COTS Implementation of a Sensor Planning Service GetFeasibility Operation - Final Status

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Abstract-This paper reports on the progress of the design and implementation of a Web-based Sensor Planning Service (SPS) that provides GetCapabilities, DescribeTasking, and GetFeasibility operations for optical and radar Earth imaging satellites. The design is founded on Analytical Graphics COTS capabilities and Standard Object Catalog (SOC).

The SOC is a community-driven library of satellites with accurate and thorough descriptions of mission capabilities. Each SOC entry consists of a searchable description and an AGI Systems Tool Kit (STK) object modeling the satellite and its imaging payloads.

Aspects of two designs have been prototyped and evaluated. The first design is based on the architecture prescribed by the Open Geospatial Consortium (OGC®) Sensor Web Enablement (SWE) initiative in which the User exchaneges XML documents with the SPS. The second design has the SPS providing its functionality thorugth a web-based interface, freeing the User from the XML-document and message exchange paradigm.

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1. INTRODUCTION

Satellite tasking is the requesting of a satellite operator to collect an image of a specific feature of interest. This paper examines two aspects of satellite tasking and the resultant Web-based OverFlight Portal.

The first aspect is the transition of sensor system architecture and design from project-unique specifications to open-source specifications. This supports the sharing and integration of sensor tasking and observations.

The transition to open-source specifications is enabled by the OGC SWE initiative that provides a collection of standards for interacting with a network of Web-connected sensors and sensor systems. The sensors can be: 1) fixed or mobile, 2) space, air, land, or sea-based, and 3) environmental, scientific, or surveillance.

The OGC standards cover: 1) discovery of sensors and sensor capabilities, 2) planning and tasking of sensors, and 3) storing, discovery, and retrieval of sensor observations.

The second aspect is satellite tasking can be costly and subject to uncertainties. User tasking of some satellites is free, while tasking of other satellites can cost $10,000 or more per image request. The uncertainties arise from the User not knowing when the satellite will pass over the feature of interest with the desired collection geometry.

A COTS SPS, covering all optical and radar imaging satellites, that provides for 1) discovering sensors and receiving sensor descriptions and 2) formulating and determining the feasibility of a collection task, would allow a User to assess the capabilities of all Imagery Providers (IPs) before placing a tasking order with a selected IP.

Sections 2 and 3, along with Figures 1 and 2, provide an overview of SWE and SPS. Section 4 outlines the benefits of a COTS SPS. Sections 5 and 6 present the core capabilities of the COTS SPS: AGI Components and the SOC. Sections 7 and 8 and Figures 5 and 6 illustrate the level of detail employed in modeling optical and radar payloads.

Sections 9 and 10 and Figures 7 and 8 present two design paradigms for the COTS SPS. The first design paradigm

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is based on the User exchanging XML documents with the COTS SPS. The second paradigm is the OverFlight Portal - COTS SPS in which a User accesses the COTS SPS functionality through a Web-based interface.

2. SENSOR WEB ENABLEMENT

Figure 1 is an overview of the OGC Sensor Web Services.

Sensor Planning Services (SPSs) provide a series of capabilities for Users, including: 1) discover sensors and receive sensor descriptions, 2) formulate and determine the feasibility of a collection task, and 3) submit a collection task and locate the results. Each SPS operation has request and response components. The User sends a request message to the service and the service returns a response message.

Sensor Observation Services (SOSs) provide the capability for Users to discover and receive sensor descriptions and to request, filter, and retrieve sensor observations. The filtering can be on time, sensor, or phenomenon. The sensor observations can be retrieved from an observation repository or streamed real-time from a sensor. There is also the capability for Sensor Management Systems (SMSs) to register and to publish sensor observations to the SOSs.

Sensor Alert Services (SASs) provide the capability for Users to discover sensor alerts and to register for and receive sensor alert messages. An alert is a notification that a certain observation event occurred at a feature of interest. There is also the capability for SMSs to register and to publish observation event messages to the SASs.

Users discover individual SPSs, SOSs, and SASs via a series of SWE registries.

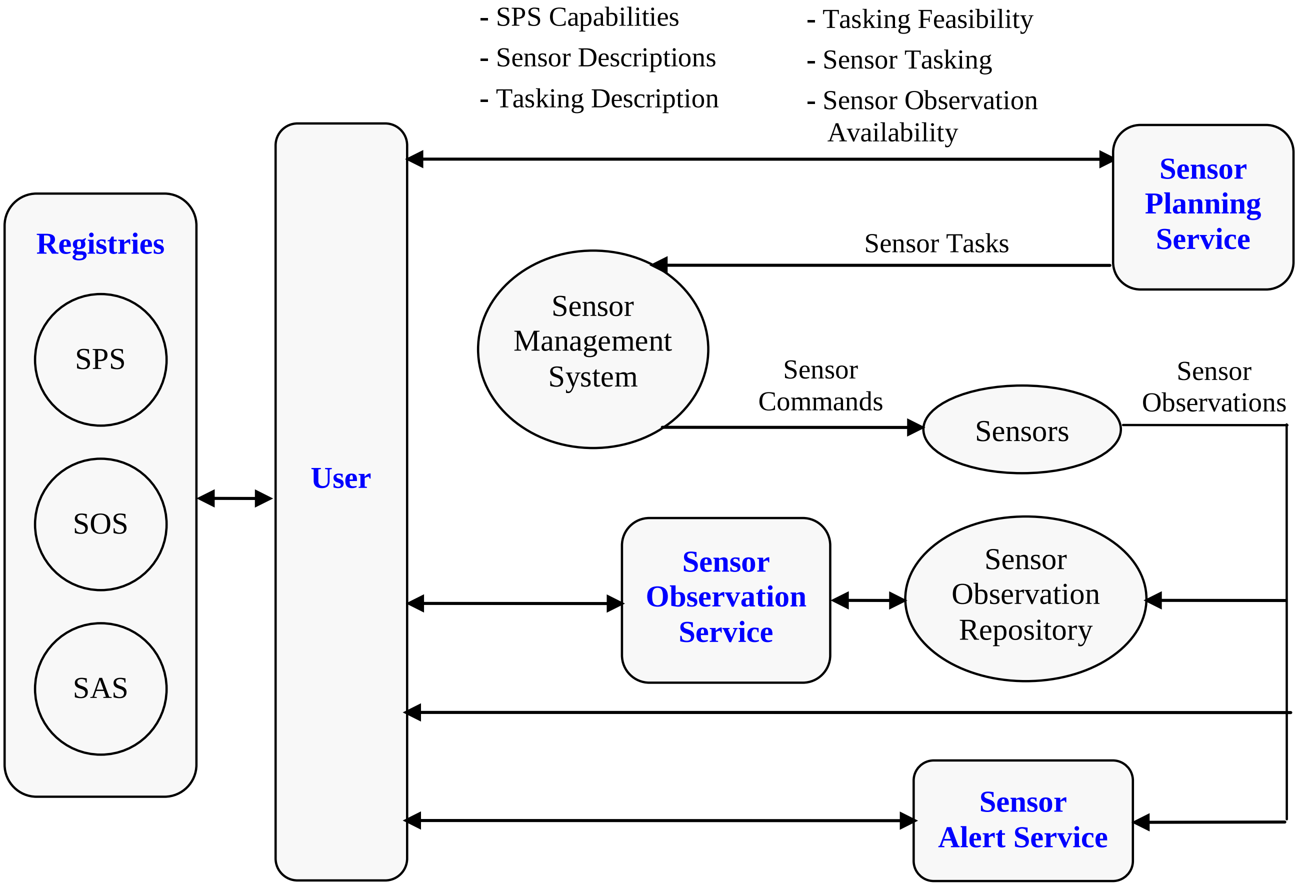


Figure 1. Overview of Sensor Web Services

3. SENSOR PLANNING SERVICE

Figure 2 is an overview of SPS capabilities to: 1) discover sensors and receive sensor descriptions and 2) formulate and determine the feasibility of a collection task.

The User exchanges XML documents and messages with the SPS in accordance with SPS Application Specification, OGC 07-014r3. [1] It includes a description of SPS operations, parameter definitions and encodings, XML schema, and sample XML documents. The XML schema provides the structure of the data passed between the User and the SPS. The XML documents are the instantiation of the schema.

The GetCapabilities operation provides a list of sensor IDs and a description of each sensor, including the phenomena that can be measured, the region the sensor operates in or can be tasked to observe, and the location of a detailed description of the sensor.

The DescribeTasking operation provides the input parameters list needed by the GetFeasibility operation.

The GetFeasibility operation provides an evaluation of the feasibility of accomplishing the collection task: feasible, not feasible, and not feasible but alternatives available. The evaluation can be as simple as checking the validity of the inputs or as complicated as modeling the collection activity.

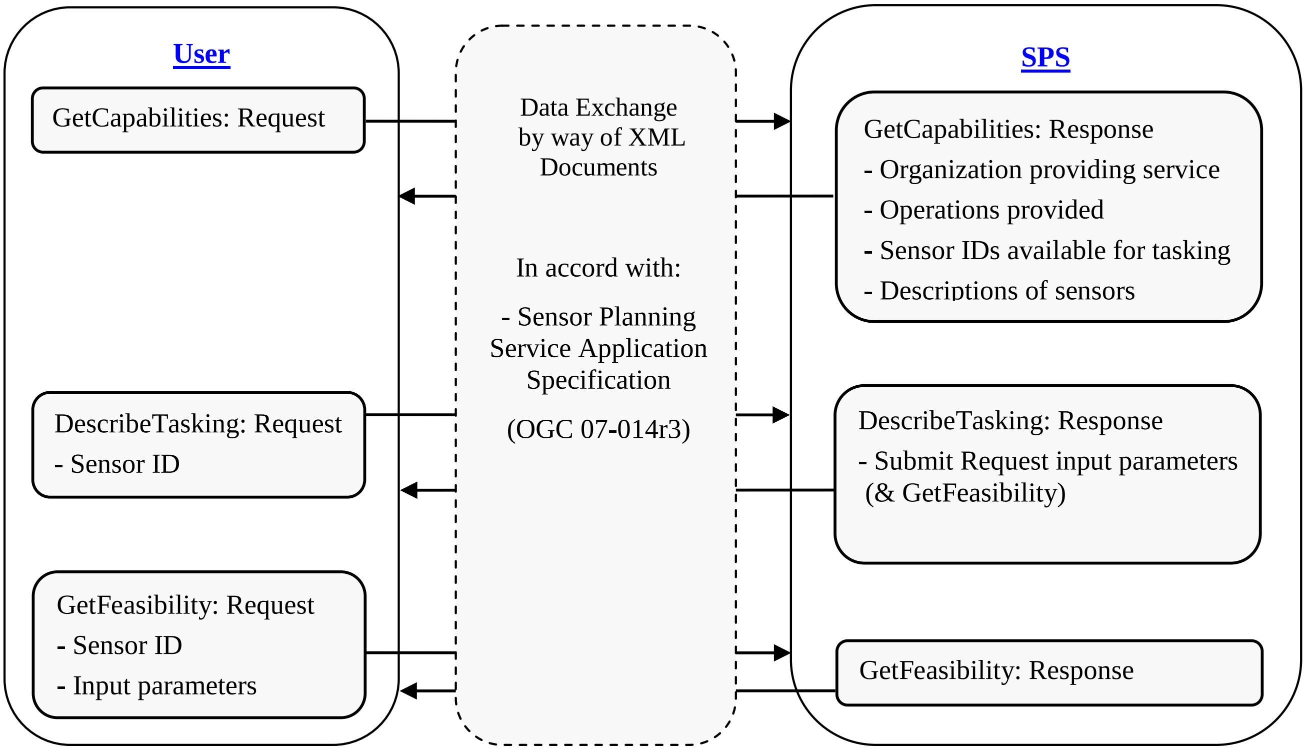


Figure 2. Overview of SPS Capabilities

4. BENEFITS OF A COTS SPS

The COTS SPS consists of the GetCapabilities, DescribeTasking, and GetFeasibility SPS operations for optical and radar Earth imaging satellites.

A benefit of a COTS SPS is the User does not need to locate SWE registries and assemble a list of individual Imagery Providers (IP) sites (all are represented in one site) and determine which IPs support User tasking of new imagery or just support ordering of existing imagery.

Another benefit is the first level of interaction with an IP is common to all IPs. Once a short list of sensors has been down selected from the COTS SPS, the User can directly interact with the selected IPs. The following could be a typical use case.

A User interacts with the COTS SPS to discover a list of candidate IPs that have the potential of satisfying a particular collection task: IP#2, IP#4, IP#5, IP#7, IP#10, and IP#12. Based on the Determine Feasibility Results provided by the COTS SPS, IP#2 is not selected due to insufficient ground resolution and IP#4 is not selected due other IPs having nearer-term access.

IP#5 and IP#7 have implemented SPSs. The User interacts with IP#5 to formulate a collection task and to determine feasibility but does not select IP#5 since the IP is not able to incorporate the collection task into a near-term schedule. The User interacts with IP#7 and submits a collection task after finding satisfactory collection feasibility and scheduling opportunity.

IP#10 and IP#12 have not implemented SPSs. The User submits orders to both IPs. The User specifies task acquisition time to IP#12 in order to force desired acquisition conditions reported by the COTS SPS.

These benefits are particularly important given the rapid growth of satellite remote sensing. In 1991, there were only 5 nations which had access to satellite remote sensing assets: United States, Japan, Russia, India, and France. [2] Since then, the world has seen the impact of low-cost and micro satellite technology spread around the world with a current fleet of 62 optical imaging satellites from over 19 countries. [3]

Forty-seven of these platforms are civilian/commercial programs, and most of their data can be procured publicly. Figure 3 shows the growth of this market along with the distribution of countries contributing to it. With so many publicly available sources of data, resolutions varying from 10s of meters to less than 1 meter, satellites with different agility (the ability to change orientation and point at a target), sensors with different swaths (the area on the Earth’s surface it can cover), payloads with different spectral coverage, and satellite orbits with different revisit rates, it becomes very challenging for a User to determine which satellite is really best for getting an image quickly and affordably. Figure 4 visually depicts this challenging problem in STK’s 3D environment populated with the active imaging satellites.

The design of the COTS SPS is founded on Analytical Graphics COTS Components capabilities and Standard Object Catalog (SOC), as described below.

5. AGI COMPONENTS

AGI Components is a family of low-level class libraries that provide access to specific analytical and 3D visualization capabilities. Dynamic Geometry Library provides modeling of time and position for accurate vehicle propagation and sensor modeling. Additionally, the library provides algorithms to compute position, orientation, and inter-visibility intervals between land, sea, air, and space assets. The Spatial Analysis Library enables component Users to compute asset coverage of gridded regions and time-dynamic platforms.

The GetFeasibility operation is based on AGI Components. It accommodates geometrical and temporal collection tasking requirements. The GetFeasibility operation does not implement a detailed ground coverage simulation, such as modeling an imaging payload that is configured on an image-by-image basis for a range of quality collections, nor does it attempt to model multiple overlapping ground coverage images. This level of GetFeasibility simulation is best provided by the individual IPs.

6. STANDARD OBJECT CATALOG

The SOC is a community driven library of satellites with accurate and thorough descriptions of mission capabilities. Each SOC entry consists of a searchable description and STK objects. The SOC entry also provides the reference sources for the satellite descriptions.

The objects are components of AGI’s mission modeling capabilities. Examples of objects are scenarios, satellites, and imaging payloads. The scenario, the highest level object, contains other objects and is the outline for a series of actions that can be visualized.

Sensor parameters provided by reliable sources are used to model a sensor field-of-view and field-of-regard. A field of view that has pointing agility can be pointed anywhere within the field of regard. Sensor models include rectangular or conic projections with a line of sight defined by an azimuth and elevation. Azimuth is measured from the satellite ECF velocity pointing x-axis and elevation is measured from the satellite nadir pointing z-axis. The field of view is defined by a rectangular projection that sweeps along the ground. The field of regard is defined by a rectangular projection if the field of view is constrained cross-track.

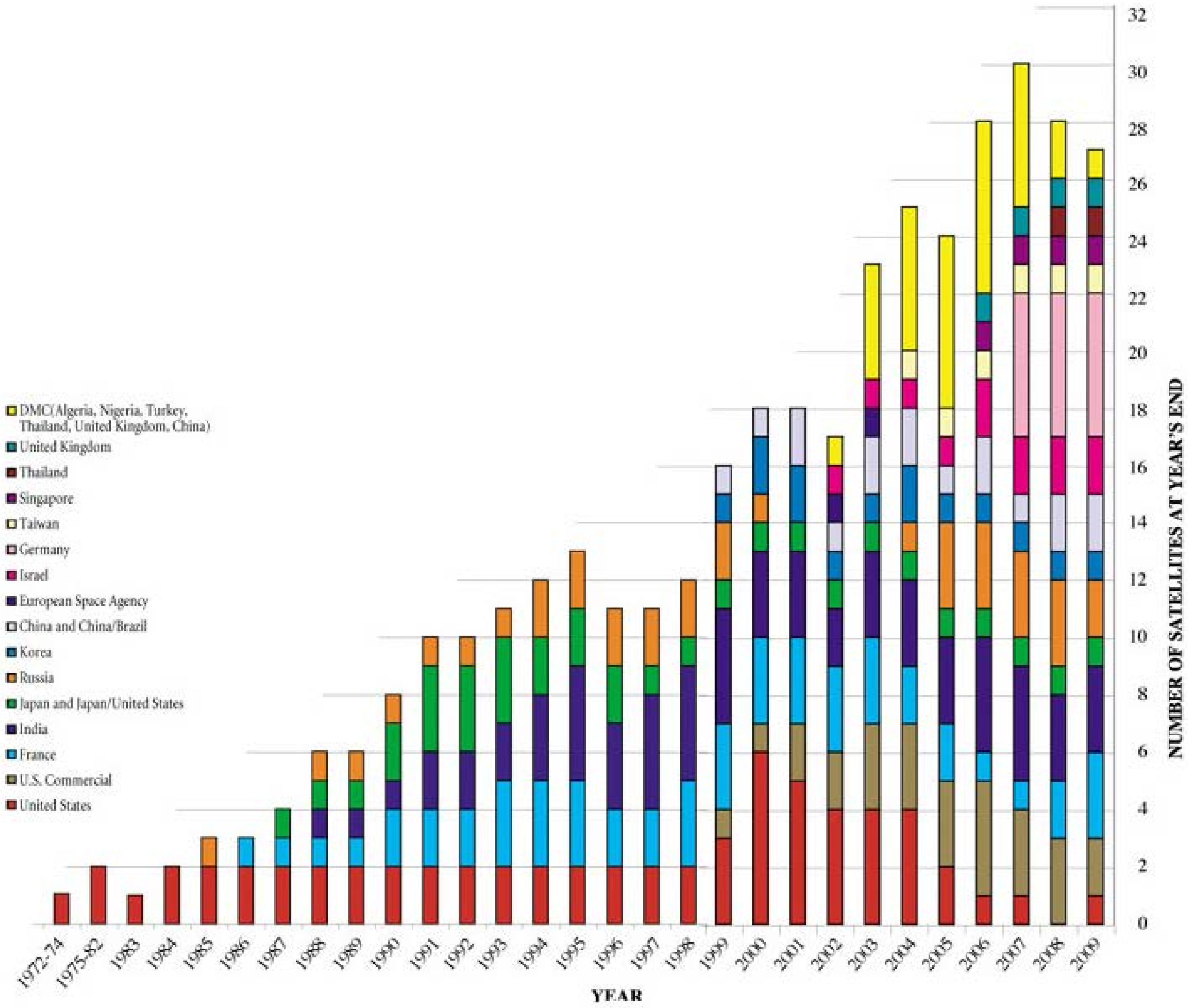


Figure 3. Number and Distribution of Commercial Imaging Satellites

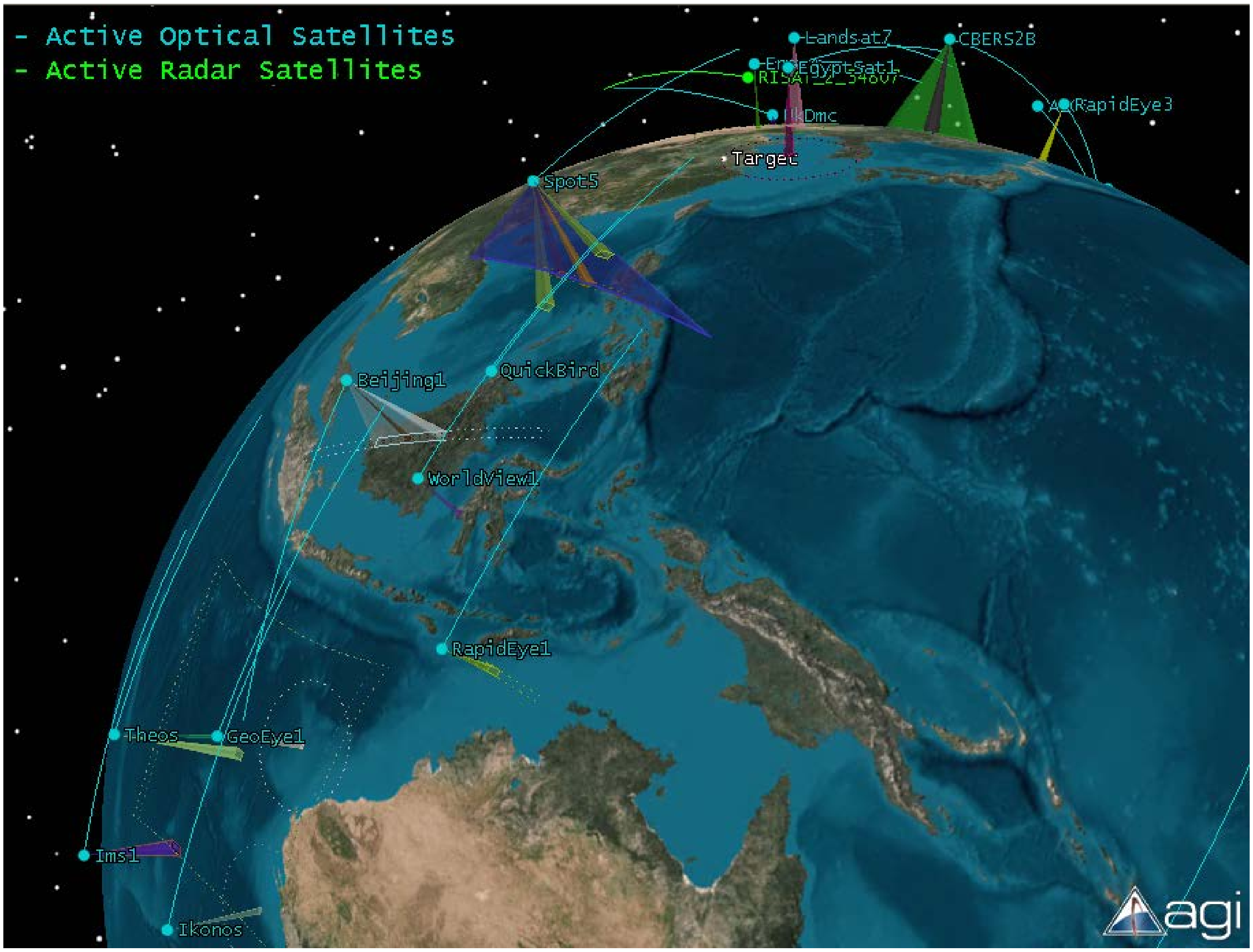


Figure 4. Screen Shot From STK 3D Environment of SOC Satellite, Orbit, and Sensor Projection

Figure 5 and Figure 6 illustrate breath and depth of the SOC data architecture. Figure 6 shows SOC data elements for satellites with optical or radar imaging payloads. Note the one-to-many relationships. A satellite can have one or more Payload elements. A Payload element can have one Optical Payload element, which can have one or more Optical Payload Operations elements. A Payload element can have one or more Radar Payload Operation elements.

The SOC also has elements for navigation and communication satellites.

The Satellite Classification element includes NORAD catalog number, name, alternate names, and country of origin. The Optical Payload element includes agility, scene size, field of view (FOV), and field of regard (FOR). The Optical Payload Operation element includes ground resolution and spectral range.

The Radar Payload Operation element includes operating band, scan mode, scene size, incident angle (a measure of agility), ground resolution, FOV and FOR . Examples of radar scan modes are spotlight and scan SAR.

The field of view is derived from scene size and nominal altitude. The field of regard is based on the agility of the satellite and imaging payload.

The level of modeling detail is illustrated in the description of the French Spot 5 optical imaging satellite in Section 7and the TerraSAR-X radar imaging satellite in Section 8.

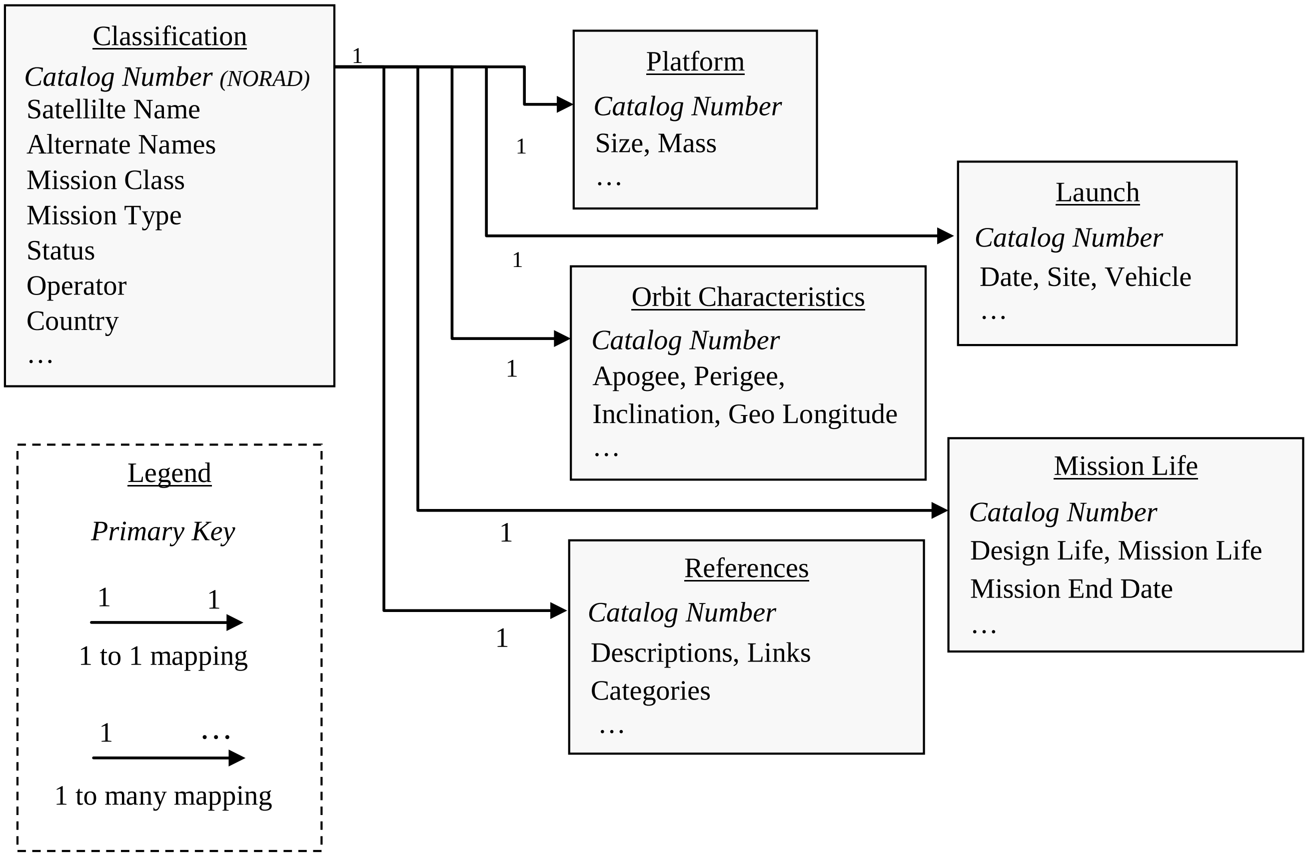


Figure 5. SOC Data Architecture - Part 1

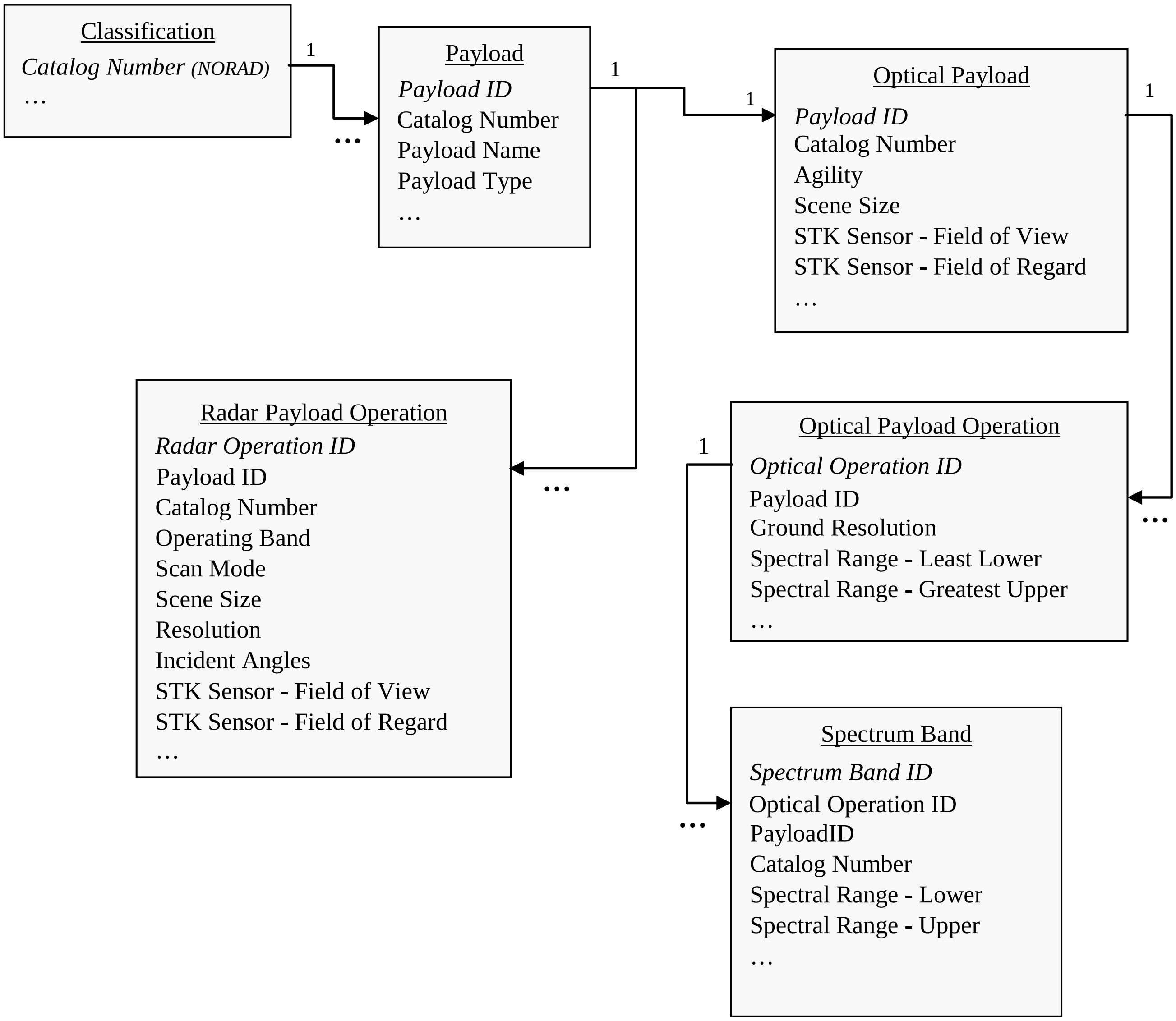


Figure 6. SOC Data Architecture - Part 2

7. OPTICAL PAYLOADS

An optical imaging payload is characterized by the nadir projection of its field of view in kilometers and cross-track ground resolution (ground sample distance) in meters at its nominal operating attitude in kilometers. The angular field of view is determined from the projected field of view and altitude.

An optical imaging satellite will have one or more imaging payloads. For example, the French Spot 5 satellite has five imaging payloads: HRG-1, HRG-2, HRS-1, HRS-2 and Vegetation. HRG-1 and HRG-2 are capable of panchromatic imaging with 5-m ground resolution, multispectral imaging across three bands with 10-m resolution, and short-wave infrared imaging with 20-m resolution. HRG has a 60-km field of view modeled with a 2.1-deg cross-track half angle.

An imaging payload is said to have agility if its field of view can pointed to image a target. Agility can be achieved by a rotating mirror, a gimbaled payload, or a steerable satellite. The agility is the payload field of regard. The HRG field of view can be pointed up to 27 deg cross-track by a rotating mirror to give a field of regard modeled with a 29.1-deg cross-track half angle.

HRS-1 and HRS-2 are for panchromatic stereo imaging with 10-m ground resolution. One camera points forward from nadir and the other points aft. HRS has a 120-km field of view modeled with a 4.2-deg half angle. The fore camera line of sight is 0-deg azimuth, 70-deg elevation. The aft camera line of sight is 180-deg azimuth, 70-deg elevation.

The fifth sensor, Vegetation, has four imaging bands with 1,165-meter ground resolution. The 2,250-km field of view is modeled with a 50.6-degrees half angle.

8. RADAR PAYLOADS

A radar imaging satellite will have one imaging payload with several selectable operational modes. The operating mode is characterized by its field of view, ground resolution, and upper and lower incident angle limits. The incident angle is the angle between the radar beam and the normal to the ground surface. The incident angles define the ground swath width. Depending on the source documentation, ground resolution is specified by the range and azimuth.

For example, the German TerraSAR-X satellite has four operating modes: high resolution spotlight, spotlight, stripmap, and scanSAR.

The high resolution spotlight mode has a 10-km cross-track field of view and 2-m by 1-m ground resolution. It has 20-deg and 55-deg incident angle limits which give a 463-km swath width. The field of view is modeled with a 0.4-deg half angle and a 90-deg azimuth, 66-deg elevation line of sight. The field of regard is modeled with a 15.4-deg half angle and a 90-deg azimuth, 56.1-deg elevation line of sight.

9. DESIGN PARADIGM 1

The first design paradigm is based on the User exchanging XML documents with the COTS SPS.

Figure 7 is an overview of the prototype work flow functionality for a COTS implementation of the GetCapabilities, DescribeTasking, and GetFeasibility operations of an SPS.

Data exchanges between a User and an SPS are specified by a schema. The prototype employs Satellite Capabilities, Tasking Definition, and Acquisition Feasibility schema. They are not intended to be one-off versions of the GetCapabilities, DescribeTasking, and GetFeasibility schema. They are sparse schemas that support the design of the data exchanges needed for employing AGI mission modeling capabilities.

Satellite Capabilities

The Satellite Capabilities Request schema, illustrated in Figure 7, consists of Country and Payload Type elements. These are the elements defined in the satellite schema's Satellite Classification and Payload Operations elements.

The User populates the Satellite Capabilities Request XML document and sends it to the Proof-of-Concept (PoC) - SPS where it is received and parsed. The PoC-SPS searches and retrieves Satellite Classification and Payload Operation data from the SOC, populates the Satellite Capabilities Response XML document, and sends it to the User.

Acquisition Feasibility

The User receives and parses the Satellite Capabilities Response XML document and selects the applicable satellite and imaging payloads. The User populates the Acquisition Feasibility Request XML document and sends it to the PoC-SPS where it is received and parsed.

The Acquisition Feasibility Request schema, illustrated in Figure 7, contains Satellite Payload Pairing, Feature of Interest, and Acquisition Constraints. A Feature of Interest is defined by a ground point. The request also includes Optical Operation from the Optical Payload element or the Scan Mode from the Radar Payload Operation.

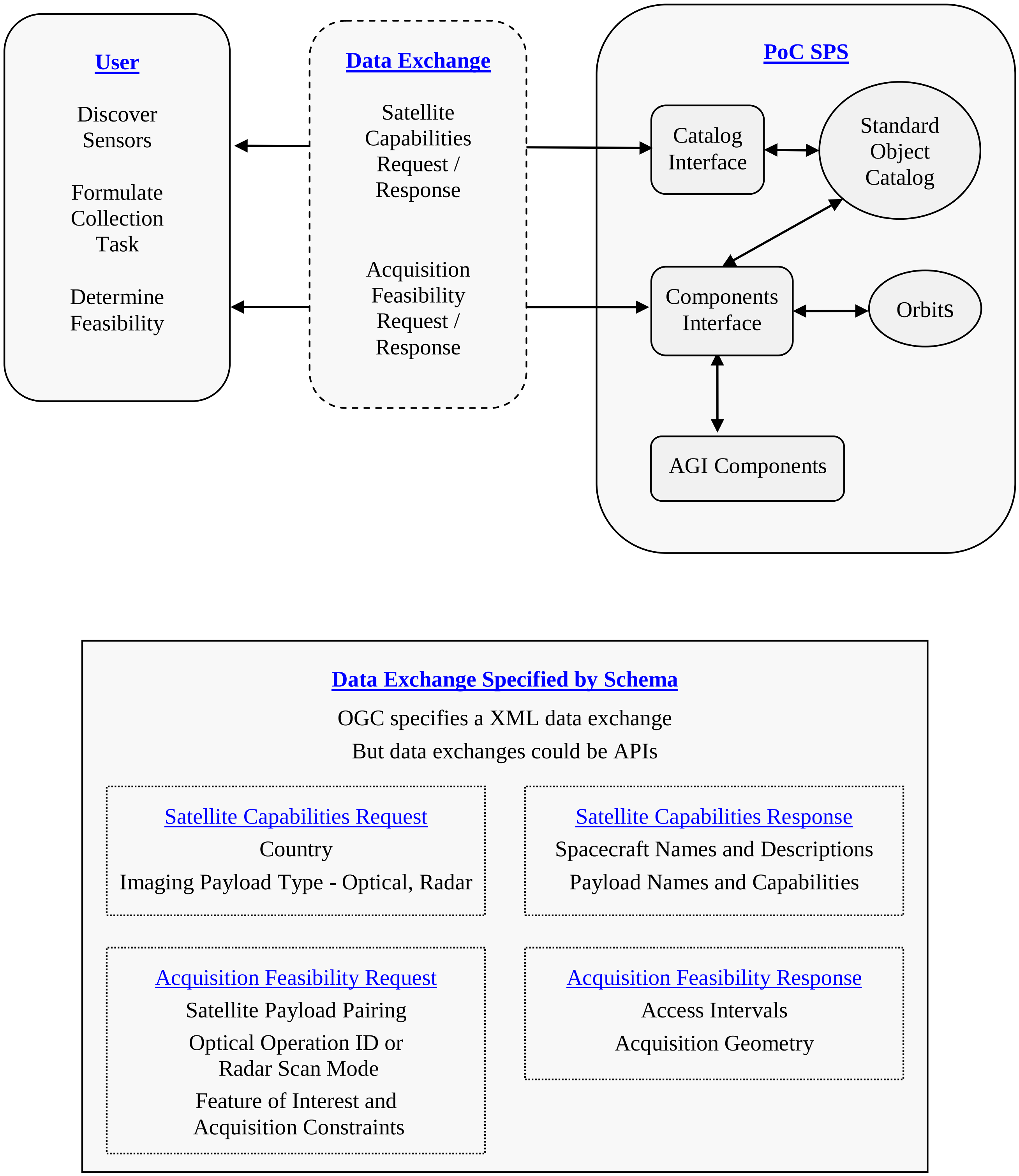
A full set of acquisition constraints includes geometric, temporal, environmental, and quality parameters.

The PoC-SPS receives and processes the Acquisition Feasibility Request. The satellite payload pairing is used to retrieve the payload field of regard from the SOC and the satellite orbital elements from CelesTrak, the authoritative source of NORAD orbital elements. Then the AGI Components are activated to determine the Acquisition Feasibility Response.

The payload field of regard is used instead of the field of view because it corresponds to the in-track and cross-track range that the payload could be pointed.

The Acquisition Feasibility Response sequence contains a number of acquisition interval start and stop times and corresponding acquisition geometry. The PoC-SPS populates the Acquisition Feasibility Response XML document and provides it to the User.

A prototype of design paradigm 1 was developed to demonstrate the Get Capabilities and Get Feasibility interface with a User and with AGI Components. The prototype proved out the functionality, but the design, based on exchanging XML documents with an SPS, is not especially User friendly.



Data Exchange Specified by Schema

OGC specifies a XML data exchange

But data exchanges could be APIs

Satellite Capabilities Request

Country

Imaging Payload Type - Optical, Radar

Satellite Capabilities Response

Spacecraft Names and Descriptions

Payload Names and Capabilities

Acquisition Feasibility Request

Satellite Payload Pairing

Optical Operation ID or Radar Scan Mode

Feature of Interest and Acquisition Constraints

Acquisition Feasibility Response

Access Intervals

Acquisition Geometry

Figure 7. Work Flow Functionality for Proof of Concept Prototype COTS SPS

10. DESIGN PARADIGM 2

The second design paradigm is the OverFlight Portal - COTS SPS in which a User accesses the COTS SPS functionality through a Web-based interface, freeing the User from developing code for the XML-document and message exchange paradigm.

Figure 8 is an overview of the prototype work flow functionality for the OverFlight Portal. The similarities to design paradigm 1 PoC SPS illustrated in Figure 7 are obvious and the data schema created for design paradigm 1 carries over to into the internal design of the OverFlight Portal.

Figures 9 illustrates graphical aspects of the prototype User work flow:

1) Specifying a Feature of Interest graphically by drilling-down on a world map. This eliminates errors and inaccuracies when entering latitude, longitude and altitude values by hand

2) Settting imaging contraints: a) Feature of Interest to satellite line-of-sight minimum elevation angle and minimum and maximum azimuth angles and b) Feature of Interest to Sun line-of-sight minimum and maximum elevation angle.

3) Creating list of candidate satellites and sensors by setting filter criteria, including imaging payload type (optical and/or radar), satellite name, operator, country, and ground resolution. The User can set spectral range filter criteria for optical imaging satellites.

4) Selecting from the candidate list of satellites and sensors, setting the scenario start and end date/times, and initiating scenario analysis. The operator data includes indentifying if the User can submit an imagery collection task request to the operator, or can just retrieve an existing imagery from a distribution source.

5) Reviewing scenario analysis results, including orbital ground track with identification of collection intervals and conditions.

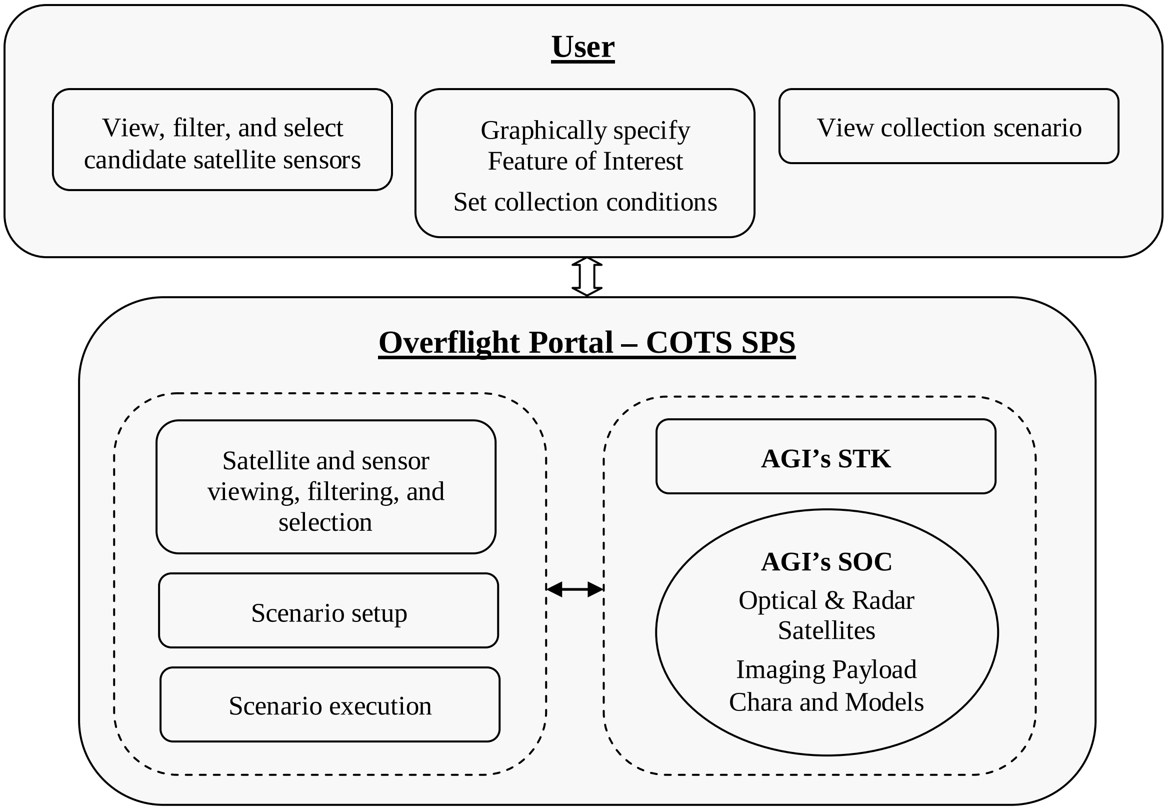
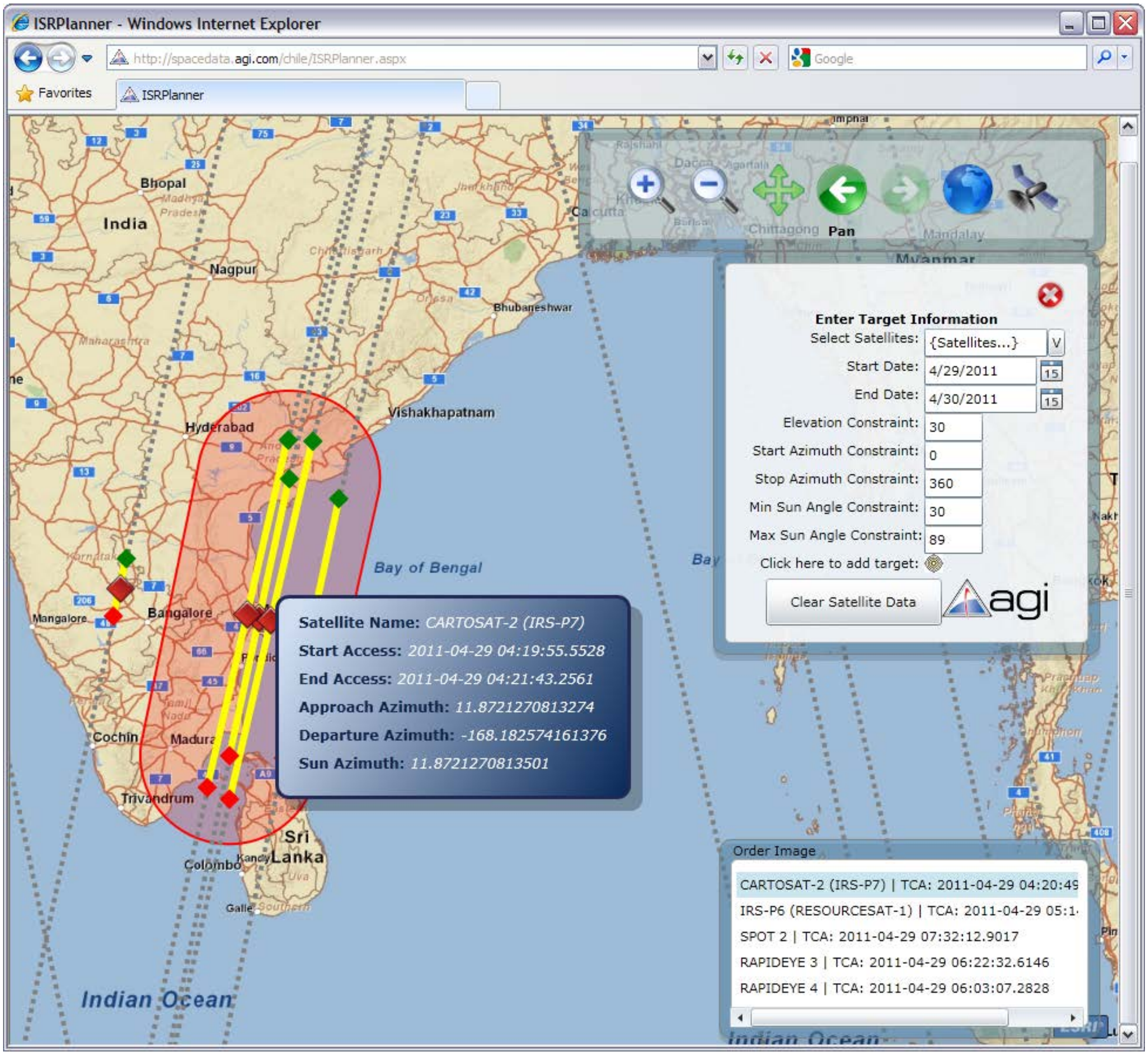


Figure 8. Work Flow Functionality for Overflight Portal



Enter Target Information

Select Satellites: {Satellites...}

Start Date: 4/29/2011

End Date: 4/30/2011

Elevation Constraint: 30

Start Azimuth Constraint: 0

Stop Azimuth Constraint: 360

Min Sun Angle Constraint: 30

Max Sun Angle Constraint: 89

Click here to add target:

Clear Satellite Data

Satellite Name: *CARTOSAT-2 (IRS-P7)*

Start Access: *2011-04-29 04:19:55.5528*

End Access: *2011-04-29 04:21:43.2561*

Approach Azimuth: *11.8721270813274*

Departure Azimuth: *-168.182574161376*

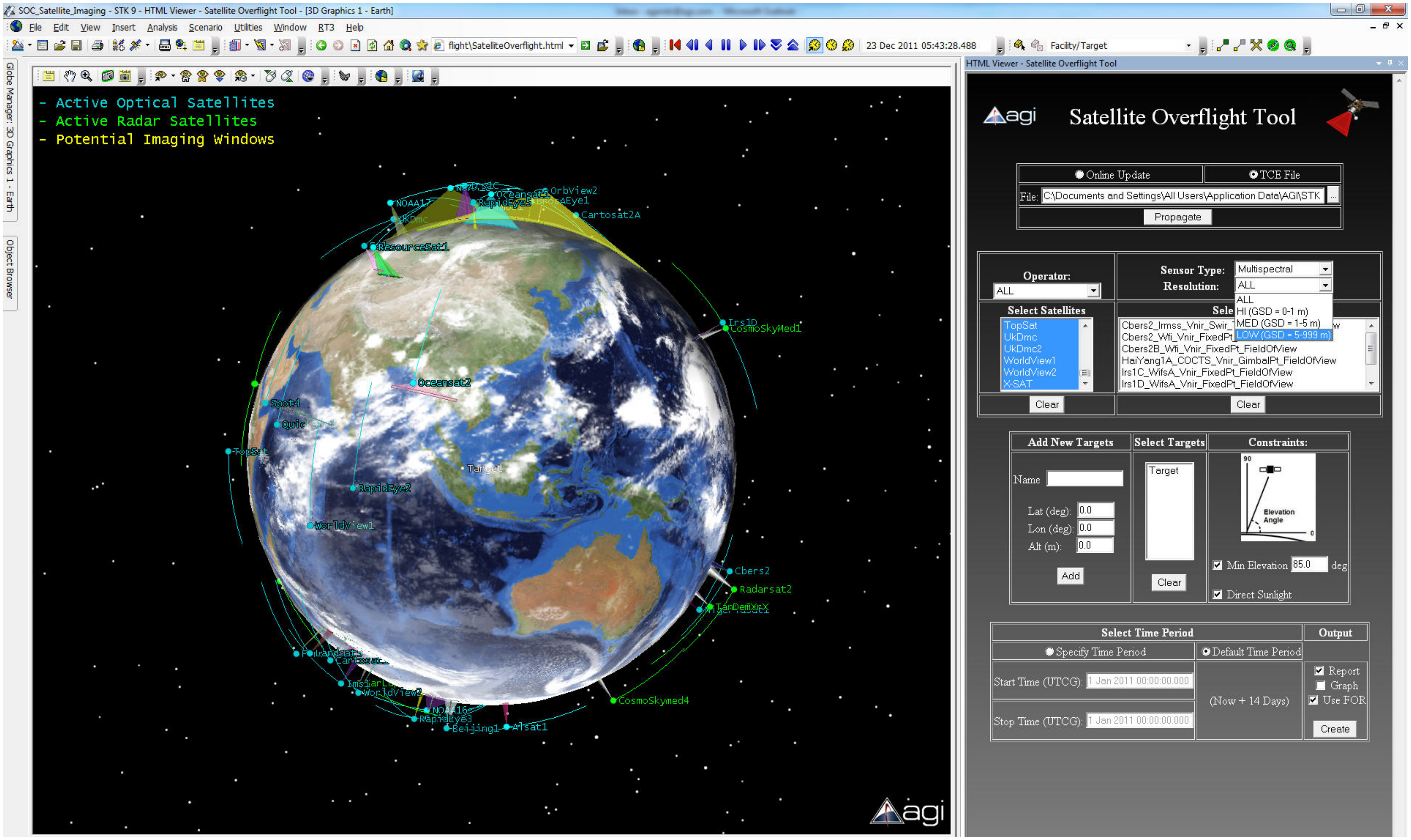
Sun Azimuth: *11.8721270813501*

Order Image

CARTOSAT-2 (IRS-P7) | TCA: 2011-04-29 04:20:49
IRS-P6 (RESOURCESAT-1) | TCA: 2011-04-29 05:1
SPOT 2 | TCA: 2011-04-29 07:32:12.9017
RAPIDEYE 3 | TCA: 2011-04-29 06:22:32.6146
RAPIDEYE 4 | TCA: 2011-04-29 06:03:07.2828

Figure 9. Proof of Concept Prototype of Overflight Portal

Figure 10 is a mock-up of the operational OverFlight Portal. The User will be able to select satelites and sensors based on satellite operator, sensor type, and resolution. The User will be able to populate and select from a pool of targets of interest as well as specify geometric and temporal collection conditions. The OverFlight Portal will display potential access intervals and sensor ground coverage.



○ Online Update ● TCE File

File: C:\Documents and Settings\All Users\Application Data\AGI\STK

Operator: ALL

Sensor Type: Multispectral

Resolution: ALL

ALL
HI (GSD = 0-1 m)
MED (GSD = 1-5 m)
LOW (GSD = 5-999 m)

Select Satellites:
TopSat
UkDmc
UkDmc2
WorldView1
WorldView2
X-SAT

Cbers2_Irmss_Vnir_Swir_
Cbers2_Wfi_Vnir_FixedPt_
Cbers2B_Wfi_Vnir_FixedPt_FieldOfView
HaiYang1A_COCTS_Vnir_GimbalPt_FieldOfView
Irs1C_WifsA_Vnir_FixedPt_FieldOfView
Irs1D_WifsA_Vnir_FixedPt_FieldOfView

Name

Lat (deg): 0.0

Lon (deg): 0.0

Alt (m): 0.0

Target

☑ Min Elevation 85.0 deg

☑ Direct Sunlight

○ Specify Time Period ● Default Time Period

Start Time (UTCG): 1 Jan 2011 00:00:00.000

Stop Time (UTCG): 1 Jan 2011 00:00:00.000

(Now + 14 Days)

☑ Report

☐ Graph

☑ Use FOR

Figure 10. Mock-up of Operational Overflight Portal

11. CONCLUSIONS

A Web-based SPS providing GetCapabilities, DescribeTasking, and GetFeasibility operations for all optical and radar Earth imaging satellites makes it easy for Users to discover and task Imagery Providers (IPs) and sensors that fulfill the User's imagery tasking needs.

The design is founded on Analytical Graphics COTS capabilities and Standard Object Catalog (SOC). The SOC has been populated with a complete list of commercial optical and radar imaging satellites and sensors.

Two design paradigms have been prototyped: 1) The architecture prescribed by the OGC Sensor Web Enablement (SWE) initiative in which the User exchanges XML documents with the SPS and 2) The SPS providing its functionality through a web-based interface. The second paradigm, the OverFlight Portal, is the preferred design. It frees the User from the XML-document and message exchange paradigm.

The OverFlight Portal can also be used to look back in time to see what IPs and sensors may have imaged a particular feature of interest with particular collection geometry.

Near term enhancement to the OverFlight Portal will include area coverage.

Longer term enhancements could include using open-source predicted cloud cover and IP provided imagery schedule times that are open for tasking.

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BIOGRAPHY

Dave Kaslow is Director, Product Data Management at AGI. He has thirty-seven years of experience in both the technical and management aspects of developing ground mission capabilities. He is also the editor of Spacecraft Digest, www.stk.com/scdigest, which tracks current and future spacecraft and spacecraft missions. He is co-author of "Defining and Developing the Mission Operations System", "Activity Planning", "FireSat" and "Spacecraft Failures and Anomalies" in Cost-Effective Space Mission Operations. He is also the author and co-author of papers for the International Council on Systems Engineering (INCOSE) Annual International Symposiums and for the IEEE Aerospace Conference.

Adam Gorski is Manager, Systems Engineering at AGI where he oversees the professional development of AGI's systems engineers. Adam holds a bachelor of science in Aerospace Engineering from the University of Illinois at Urbana-Champaign and is a graduate of the US Marine Corps Officer Candidates School in Quantico, VA. Prior to his current role, Adam was the lead engineer for AGI in the Asia-Pacific region providing training and support for customers and AGI business partners.

Todd A. Smith is AGI's Geospatial Market Evangelist. In this role, Todd develops strategy to integrate and apply AGI's ISR analysis and visualization capability into broader C4I market areas. Todd also advocates COTS interoperability between complementary industries such as GIS, C2 and modeling and simulation. With Todd's deep knowledge and experience in the enterprise geospatial tradecraft, he also positions AGI technology within federated, enterprise and service-oriented architectures. Todd gives support to global ISR communities to develop requirements and solutions via AGI software technology. Before joining Business Development, Todd was AGI's product manager for enterprise integration. Prior to joining AGI in 2006, Todd served as a technical project manager of military solutions at GeoDecisions. He holds a B.S. in geography and GIS from Penn State University.