Ground Segment Integration: a nightmare turning into sweet dreams thanks to CCSDS SM&C

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Would you like to be able to assemble your next ground segment by reusing a number of available components? Imagine if, for each component, say for example the Mission Planning System, you could choose from reusing either what you had developed for a previous mission or a set of components some of which possibly available commercially. Imagine also that these components would just seamlessly plug-in your system leaving you with just an (easy) integration task. If you are interested in all this, then read this paper!

Nomenclature

AMS = Asynchronous Messaging Service  
API = Application Programming Interface  
CCSDS = Consultative Committee for Space Data Systems  
ESA = European Space Agency  
MAL = Message Abstraction Layer  
MO = Mission Operations  
SM&C = Spacecraft Monitoring and Control  
WG = Working Group

I. Introduction

Four years after its inception, the CCSDS Spacecraft Monitoring and Control (SM&C) working group has been able to cast its vision down into a concrete prospective, the SM&C framework, to the benefit of any organisation responsible for the procurement and integration of ground segments for space missions.

The SM&C framework is based on a Service Oriented Architecture which is meant to largely simplify the job of ground segment project managers, including:

- Ability of building up the ground segment by simple integration of available commercial and non-commercial plug-in components
- Independence from underlying technology
- Simplified maintenance via individual replacement of outdated components
- Interoperability with several suppliers of components and partner organisations.

And, of course, all the above will be achieved for just a fraction of the cost, the schedule and the risks. To achieve this, the basic building blocks are already in place.

The SM&C Message Abstraction Layer (MAL), a soon-to-be approved CCSDS standard, provides a generic mechanism to all application-level services to allow for software language and message transport and encoding independence. A software language mapping is required to map the independent MAL interfaces into the required language, a transport/encoding mapping is required to map to the chosen message transport and encoding. The SM&C WG is finalising the software language mapping into Java and it is currently working on a number of transport mappings.

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2 Participation by 10 space Agencies from Brazil (INPE), Canada (CSA), Europe (ESA), France (CNES), Germany (DLR), Italy (ASI), Japan (JAXA), Russia (FSA), UK (BNSC), USA (NASA).
The SM&C Common Services, another soon-to-be approved CCSDS standard, provides services, defined in terms of the MAL, that are common to all application-level services, such as Directory, Login, Configuration, Interaction, Retrieval and Replay services.

These two basic building blocks allow the definition of a homogeneous set of application-level services, the SM&C Mission Operations (MO) services, that define the framework for spacecraft monitoring and control. As an example, the Mission Planning service, one of the MO services, will define the interfaces exposed by a mission planning system. This will allow the development of mission planning tools that could seamlessly plug-in into existing ground segments. It follows that industrial competition will become more global with different organisations promoting their own SM&C-compatible tool with focus on the smartness of their functionality. In other words, SM&C has removed the boring and trivial part to component development and left the clever, algorithmic part for competition. The following provide the lists of the currently identified MO services:

- Classical TM, Event monitoring & TC generation (Core Services)
- Remote software management
- Time management
- Mission product data management
- Mission planning and automation
- Orbit, Attitude and Position determination
- Standard interaction with the operator.

The SM&C Core Services, the first MO service suite soon-to-be approved as CCSDS standard, provides operations for generic monitoring and control of a remote service provider. Other MO services are under definition such as Planning, Scheduling, Automation, Flight Dynamics, Time, Software Management, Location, and Data Buffer. Once available, they will provide a standard and coherent set of interfaces that will make the development of future ground segments a simple operation of just integrating components. Additionally, the functionality provided by one component will be easily replaceable by another component providing a more advance level of functionality.

II. Overview

A service is an operation, or set of operations, that is well defined, self-contained, and does not depend on the state or context of another service. The services given in reference [1] are based on a generic service pattern. This pattern covers not only the primary service interface, but also includes the configuration data and history associated with the service. This is illustrated in the figure below:

![Figure 1: Generic Service Model](image)

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The pattern comprises four main components:

- The **Service Provider** is responsible for supporting the service functions.
- The **Service Consumer** is a user of the service functions, and is typically either a Human-Computer Interface, or another software application.
- The **Service Configuration** specifies the entities that exist for a specific instance of the service. This must be available to both Service Provider and Service Consumer if they are to communicate effectively; however for simple services this may be implicit for one component if the configuration is hard-coded into it.
- The **Service History** maintains persistent storage of service history, such that a Service Consumer can retrieve historical information for the service.

### A. Patterns of Interaction

An operation of a service is composed of a set of messages exchanged between a service provider and consumer and forms a pattern of interaction. Analysis of the services given in reference [1] shows that there are a limited number of these patterns of interaction, actually six, that can be applied to all currently identified services.

Standardising a pattern of interaction, which defines the sequence of messages passed between consumer and provider, makes it possible to define a generic template for an operation of a service.

The Message Abstraction Layer (MAL) defines this limited set of generic interaction patterns (templates) that must be used by services defined in the SM&C service framework. Each operation of a service is defined in terms of one of the MAL interaction patterns.

By defining a pattern and stating that a given operation is an instance of that pattern, the service specification can focus on the specifics of that operation and rely on the standard pattern to define the messaging rules.

For example, if an operation named ‘sendCommand’ were defined and it were to be stated that it is an instance of a pattern called ‘SUBMIT’ then this operation can be separated into two parts, the pattern of messages that are exchanged (the ‘SUBMIT’ pattern) and the meaning of those messages and what ‘sendCommand’ does. By defining the pattern as a standard (‘SUBMIT’) the service specification defines ‘sendCommand’ only need define the meaning of the messages and what the operation does. The MAL defines this set of patterns.

### B. SM&C Message Abstraction

To provide implementation language and message transport independence, all operations of a service must be defined by a language/platform/encoding agnostic specification for the sake of implementation language and message transport independence. The MAL defines this set of basic data types, and how they must be used to build up the messages that make up the operations of a service, as an abstract API. This only then has to be mapped once, in a SM&C standard, to a specific implementation language or transport encoding to apply to all services that are defined in terms of the MAL.

In addition to the patterns of interaction and the abstract API, the MAL provides support for the following:

- generic concepts, such as domain, session and zone
- generic facilities such as access control (authentication and authorisation) and Quality of Service.

### C. SM&C Common services

Whilst the MAL provides message abstraction and generic concepts such as access control and quality of service, there is a set of facilities that are common to all missions that conceptually reside above the MAL as services. These facilities are split into a Common Model and the associated Common Services that support the model.
The Common Model defines a standard service model that, if exploited by a Mission Operations (MO) service, allows the Common Services to provide support facilities and functionality to the MO service.

The Common Services are defined in terms of the MAL and are used to support the specific MO services. The Common Services are:

- **Directory**: This service allows provider applications to publish their services and consumer applications to lookup for needed services.
- **Login**: This service allows operator login and provides authorisation to use all or part of the operations offered by a given service.
- **Configuration**: This service allows a consumer application to configure the service according to its needs.
- **Interaction**: This service allows a provider application to request inputs from the operator (e.g. confirmation of a critical automated action).
- **Retrieval**: This service allows a provider application to make available historical information in the form of retrieval (i.e. when all items relating to a time period are extracted from history and delivered to the consumer as a single archive product or block of data).
- **Replay**: This service allows a provider application to make available historical information in the form of replay (i.e. when historical items are retrieved and played back in the original sequence to the consumer).

The layering of the MAL, message transport, Common and MO services and the service provider and consumer is shown below (each layer builds upon the layers below):

![Service Stack View](image)

**Figure 2: Service Stack View**

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Clearly, a benefit of implementing multiple services over a message abstraction layer is that it is easier to bind these to different underlying technologies and protocol encodings. All that is required is an ‘adapter’ layer between the MAL and the underlying protocol to enable all services over that technology, this can either be an implementation of the MAL that is bound to a specific technology or an implementation that supports multiple technologies. Hence the same service can be implemented over ground-based network technologies and middleware, or it could even be carried across the space link itself.

The services, in the form of standard language specific APIs, themselves provide the ‘plug-and-play’ interface for applications, allowing them to be integrated and deployed wherever is appropriate for the mission.

D. SM&C Core Services
The SM&C Core Services are the first MO service suite produced by the WG and it builds upon the layering concept outlined above. The SM&C Core services are defined in terms of the SM&C MAL, so it is possible to deploy them over any supported protocol and message transport.

The SM&C Core Service suite provides operations for generic monitoring and control of a remote service provider (e.g., a spacecraft or ground system component) in terms of three fundamental mechanisms and associated data items:

- Parameter Status—Monitoring Parameters
- Action Invocation—Actions
- Alert Notification—Alerts.

The communication of status information allows the remote service provider to be monitored. In principle, the remote service provider publishes its status to a number of active or passive observers, or clients, which may subscribe to a selective subset of available parameter, action, and alert data.

The invocation of actions upon the remote service provider enables an active client to effect control over it.

The term Event is used to refer to any time-stamped notification of change of state or asynchronous response, and as such may relate to Monitoring Parameters, Actions, and Alerts. The term Alert is used to differentiate the notification of operationally significant asynchronous events, such as anomalies or threshold transitions, from routine events such as nominal monitoring parameter value change.

The SM&C Core Service suite includes the following groups of services:

- Standard Core services
  - Parameter Service: basic ability to monitor a telemetry parameter
  - Action Service: basic ability to send commands and verify their proper reception/execution
  - Alert Service: basic ability to make available operationally significant asynchronous events.

- Enhanced Core services
  - Check Service: capability to check telemetry parameters against expected behaviour definitions
  - Statistic Service: capability to evaluate statistics of telemetry parameters (e.g., min, max, mean, standard deviation)
  - Aggregation Service: capability to acquire several parameters in a single request
  - Conversion Service: capability to convert parameters in their engineering units.
The first group provide the ability to get a (telemetry) parameter (for further processing) and an event (alerts) from the monitored object. Additionally, it allows sending commands (actions). These are obviously, the basic bricks to monitor and control an object.

The second group allows more sophisticated actions, including to check the parameters in various ways, to build up statistics of telemetry parameters, to group (aggregate) parameters in logical groups (imagine, for instance, all telemetry parameters belonging to a given instrument on board), to calibrate parameters.

It is noted that these services are not dependent on any of the other services and are complete in their own right. An implementation is free to opt out of any service and also any capability set of those services. However, it may not make sense to support certain services without others.

The reader may wonder what is so clever about these services, as most mission control systems offer already these functionalities. Indeed, nothing new is offered in terms of new functionality. However, the good news is that the SM&C WG has specified the Core Services using the SM&C framework, which makes them technology agnostic (i.e. expandable, portable, maintainable,...). Additionally, there is no internationally available standard set of services for this and every organisation does basic monitoring and control its own way. Finally, the SM&C Core Service is the first one of a set of compatible MO services that will constitute a suite of homogeneous SM&C services. This will allow defining standard components, which will make the procurement of ground systems quicker and cheaper.

E. SM&C Framework

The service specifications and the MAL are abstract in their definition; they do not contain any specific information on how to represent them for a particular implementation language or transport encoding.

However the service specifications are supplemented by a set of standard SM&C specifications for representing the MAL in specific implementation languages and also for mapping the MAL to a specific message encoding and transport:

Figure 3: Service Layering
It is to be noted that only the MAL specification needs to be mapped to a specific implementation language. The service specifications are defined in terms of the MAL and therefore the same language mapping applies to these services unmodified.

Of the Recommended Standards produced for the SM&C specification, each book falls into one of the following four categories:

a) Language mapping:
   - One book for each mapping from the MAL to the specific implementation language.

b) MAL specification:
   - Only one book exists defining the MAL.

c) Service specifications:
   - Only one book exists for each service specification.

d) Transport mapping:
   - One book for each mapping from the MAL to the specific transport and encoding.

Language-mapping Recommended Standards define a standard mapping of the MAL to a specific implementation language. This provides a standard API for application developers to develop against allowing the reuse of both applications and also MAL implementation.

Transport-mapping Recommended Standards define technology mappings to specific transports, such as CCSDS AMS (Asynchronous Messaging Service), and message encodings such as XML, ASCII and CCSDS Space Packets. This allows system engineers to choose a message transport and encoding appropriate for a specific deployment. To provide a working implementation of a service one book of each category must be selected and used.

F. Interoperability
The MAL is defined in a language- and protocol-agnostic manner as it only standardises the message exchange at an information level; it leaves the language used to implement it, the encoding mechanism, and the transport used open to be selected in the system implementation phase.

This flexibility in the specification of the MAL allows two types of interoperability to be provided: firstly the choice of encoding and transport allows interoperability between entities such as cooperating agencies, and secondly the choice of language allows interoperability of an application with a specific implementation of the MAL (allow reuse of software across missions).

For two agencies to interoperate they must standardise on the transport and encoding selected. The choice of implementation language chosen at each agency is hidden from the other by the MAL and therefore not required for entity interoperability:

![Figure 4: Example Entity Interoperability](image)
The key benefits of this approach are:

- support for heterogeneous implementations;
- ability to change the transport infrastructure within a system, without major re-work to the application level software. Only have to re-do the mapping to the transport encoding.

The separation of information interoperability (MAL and higher layers) and protocol interoperability (encoding and transport) allows simple processes to be created that allowing bridging from one encoding/transport choice to another:

![Diagram of protocol bridge example]

**Figure 5: Protocol Bridge Example**

Figure 5 shows that the two components are still fully interoperable even though they utilise different transports encodings. An implementation of the MAL may be fixed to one specific encoding and transport but the MAL specification permits this to still be interoperable with other implementations using a different transport/encoding through the use of the protocol bridge. It should be noted that a bespoke transport/encoding can be used, for example to utilise existing infrastructure, all that is required is a mapping from the MAL to that transport.

### III. Conclusions

This paper has described the approach of the SM&C WG at standardising the service interfaces between major components of a space system. The approach allows for software language and technology independence and thus permits long term maintainability and preservation of the investment. Any ground segment project manager would love to avoid the risks of specific developments, of integrating heterogeneous subsystems developed in dubiously coordinated manner and to have to deal with many non-standard interfaces.

At the time of writing, (April 08), the 3 books (MAL, Common and Core) are planned to become CCSDS standards before the summer 08. After that, clearly the SM&C has to demonstrate its value on the field. For this reason, the SM&C WG is trying hard to support the potential user community by organising events that help SM&C adoption. In this context, the 1st SM&C Users Workshop took place in Washington DC in March 2008 with a good attendance. Such event could be repeated if there is enough interest.

### IV. References