Reconfigurable Satellite Planning Tool

Princeton Satellite Systems
6 Market St. Suite 926
Plainsboro, New Jersey 08536

Joseph Mueller
Phone: 763-634-1553
Fax: 609-275-9609
Email: jmueller@psatellite.com
Website: www.psatellite.com

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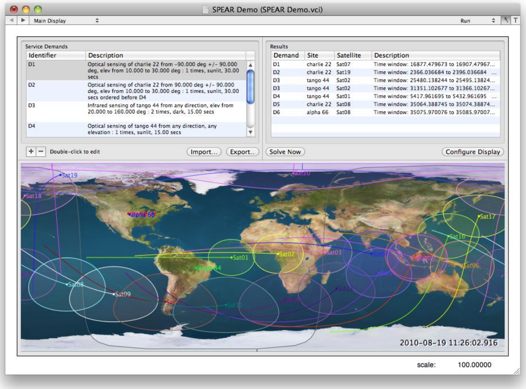

Identifier	Description
D1	Optical sensing of charlie 22 from -90.000 deg +/- 90.000 deg, elev from 10.000 to 30.000 deg : 1 times, sunlit, 30.00 secs
D2	Optical sensing of charlie 22 from 90.000 deg +/- 90.000 deg, elev from 10.000 to 30.000 deg : 1 times, sunlit, 30.00 secs ordered before D4
D3	Infrared sensing of tango 44 from any direction, elev from 20.000 to 160.000 deg : 2 times, dark, 15.00 secs
D4	Optical sensing of tango 44 from any direction, any elevation : 1 times, sunlit, 15.00 secs

Demand	Site	Satellite	Description
D1	charlie 22	Sat07	Time window: 16877.479673 to 16907.47967...
D2	charlie 22	Sat19	Time window: 2366.036684 to 2396.036684 ...
D3	tango 44	Sat02	Time window: 25480.138244 to 25495.13824...
D3	tango 44	Sat02	Time window: 31351.102677 to 31366.10267...
D4	tango 44	Sat01	Time window: 5417.961695 to 5432.961695 ...
D5	charlie 22	Sat08	Time window: 35064.388745 to 35074.38874...
D6	alpha 66	Sat08	Time window: 35075.970076 to 35085.97007...

PROBLEM STATEMENT

The Navy relies on many different satellite systems to meet its worldwide obligations. Satellites are used routinely to conduct vital communications and sensing functions that create a global network of information, extending the reach and capability of our forces. As these orbiting platforms provide a critical piece of the warfighter's operational support service, any disruption can have a significant impact on the mission. In the event of a threat to a satellite or a component failure, satellite operators and operational commanders must make timely decisions to reconfigure our space assets to minimize disruption of service. The goals are clear: maintain warfighter support and preserve the life of the satellite. The challenge is to quickly determine how to meet these goals.

In general, on-orbit reconfiguration is a response to unpredictable events, or a contingency to predicable events, where the response uses one or more space assets by augmenting its nominal function. The anomalous events leading to a reconfiguration include hardware failures, threats and changing mission requirements. The appropriate response to any event depends upon the unique details of the event, mission, satellite, and payload. This represents a set of challenging tasks for decision-makers who must quickly determine how to best utilize existing space assets, while satisfying the complex set of physical constraints imposed by the payload and different spacecraft subsystems. Therefore, a need exists for a satellite reconfiguration planning tool that automatically determines possible satellite system configurations and courses of action in response to anomalous events. Such a tool would reduce the time required to optimize payload and system configurations that meet the commander's intent, thereby minimizing disruption of critical services to the warfighter.

WHO ELSE CAN BENEFIT?

As the complexity of space systems grow and the number of possible configurations increases exponentially, innovative new optimization tools are needed to quickly identify the best possible configuration to respond to changing conditions. Leveraging a common tool to support on-orbit planning across multiple missions and satellite buses has a number of advantages. It enables a library of common tools to be developed that can be shared across multiple missions. It prevents individual "stove-piped" solutions that are wholly unique to each mission, and tend to require legacy software that is costly to maintain. Finally, and perhaps most importantly, it allows for responses to anomalous events to be planned pro-actively rather than re-actively, enabling a much more rapid and better-designed response.

Alternative reconfiguration plans, or courses of action, can be designed to maximize different aspects of satellite performance. The decisions and inherent tradeoffs associated with a reconfiguration can be shared across different Command and Control (C^2) nodes, enabling different stakeholders to simultaneously view alternative courses of action to allow collaborative decision-making. For example, this capability would enable commanders at the Joint Space Operations Command (JSpOC), planners at the Global SATCOM Support Center (GSSC) and operators at the Naval Satellite Operations Center (NAVSOC) to collaborate with a shared view of the decision space. This collective approach brings together different parties that are responsible for different aspects of satellite performance – so that suitable, well-informed decisions can be made.

BASELINE TECHNOLOGY

Currently, satellite systems are built in seven to ten years and allow little, if any, ability to reconfigure resources. Consequently, operational systems are: 1) built to ten-year old requirements, and 2) not designed to support significant on-orbit changes in operation. The Navy, the Office of Operationally Responsive Space, and other elements of DoD are seeking to improve mission responsiveness through the development of future space systems that are increasingly reconfigurable and reprogrammable.

On-orbit reconfiguration of satellites has been used operationally to save missions and extend the life of spacecraft. Modern satellites have flight computers that can be reprogrammed and in many cases have reconfigurable payload processors. Examples of recent innovations at the sub-system level are radiation-hardened Field Programmable Gate Arrays (FPGA) and Software Defined Radios (SDR). These technologies increase the flexibility of payloads and thus enable reconfiguration. However, planning and optimizing a reconfiguration for the whole satellite is an emerging capability that requires suitable ground-based decision support software to realize the full potential. Because the capabilities and requirements of each satellite mission vary so greatly, there exists no single baseline technology for planning on-orbit reconfigurations. Instead, the satellite operators and space system commanders deal with anomalous events on a case-by-case basis.

Satellite operations teams are typically not equipped with the necessary expertise and/or planning tools needed to rapidly develop a suitable course of action. Instead, the response tends to be overly conservative and slow, typically placing the satellite into safe mode until engineers can recover and resume nominal operations. Of course, the cost of delaying operations can be significant at best, catastrophic at worst. In the case of the Mobile User Objective System (MUOS), for example, maintaining connectivity to our global military forces is critical.

Many design, modeling and analysis tools currently exist to visualize a variety of predetermined satellite missions. Some of the currently available tools include Satellite Tool Kit (STK), Spacecraft Design Tool (SDT), Satellite Orbital Analysis Program (SOAP), and NASA's SPICE. However, no tool provides the ability to plan for changing mission sets requiring the reconfiguration of the satellite system.

TECHNOLOGY DESCRIPTION

We are developing the software application "SPEAR" – Satellite Planner for Execution and Reconfiguration. SPEAR is a decision support tool that automatically generates alternative courses of action (COA) in response to specific events, such as a failure, threat, or changed mission objective. Each potential course of action represents a solution that optimizes a specific aspect of overall performance, such as extending mission life or maximizing connectivity. The user can visualize the results through a set of configurable displays, and share these views with other SPEAR users on the network. This provides an important capability, enabling the predicted performance and tradeoffs of alternative plans to be viewed simultaneously by different stakeholders and decision-makers.

The complete SPEAR application includes a configurable user-interface, a generic simulation engine and database, and a plug-in architecture. The SPEAR decision support tool provides a structured framework for navigating the decision-making process, which includes five main steps: 1) Defining the reconfiguration scenario data; 2) Formulating the scenario as an optimization problem; 3) Categorizing the problem; 4) Solving the optimization problem; and 5) Displaying the resulting solution(s). The first step is supported by a customizable user interface to facilitate the definition of new requirements, objectives and priorities, and the selection of space assets that may be utilized. The problem formulation step utilizes an open underlying optimization framework (SPEAROpt) and an associated C++ library of support functions. The structure of the problem is analyzed and is then passed through a plug-in interface to an appropriate solver. Several interfaces to commonly used solvers are built-in, and more can be added by the user. Finally, the solution data is visualized using a menu of displays or through additional custom-built display plug-ins.

Feature	Advantage	Benefit
Modular, object-oriented framework	Enables reuse and custom integration of constituent modules	Systematic method for extending functionality
Drag-and-drop	New workflows can be built at	Custom solutions can be rapidly

interface	run-time without writing new source code	developed
Uses standard optimization problem formulations	Third party optimization solvers may be leveraged.	Reduces development time and risk
Multiple COAs presented with sensitivity data	Illustrates alternative solutions that optimize different aspects of performance	Users can more easily understand the tradeoffs associated with prioritizing different performance metrics
Performance metrics derived from Unified Joint Task List	Alternative COAs may be evaluated with respect to how well they serve specific items from the Unified Joint Task List (UJTL)	Decision-makers have immediate reach-back to formal requirements / objectives

The SPEAR software architecture is designed so that it can be easily extended to a broader range of applications. Modular software components are used to organize functionality, providing a menu of reusable interconnecting plug-ins that span three basic categories: interfaces, processors, and displays. To address a potential scenario, these plug-in modules are connected to a custom-designed “Problem Formulation” component, establishing an automated workflow that will produce and display alternative courses of action in response to triggering events. The diagram below illustrates a sample workflow, with external data acquired by interface modules and passed through a series of processor modules. The processed data is then passed to the Problem Formulation component, which generates a series of alternative COAs that are displayed to the user.

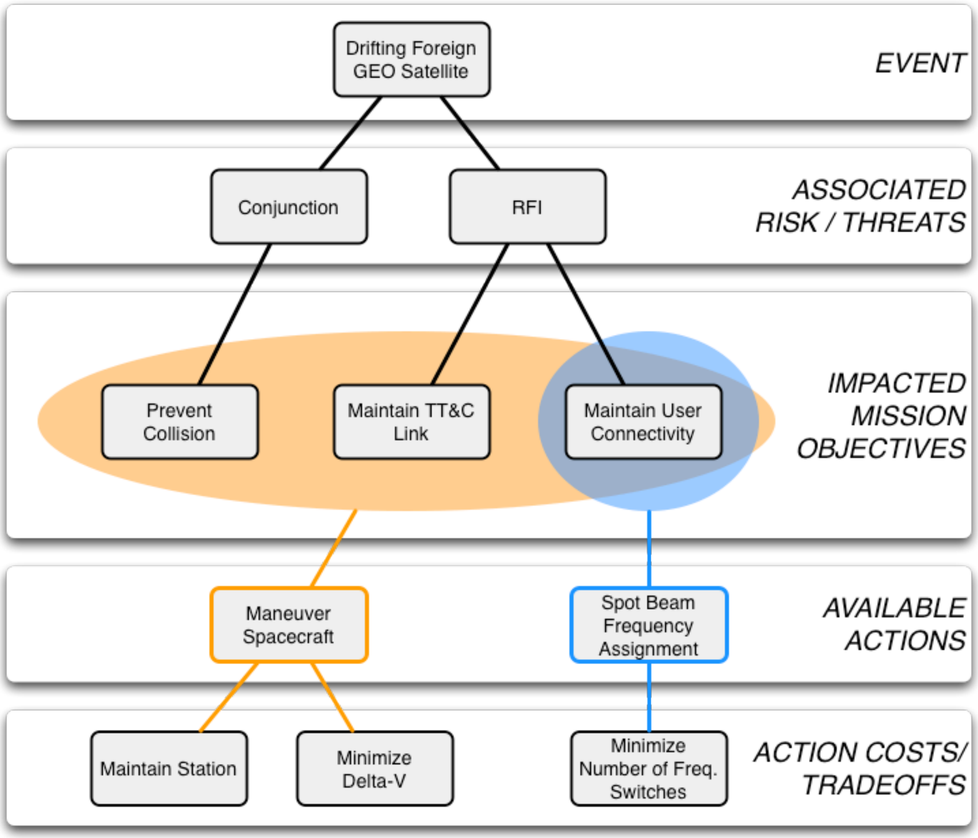

Figure 1: Event-Response Diagram for Drifting Satellite Scenario

CURRENT STATE OF DEVELOPMENT

The preliminary concept demonstration in September 2010 showed the application of the optimization algorithms applied to satellite beam patterns modeled after MUOS. The demonstration included a set of operational constraints that were used to produce an optimal allocation of frequency bands to spot beams in order to best support worldwide users, subject to geographic and frequency re-use constraints.

The prototype system demonstration in November 2011 showed the operation of SPEAR within a complex workflow and its ability to produce multiple courses of actions within a set of operational and satellite system constraints. The operational scenario developed for this demonstration is the determination of alternative COAs in response to a “rogue” drifting satellite that may collide with MUOS or – at a minimum – interfere with its communications. The operational requirements and user tasks were derived from the Unified Joint Task List and the satellite constraints were modeled after MUOS.

The demonstration includes an extensive set of plug-ins and a user interface that interactively communicates the COA’s to the user, allowing them to adjust the priority of performance metrics to generate new plans and outcomes. Figure 1 shows how the event maps to the risks of collision and Radio Frequency (RF) interference, which in turn impact several mission objectives. The available actions to mitigate the impact of these risks include orbital maneuvers and payload reconfiguration – and these actions have associated trade-offs. SPEAR develops a set of different potential courses of action that optimize these competing performance metrics to varying degrees, based on user-supplied priorities, and displays the predicted outcomes to the user.

REFERENCES

Technical Point of Contact: 619-981-1852

WHEN THE TECHNOLOGY WILL BE READY FOR USE

The version 1.0 release in September 2012 will provide a complete stand-alone system with built-in examples and supporting documentation. At this point the software will be ready for users to evaluate SPEAR's capabilities and its user interface. Ideally, these users and operators will come from government organizations and prime contractors that develop, operate and use satellites. Their input will add to SPEAR's set of optimization scenarios and provide critical feedback to the user interface.

The full system demonstration, scheduled for March 2013, completes the User Interface design and includes the ability for an operator to obtain COA's from a broad set of mission scenarios. With support from government organizations and satellite developers and operators this demonstration could be structured around solving their specific problems with satellite anomalous operations and reconfiguration.

In late-spring 2013, SPEAR will be implemented as a collection of Java web services for integration with the JSpOC Mission System (JMS) as a decision support tool. The integrated software will allow real-time access to the JSpOC's satellite database, threat data and allow JMS users to obtain COA's in response to their mission-specific scenarios. With the support described above, the implementation into JMS will be testable with operational-ready scenarios and user interfaces that have been fine-tuned by military users.

Milestone	TRL	Risk	Measure of Success	Date
Preliminary Concept Demonstration	3	-	Demonstration of algorithms to provide solutions in run-time setting	Sept 2010
Prototype System – MUOS Demonstration	5	Low	Demonstration of complex workflow and multiple COA generation	Nov 2011
SPEAR version 1.0	5	Low	Release SPEAR Software with built-in examples and comprehensive documentation	Sept 2012
Full System – MUOS Demonstration	6	Moderate	Demonstration of SPEAR with multiple reconfiguration scenarios supporting MUOS	March 2013
Integration with JMS	8	Moderate	Integration of SPEAR with JSpOC Mission System web services	March 2014

Upon completion of the SPEAR 1.0 release in September 2012, the software will be fully functioning in a standalone configuration with a set of relevant operational scenarios. Resources to allow development of a transition to the MUOS ground station in March of 2013 would increase the TRL of SPEAR and also provide distinct benefits to MUOS. Development of plug-ins to ingest MUOS mission data would allow further development of MUOS specific scenarios to be developed in SPEAR, providing immediate capability enhancement to the MUOS program.

ABOUT THE COMPANY

At Princeton Satellite Systems, Inc., we apply our expertise in guidance, control, estimation, and simulation to a broad range of aerospace problems. For the past 20 years, we have developed innovative solutions for missile defense, defensive counter-space, formation flying, collision monitoring and avoidance, and high-altitude airships. Our success in research and development across these fields stems from a core background in satellite orbit and attitude control. We developed the attitude control system for the Indostar, Cakrawarta-1 and BSat commercial communications satellites, and recently developed the safe orbit guidance mode for Prisma, a two spacecraft formation flying mission. We also sell commercial engineering software, including the Spacecraft Control Toolbox, which is used by numerous organizations throughout the world.