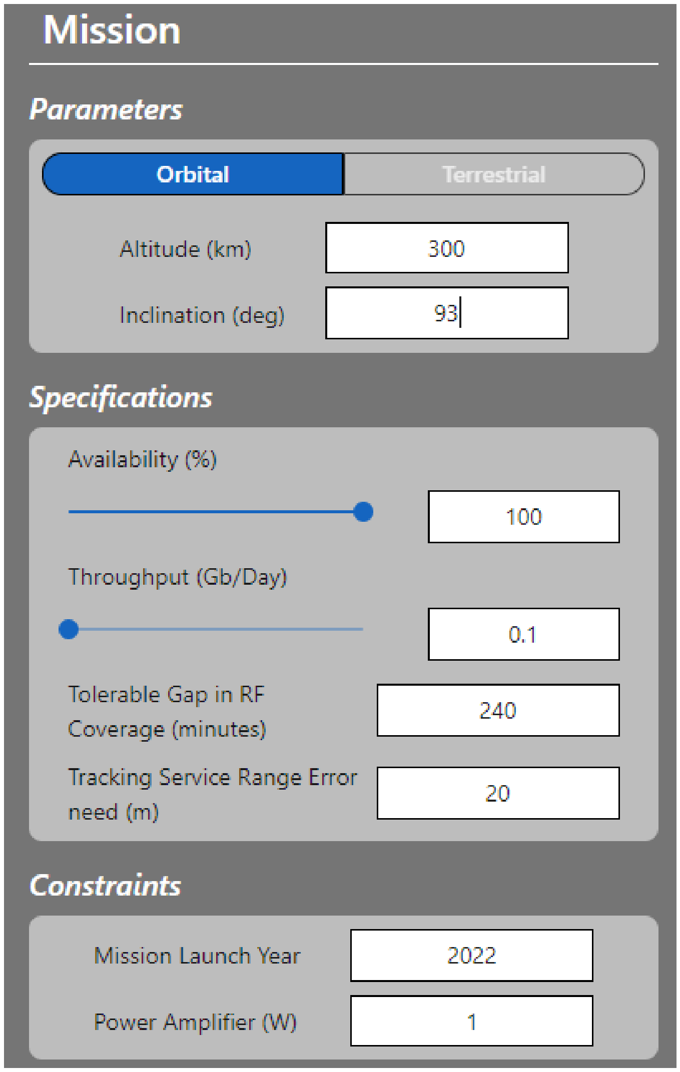


Figure 13-21: Mission Input Panel for SAT B

Step 8: Re-Run Analysis

Once this has been completed, navigate back to the Mission Parameters dialog box and click the “Run Analysis” button on the bottom of the screen.

Step 9: Observe SAT B Performance Parameters for all Relay Networks

When the analysis for Satellite B has completed, open the Comparison tab and review the Max Gap, Average Gap, Mean Response Time, Average Contact Duration, and Throughput regressions for each relay system. The performance results for the specified metrics of Satellite B are summarized in Table 13-17 and the systems that passed the mission requirements are highlighted in green.

Table 13-17: Target Metrics for SAT B

Relay Networks	Sat B - 393 km / 93 deg User				
	Max Gap (min)	Average Gap (min)	Mean Response Time (min)	Average Contact Duration (min)	Throughput (Gb/Day)
Eutelsat	34.4	23.5	6.5	42.7	173.3
Globalstar	30.9	11.6	3.7	3.1	13.3
Inmarsat-4	5.6	0.64	4.6	32.1	42.0
IntelsatEpicNG	130.7	15.9	37.8	3.5	2199.9
IridiumNext	19.0	3.7	0.91	4.6	32.2
O3b mPOWER	72.6	45.0	10.9	124.3	4,140.2
OneWeb MEO	15.3	15.5	2.4	15.1	1,491.5
SpaceX 1110	9.7	3.6	1.5	94.1	62,568.1
Viasat3	21.6	19.9	4.9	137.5	5,314.8
O3b Legacy	25.6	24.5	7.1	13.0	4,042.8
Inmarsat-5	3.1	2.31	1.74	1119.9	432.0

Analysis Note: *Like SAT A, the 5-minute (300 sec) contact duration objective for SAT B is not met by:*

- *Globalstar*
- *IntelsatEpicNG*
- *IridiumNext*

A throughput of 0.1 Gb/Day along with the 4-hour (240 minute) latency requirement is satisfied across all systems. ,

Step 10: Enter SAT C Mission Input Parameters

Navigate back to the Mission Parameters panel, leave the parameter selection at Orbital, and enter the altitude of 600 km and an inclination of 56 deg corresponding to Satellite C. In the Mission Specifications panel, enter the mission's desired availability as 100 percentage and enter a throughput of 0.1 Gb/day. Inside of the mission specifications panel, enter the tolerable gap in RF coverage as 240 minutes and leave the tracking service range error as the default value. Finally, in the Mission Constraints panel, leave the mission launch year as the default value of 2022, and the power amplifier as the default value of 1 Watt, as shown in Figure 13-20 below.

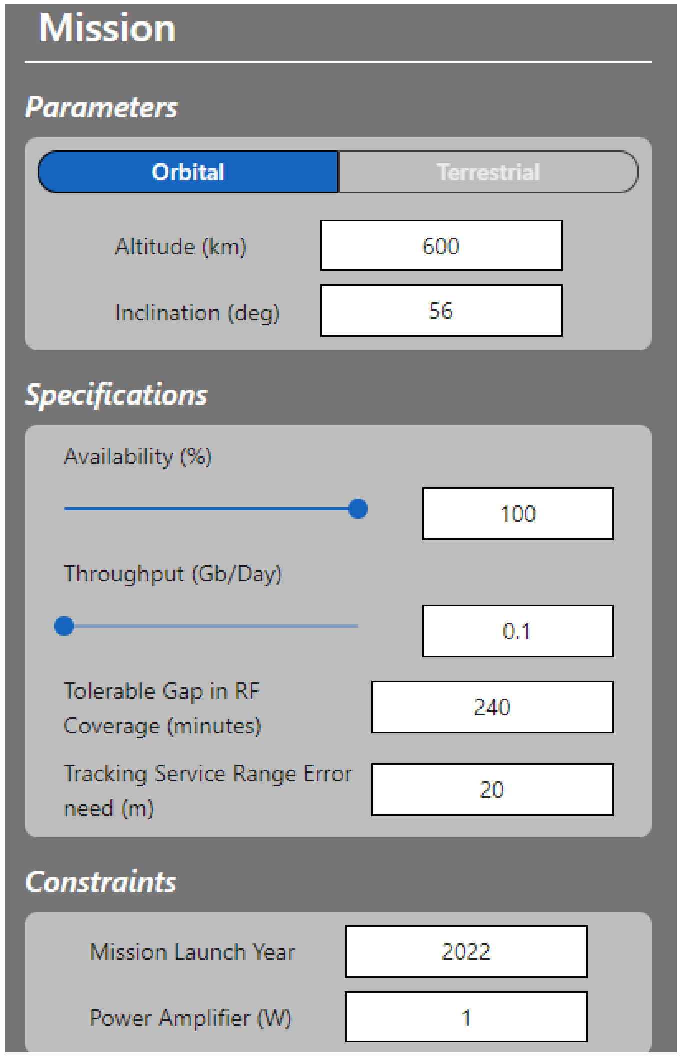


Figure 13-21: Mission Input Panel for SAT C

Step 11: Re-Run Analysis

Once this has been completed, click the "Run Analysis" button on the top right-hand side of the main panel.

Step 12: Observe SAT C Performance Parameters for all Relay Networks

When the analysis for Satellite C has completed, open the Comparison tab, then open and observe the Max Gap, Average Gap, Mean Response Time, Average Contact Duration, and Throughput regressions for each relay system. The performance results for the specified metrics of Satellite C can be observed in Table 13-18 below and the systems that passed the mission requirements are highlighted in green.

Table 13-18: Target Metrics for SAT C

Relay Networks	Sat C - 393 km / 56 deg User

	Max Gap (min)	Average Gap (min)	Mean Response Time (min)	Average Contact Duration (min)	Throughput (Gb/Day)
Eutelsat	33.3	15.1	2.9	27.3	164.7
Globalstar	38.9	0.78	4.8	3.3	7.9
Inmarsat-4	5.5	0.8	0.18	172	39.3
IntelsatEpicNG	96.5	20.3	26.6	3.8	1864.8
IridiumNext	79.3	20.1	10.6	1.2	2.1
O3b mPOWER	43.3	39.9	15.8	52.6	4,240.0
OneWeb MEO	0.0	0.0	0.0	510.4	2,046.1
SpaceX 1110	3.2	8.9	2.8	23.3	74,357.2
Viasat3	21.9	13.7	3.4	0.0	6,042.2
O3b Legacy	23.3	23.2	5.5	35.7	4462.1
Inmarsat-5	0.0	0.0	0.0	1110.3	431.9

Analysis Note: *Like SAT A, the 5-minute (300 sec) contact duration objective for SAT B is not met by:*

- *Globalstar*
- *IntelsatEpicNG*
- *IridiumNext*

A throughput of 0.1 Gb/Day along with the 4-hour (240 minute) latency requirement is satisfied across all systems.

Step 13: Re-Run Analysis for SAT A for User Burden Assessment

Navigate back to the mission parameters panel and re-enter in the altitude and inclination for SAT A (450 km / 0 deg) and re-click on the "Run Analysis" button; when the analysis is completed, re-open the Comparison tab and open the User Burden Antenna Options dialog box. Observe the required EIRP and antenna requirements for the mission to use the various the relay systems.

Step 14: User Burden: Antenna Options Comparison

Repeat **Step 13** for SAT B and SAT C. Once this step is completed, the analysis results for each user can be summarized, as shown in Table 13-19 and Table 13-20.

Table 13-19: EIRP Metrics for SAT A, B, and C

	Sat A	Sat B	Sat C

Commercial Relay Networks	User EIRP (dBW)	User EIRP (dBW)	User EIRP (dBW)
Eutelsat	48.74	48.78	48.7
Inmarsat-4	11.8	11.84	11.77
O3b mPOWER	52.98	53.15	52.81
OneWeb MEO	58.96	59.12	58.79
SpaceX 1110	31.99	33.77	29.75
Viasat3	41.66	41.7	41.63
O3b Legacy	55.25	55.42	55.08
Inmarsat-5	39.15	39.18	39.11

Table 13-20: Parabolic Antenna Diameters for SAT A, B, and C

Commercial Relay Networks	Sat A Parabolic Antenna Diameter (m)	Sat B Parabolic Antenna Diameter (m)	Sat C Parabolic Antenna Diameter (m)
Eutelsat	2.4	2.4	2.3
Inmarsat-4	0.28	0.28	0.28
O3b mPOWER	1.8	1.9	1.8
OneWeb MEO	2.2	2.2	2.1
SpaceX 1110	0.34	0.42	0.26
Viasat3	0.49	0.5	0.49

O3b Legacy	2.5	2.5	2.4
Inmarsat-5	0.37	0.37	0.37

Analysis Notes: The analysis of Satellites A, B, and C shows that Satellite B has the largest required EIRP across all commercial networks; it drives user burden requirements for a common design.

Of the systems that remain viable based on throughput, contact duration, and latency metrics, Inmarsat-4 offers the best overall latency performance, the lowest nominal EIRP, and the smallest and most consistent user terminal parabolic antenna size.

Step 15: Save Mission Project

On the top right-hand side of the main panel next to the status bar, click on the "Save" button to save this mission configuration. Once the "Save" button has been clicked ensure that the status bar states, *"Relay_Network_Analysis_1 – Saved Successfully"*. [**Future Release**]

Results and Conclusions

Inmarsat-4 meets the mission requirements with the lowest user burden. The key measures of performance are summarized in Table 13-21.

Table 13-21: Inmarsat-4 Performance Metrics

Metrics	Inmarsat-4		
	SAT A	SAT B	SAT C
Maximum Gap (min)	0.0	5.6	5.5
Average Gap (min)	0.0	0.64	0.8
Mean Response Time (min)	0.32	4.6	0.18
Average Contact Duration (min)	880.0	32.0	172.0
Throughput (Gb/Day)	42.5	42.0	39.3
EIRP (dBW)	11.8	11.8	11.7
Parabolic Antenna Dia. (m)	0.28	0.28	0.28
Operational Year	2006		

CoSMOS does not generate risk assessments for any network; however, several observations can be made based on knowledge of the mission and of each of the systems that are in the system library, as summarized in Table 13-22.

Table 13-22: Risk Summary

	Inmarsat-4

Design Risks	• Commercial company, AddValue, has been offering a satellite relay service via Inmarsat-4 – first commercial user contracted with AddValue in late 2020. IDRS user terminals are available. On orbit testing and the subsequent commercial service reduces risk somewhat. • GEO system – good coverage, relatively low risk from a dynamics standpoint.
Programmatic Risks	• Spectrum use (for space-to-space relay) is currently experimental, non-interference-basis. • Use of a proprietary IDRS terminal limits the user to that service, e.g., vendor lock-in becomes a risk unless the mission carries an additional terminal. • Inmarsat is an established entity and Inmarsat-4 is operational—potentially lower risk than newer entrants to the market.
Mitigations	NASA will be sponsoring funded space act agreements for demonstrations of SATCOM services. If Inmarsat-4 (or service intermediary like AddValue) is selected, the demonstration may buy down risk by validating capability and performance for NASA use cases.

13.3 Scenario 3: DTE Service Analyses – How to Meet Throughput / Contact Requirements

This scenario is based on the work that was completed several years ago by NASA to determine viable ground options for the NISAR and PACE missions. Table 13-23 provides an overview of each of the missions and their respective communications requirements. The prior study determined that such high data offloading requirements were incapable of being met by the NSN (former NEN) S-band, X-band, or limited Ka-band capabilities at the time.

Initially only one ground segment at Svalbard, Norway was studied, after which it was determined that multiple ground segments would be needed to support both missions. A three-node Ka-band network was then proposed with antennas located at Fairbanks, Alaska (AS3), Svalbard, Norway (SG1), and Punta Arenas, Chile (PA1). The study concluded that a combination of two of these three nodes would be able to support either PACE or NISAR individually, but not both missions simultaneously. To support the maximum throughput of 38 terabits per day, all three ground segments would be required to support both missions.

These missions are used to illustrate typical analyses process and how CoSMOS enables similar evaluations. The first case is the evaluation of a single antenna – AS3 at Fairbanks, Alaska.

Table 13-23: NISAR & PACE Mission Information

Parameter	NISAR	PACE
Mission Goal	To help scientists better understand Earth's processes and changing climate and aid future resource and hazard management by collecting data on complex processes, including ecosystem disturbances, ice-sheet collapse, and natural hazards such as earthquakes, tsunamis, volcanoes, and landslides	To extend key systematic ocean color, aerosol, and cloud data records for Earth system and climate studies, and to address new and emerging science questions using its advanced instruments, surpassing the capabilities of previous and current missions
Orbit	747 km altitude, 98° inclination	675 km altitude, 98.4° inclination
Polarization	LHCP & RHCP, simultaneous	RHCP
Daily Data Volume	33 Tbits/day	5 Tbits/day

Contact Requirements	1 contact per orbit	1 contact per 6 hours
Minimum Pass Duration (assumed)	3 minutes	3 minutes
Daily Contact Time (derived)	123.8 minutes	138.9 minutes (600 Mbps) 69.4 minutes (1.2 Gbps)
Ka-Band Downlink Data Rate	3.5 Gbps (1.75 Gbps per polarization)	600 Mbps or 1.2 Gbps (single polarization)

Step 1: CoSMOS Login and Project Start

Opens the preferred web browser, types in the web address https://cosmos.teltrium.com and press enter. When CoSMOS loads, click on the "New Project" button.

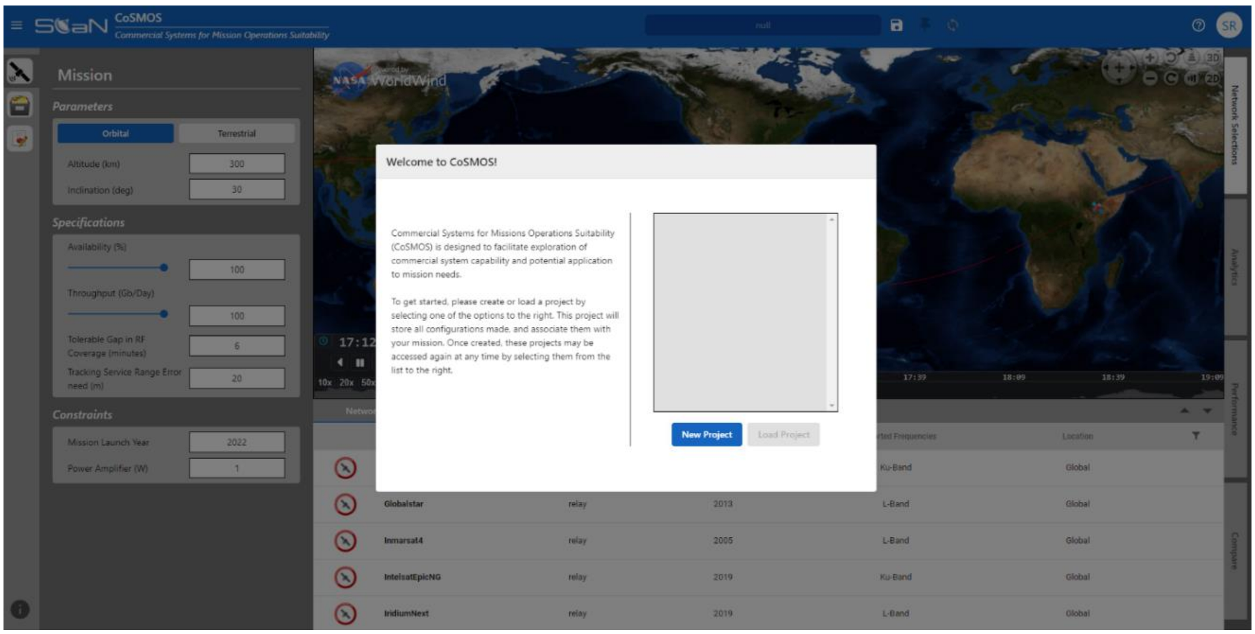


Figure 13-22: New Project Dialog Box

Step 2: Enter Project Name

In the CoSMOS Project Details dialog box, enter in the desired project name, mission name, and a general description of the mission if applicable. Then click the "Create" button to start the new project.

Note: A suggested project name would be NISAR_Phase_1.

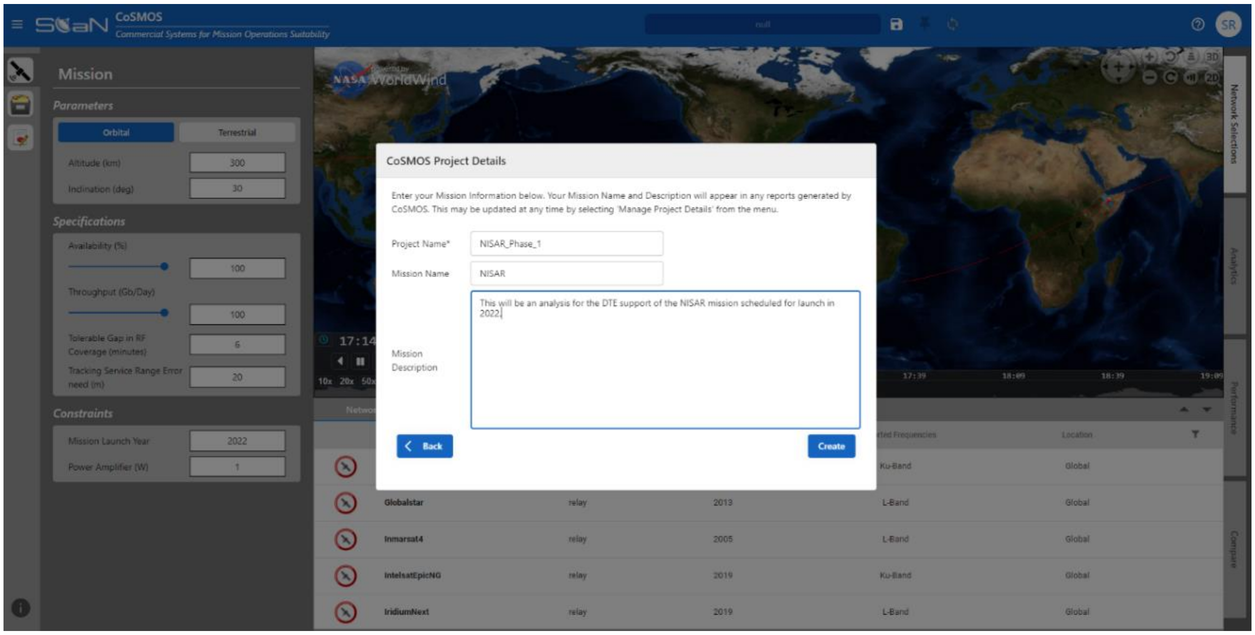


Figure 13-23: New Project Creation Dialog Box

Step 3: Enter Mission Input Parameters

In the Mission Parameters panel, leave the user choice at orbital and enter the mission's desired altitude of 747 km and an inclination of 98 deg. In the Mission Specifications section, leave the throughput and availability at their maximum. In the mission constraints panel, leave the mission launch year as the default value, and the power amplifier as the default value.

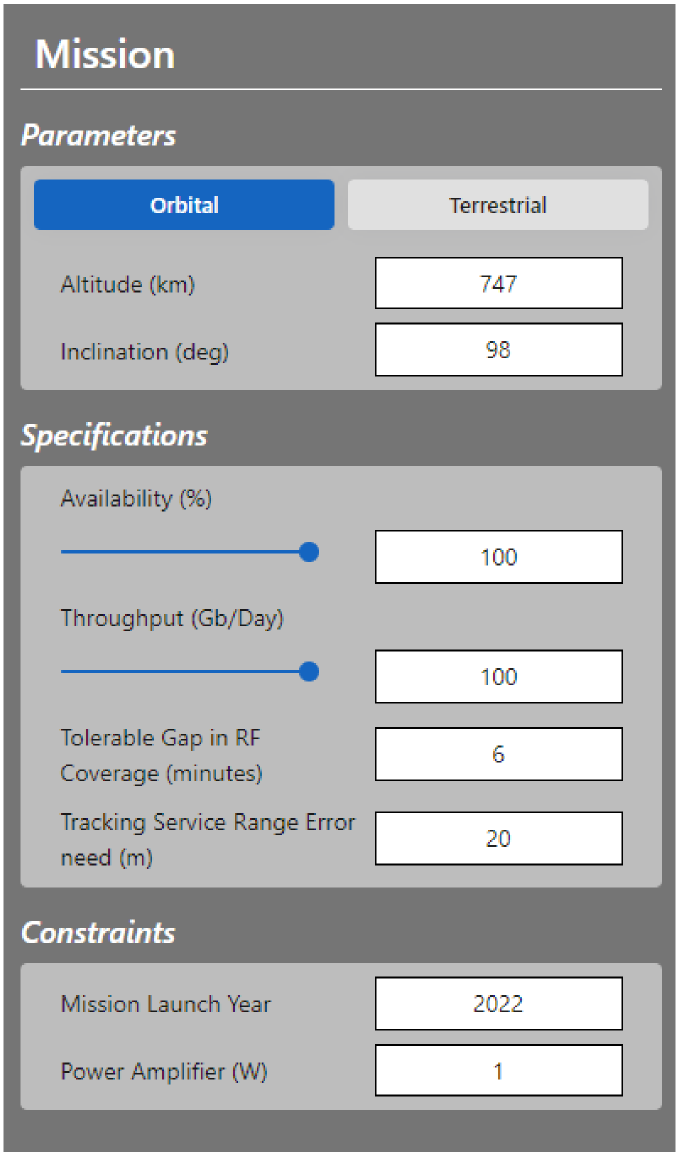
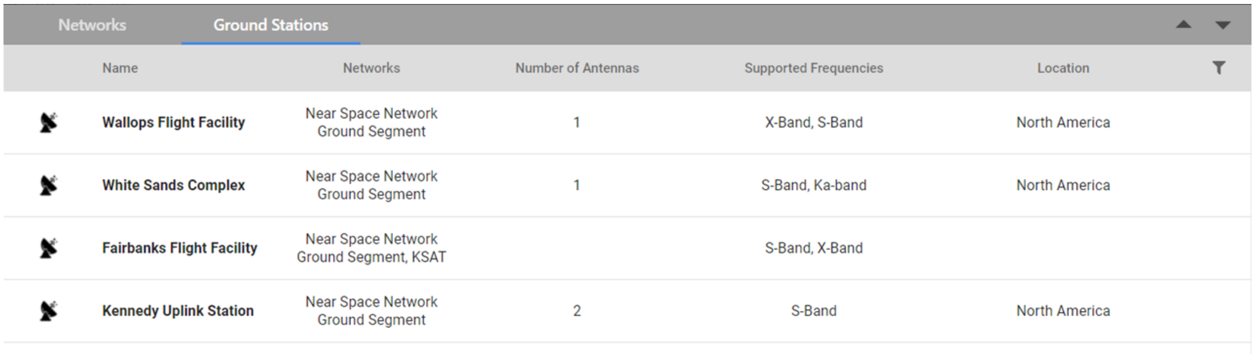


Figure 13-24: NISAR Mission Inputs

Step 4: View All DTE Ground Station Locations

At the bottom of the 3-D visualization of the Earth, the Network Options Panel will be visible. Click the Ground Stations tab at the top of that panel. This will display all the ground locations that are available from NASA's Near Space Network, Swedish Space Corporation, KSAT, and Amazon Web Services.



Name	Networks	Number of Antennas	Supported Frequencies	Location
Wallops Flight Facility	Near Space Network Ground Segment	1	X-Band, S-Band	North America
White Sands Complex	Near Space Network Ground Segment	1	S-Band, Ka-band	North America
Fairbanks Flight Facility	Near Space Network Ground Segment, KSAT		S-Band, X-Band	
Kennedy Uplink Station	Near Space Network Ground Segment	2	S-Band	North America

Figure 13-25: Ground Station Library Display (Partial View)

Step 5: View Fairbanks Ground Station Details

Single-click the Fairbanks Ground Station name to view the location on the 2-D visualizer. Next, double-click on the Fairbanks Ground Station name to view its specifications, including supported frequency bands, coordinates, antennas, and supported modulation and coding. Once satisfied with the Fairbanks Library information, exit the dialog box, and navigate back to the list of all Ground Stations.

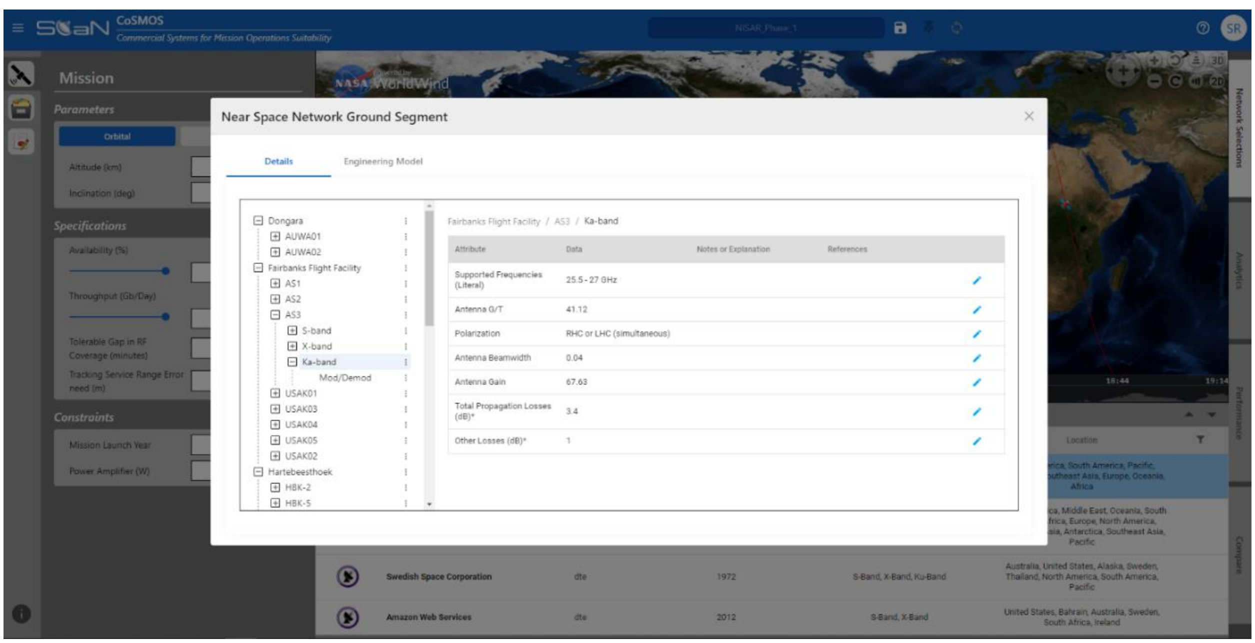


Figure 13-26: Fairbanks AS3 Library Visualization

Step 6: Select Fairbanks Ground Station

Next, click on the Network Selection Tab to open it. Right-click and select the Fairbanks Ground Station to populate it to the Network Selection box. The Fairbanks Ground Station is one of the few station choices that has been upgraded for Ka-band capabilities. Choose the Ka-band option from the frequency band drop down under Options section (located next to the Network Options panel).

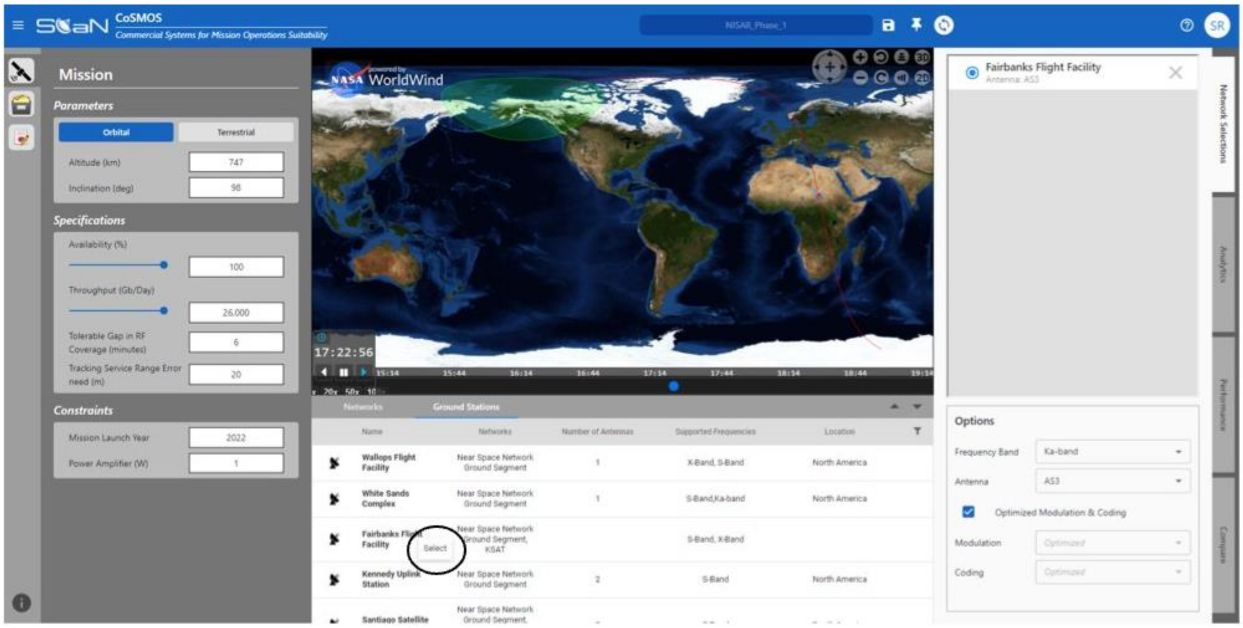


Figure 13-27: Fairbanks Ground Station Selection

Step 7: Selecting AS3 Antenna

Click on the antenna selection dialog box and select the AS3 antenna, as this is the only NEN antenna in Alaska that supports Ka-band missions.

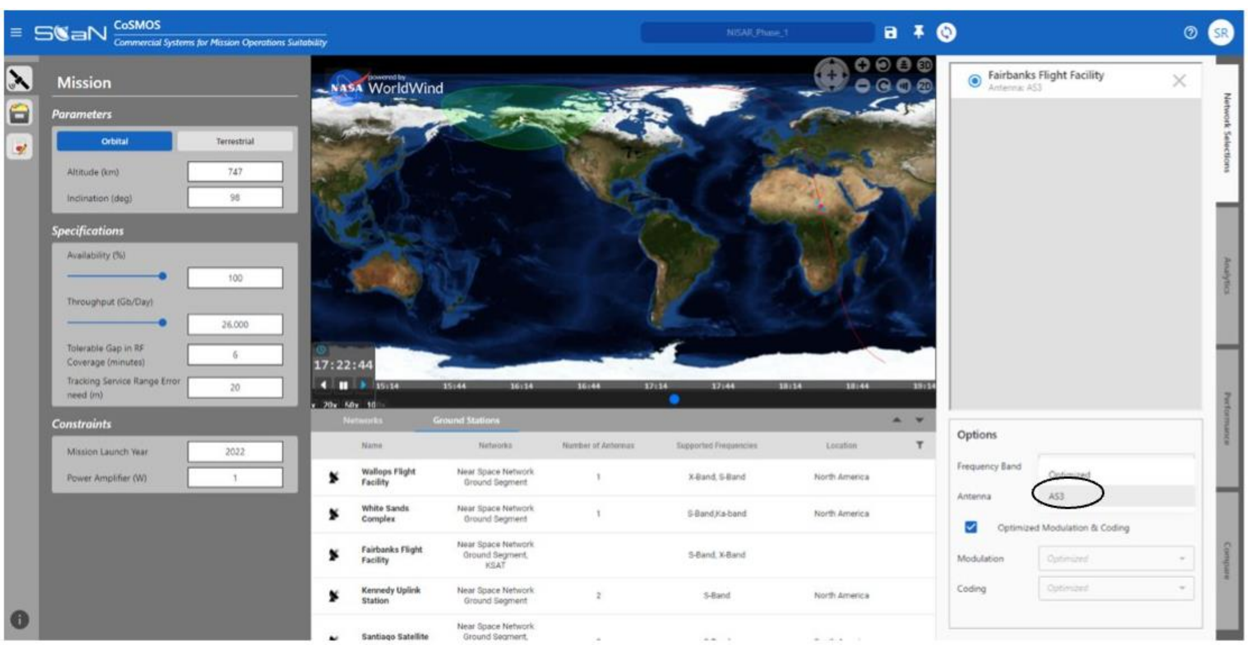


Figure 13-28: AS3 antenna selection

Step 8: Select Custom Modulation & Coding

Once the Fairbanks Ground location has been placed inside of network selection panel, un-check the optimized modulation and coding dialog box. For both NISAR and PACE, their Radio Frequency Interface Control Document's (RFICD) states that the mission will employ a modulation of QPSK at a coding rate of 7/8. Therefore, click on the custom modulation and coding dialog box and choose QPSK and a Code Rate of 7/8.

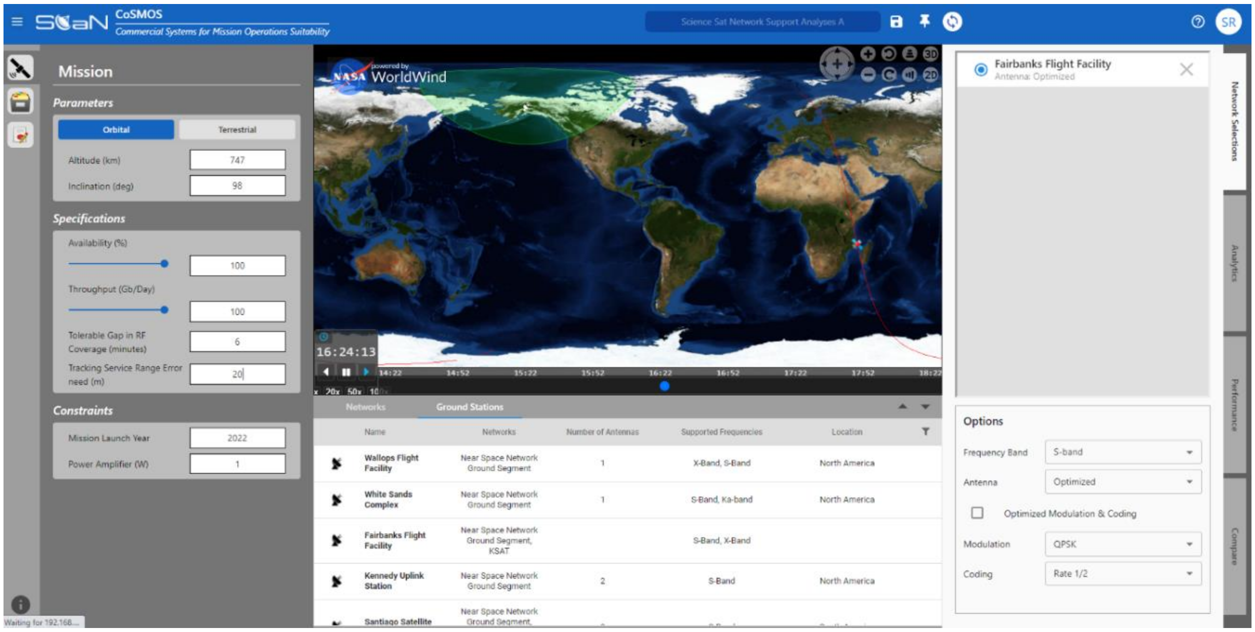


Figure 13-29: Modulation and Coding Selection

Step 9: Observe AS3 Performance Metrics

Open the RF Coverage metric under the performance panel to display the RF Coverage graph. Observe the data RF Coverage metric, along with the Data Rate and Throughput metrics, under the Performance panel and compare with the Return Link Budget to see if the output correlates with the return link calculations. Visualize that the throughput of the Fairbanks AS3 Antenna is 7223.53 Gb/Day (14,447.06 Gb/Day dual polarization) which is not sufficient to satisfy both mission's combined throughput requirement of 38,000 Gb/Day. Close the Performance tab when finished.

Step 10: View AS3 Link Analysis

Once back in the main view of CoSMOS click on the Performance Tab. Inside of the Performance Tab,click on the EIRP value under "User Burden:Antenna Options" section. This will display the link budget for the Fairbanks AS3 Antenna.

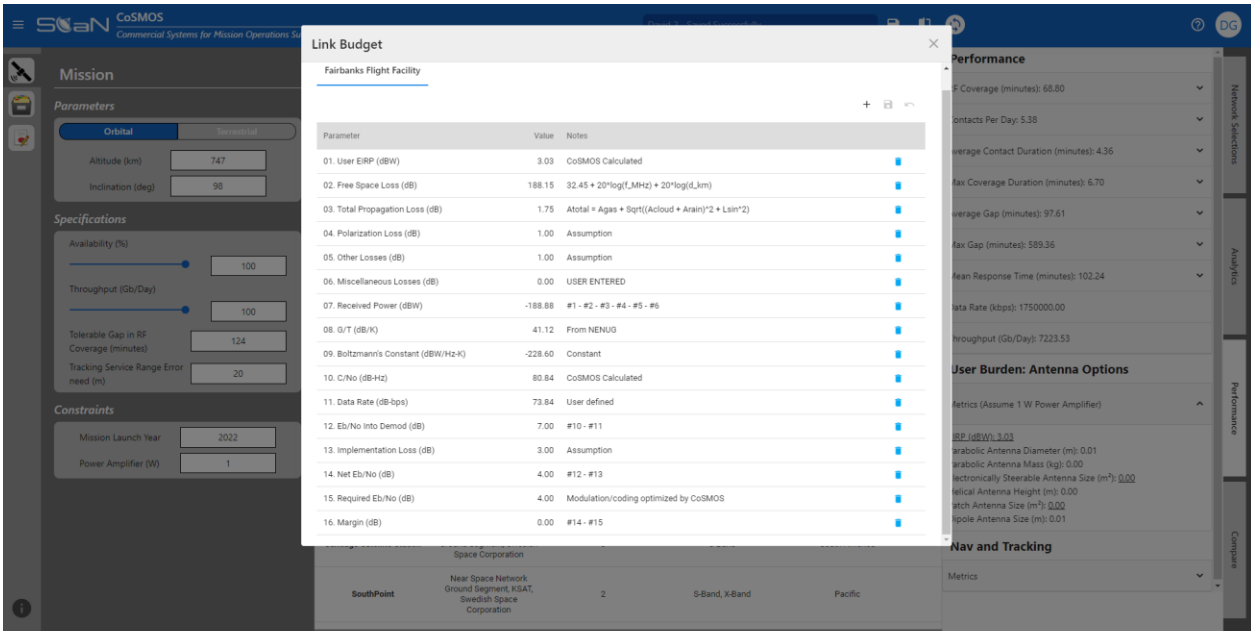


Figure 13-29: AS3 Return Link Budget Visualization

Step 11: Select Svalbard Ground Station

Open the Network Selection tab. In the library panel, scroll down until the Svalbard Location can be visualized. Right-click and select the Svalbard Ground Station to the dialog box where the Fairbanks Ground Station is located.

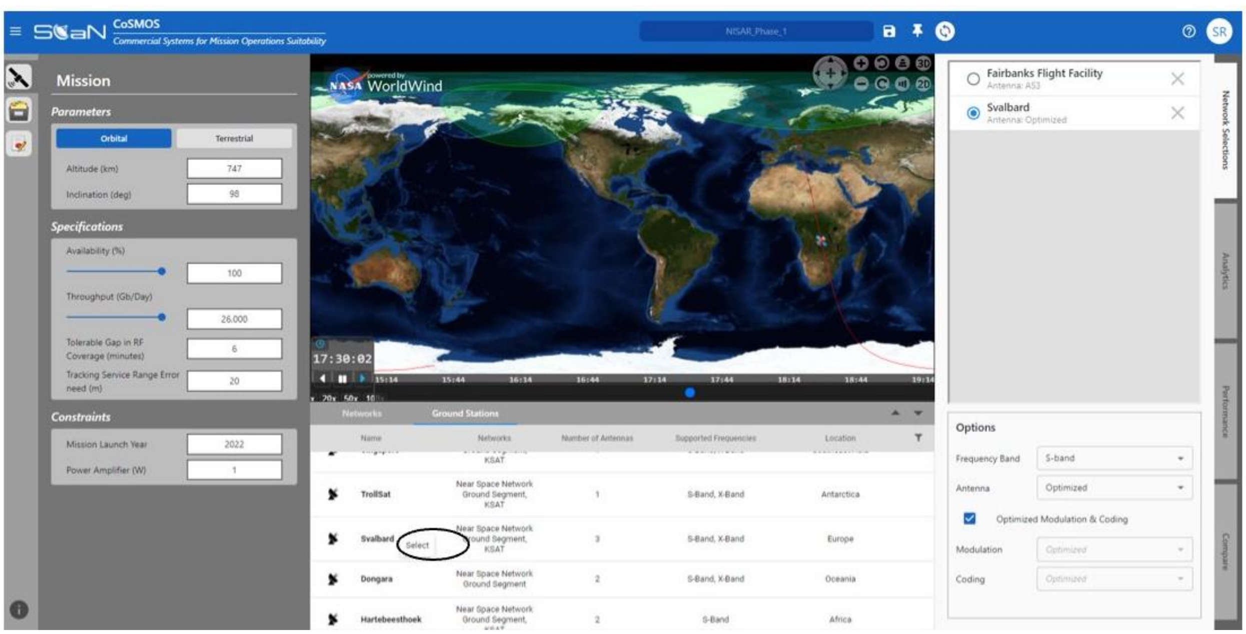


Figure 13-30: Svalbard Station Selection

Step 12: Select Svalbard SG1 Antenna

Select the SG1 antenna in the Antenna drop down under the Options section (located next to the Network Options panel). Then, click on the "Run Analysis" button to refresh the analysis. Next, un-check the modulation and coding box, and then select the QPSK modulation type and a code rate of 7/8.

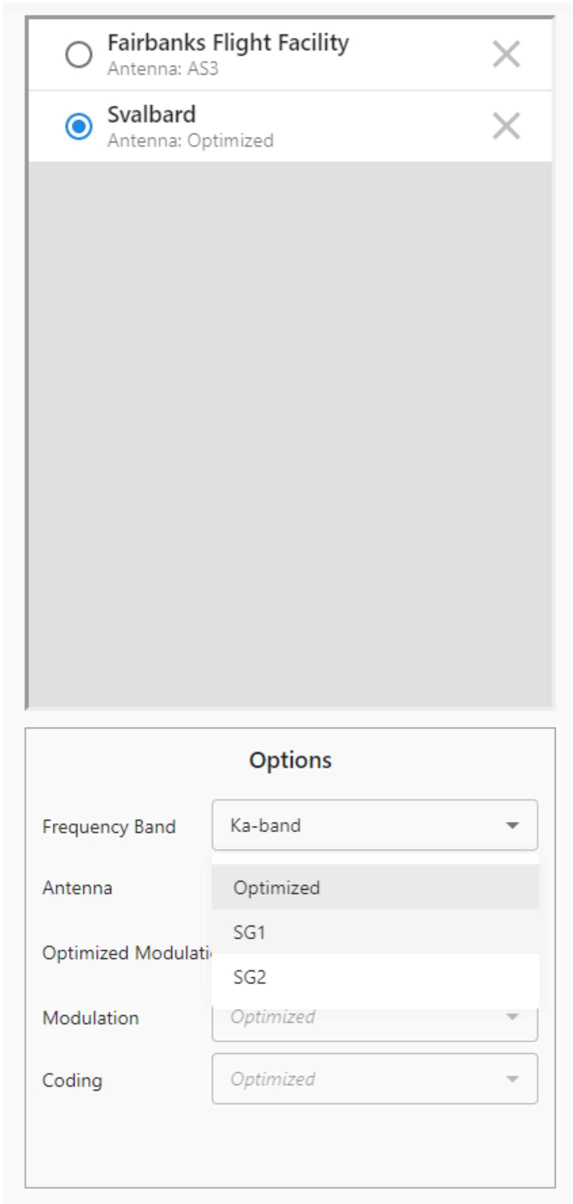


Figure 13-31: SG1 Antenna Selection

Step 13: Observe Combination Performance Metrics

Once the analysis has been completed, click on the Performance Tab. Open the RF Coverage metric under the performance panel to display the RF Coverage graph. Observe the RF Coverage, Data Rate, and Throughput metrics under the Performance Panel and compare with the Return Link Budget to see if the output correlates with the Return Link calculations. Visualize the combined throughput of the Svalbard

SG1 Antenna and the Fairbanks AS3 antenna is 18,290.5 Gb/Day (36,581.84 Gb/Day with dual polarization), which again is insufficient to satisfy the combined mission's throughput requirement of 38,000 Gb/Day. Therefore, a third antenna is going to need to be added and a third combination will have to evaluated.

Step 14: Select Punta Arenas Ground Station

Open the Network Selection tab. In the library panel, scroll down until the Punta Arenas Location can be visualized. Right-click and select the Punta Arenas Ground Station to the dialog box where the Fairbanks and Svalbard are located.

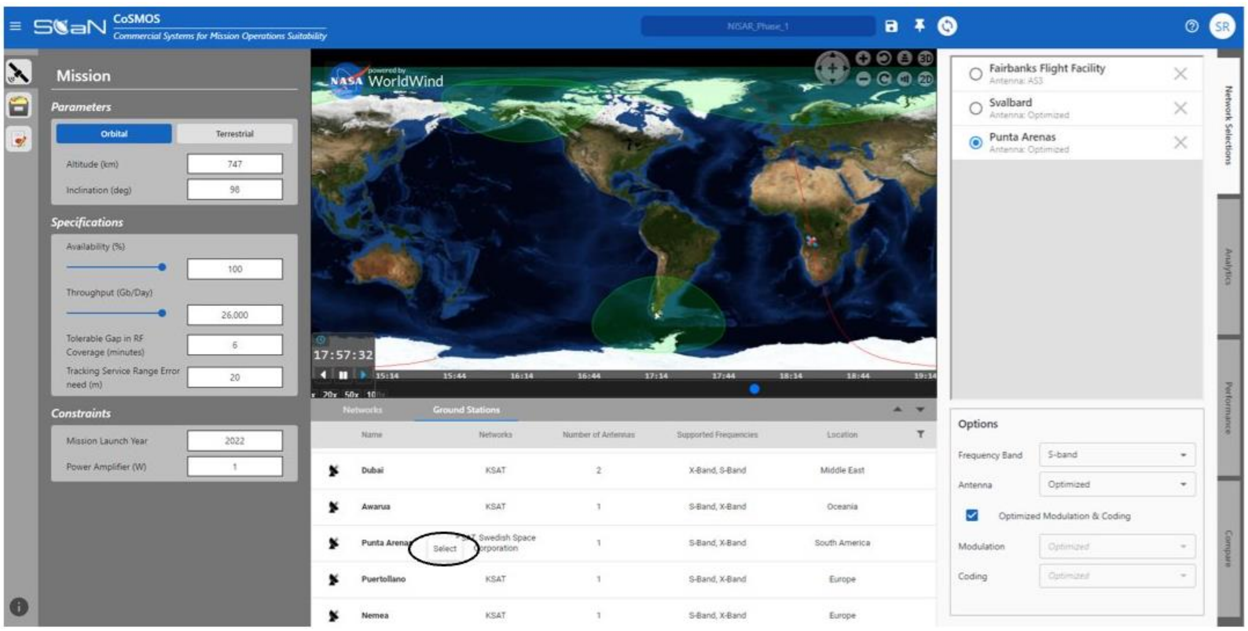


Figure 13-32: Punta Arenas Location Selection

Step 15: Select Punta Arenas PU1 Antenna

Select the PU1 antenna in the Antenna drop down under Options section (beside network options panel). Next, un-check the modulation and coding box, and then select the QPSK modulation type and a code rate of 7/8. Then, click on the "Run Analysis" button to refresh the analysis.

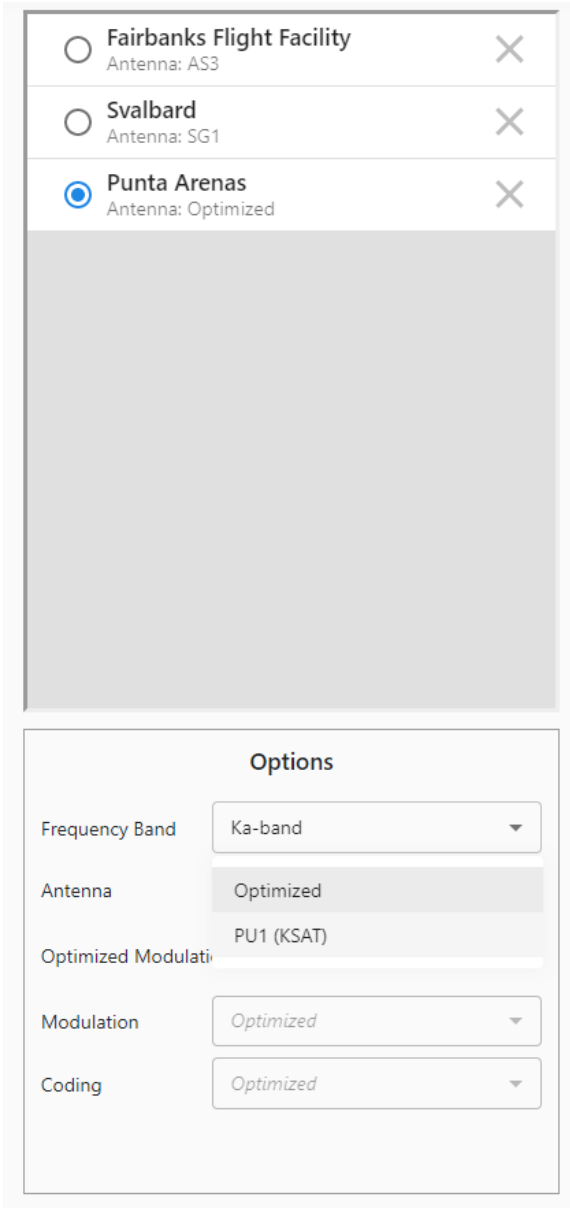


Figure 13-33: PU1 Antenna Selection

Step 16: Observe Combination Performance Metrics for All Three Antennas

Once the analysis has been completed, click on the Performance Tab. Open the RF Coverage metric under the performance panel to display the RF Coverage graph. Observe the data RF Coverage, the Data Rate and Throughput metrics under the performance panel and compare with the Return Link Budget to see if the output correlates with the return link calculations. Note that the combined throughput of the Svalbard SG1 Antenna, the Fairbanks AS3 antenna, and Punta Arenas PU1 antenna, is 45,4800 Gb/Day which is sufficient to satisfy the combined mission's throughput requirement of 38,000 Gb/Day. Step 17: Save Mission.

Once the save button has been clicked, ensure that the status bar states, *"User Mission Name – Saved Successfully."* [**Future Release**]

Results and Conclusions

Table 13-24: Results and Conclusions

Commercial Relay Networks	Modulation	Coding	Data Rate (Mbps)	Throughput (Gb/Day)	Dual Polarization Throughput (Gb/Day)
ASF3	QPSK	Rate 7/8	3500	7415.74	14,831.48
SG1	QPSK	Rate 7/8	3500	10,875.18	21,750.36
PU1	QPSK	Rate 7/8	3500	4451.19	8902.38

NASA's 3-node 26 GHz Polar Subnet, with stations at Fairbanks and CSP Ground Stations at Svalbard and Punta Arenas, will be capable of accommodating NISAR and PACE downlink communications with a 10° ground antenna elevation angle for support to both missions and PACE operating at 600 Mbps. The required 38,000 Gb/Day throughput for both missions can be easily achieved by the 3-node subnets combined throughput of 45,4800 Gb/Day with dual polarization. The polar subnet offers higher data rates and higher science data return, which enable scientific sensors with higher resolution and wider coverage, a less congested spectrum environment, and no difficulties during operations for missions using the Ka-band in other orbits for or for space-to-space communications.

APPENDIX A: ACRONYMS

Acronym	Definition
CoSMOS	Commercial Systems for Mission Operations Suitability
dB	Decibels
dB-Hz	Decibels per Hertz
dB/K	Decibels/Kelvin
DBW	Decibel Watt
DEG	Degrees
DEG/S	Degree Per Second
DTE	Direct to Earth
Eb/No	Ratio of Energy per Bit (Eb) to the Spectral Noise Density (No)
EIRP	Effective Isotropic Radiated Power
ESA	European Space Agency
FCC	Federal Communications Commission
GNSS	Global Navigation Satellite System
Gb/Day	Gigabyte Per Day
G/T	Gain to Noise Temperature Ratio
KaSA	Ka-Band Single Access
KBPS	Kilobits Per Second
KG	Kilogram
M	Meter
MAX	Maximum
MBPS	Megabits Per Second
MHZ	Megahertz
MIN	Minimum
NASA	National Aeronautics and Space Administration
NSN	Near Space Network
RFICD	Radio Frequency Interface Control Document
SATCOM	Satellite Communications
SCaN	Space Communications and Navigation
SNUG	Space Network Users Guide
SSA	S-band Single Access
SSL	Satellite-to-Satellite

Acronym	Definition
STK	Systems Tool Kit
TDRS	Tracking and Data Relay Satellite
TT&C	Tracking Telemetry and Command