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CCSDS MISSION PLANNING AND SCHEDULING SERVICES OPENING THE DOOR FOR CROSS-AGENCY INTEROPERABILITY

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Abstract

Mission Planning and Scheduling are integral parts of Mission Operations and closely related to the other aspects of the overall Monitoring and Control of space missions. Mission Planning is an activity that often requires interaction between multiple entities, where also cross-agency collaborations could potentially be facilitated. In the absence of commonly agreed international space standards for typical mission planning and scheduling exchange interfaces, the current approach is to define such interfaces on a per-mission or per-agency basis. This hinders the potential for reuse and increases the development and operations costs due to proliferation of implementations of the same functionality in different contexts.

The Mission Planning and Scheduling (MPS) Working Group (WG) of the Consultative Committee for Space Data Systems (CCSDS) has been formed in 2015, with the current participation from 8 space agencies. The MPS WG has the objective of specifying generic, interoperable mission planning and scheduling interfaces. This paper will provide an overview of the current progress of the standardization work in this area. It will depict an outline of the comprehensive Information Model that has been worked out by the MPS WG and will describe the Services Specification for exchange of the relevant information.

Acronyms

CCSDS	Consultative Committee for Space Data Systems
CSS	Cross Support Services
MAL	Message Abstraction Layer
MO	Mission Operations
MOIMS	Mission Operations and Information Management Area
MPS	Mission Planning and Scheduling
PI	Principal Investigator
SM&C	Spacecraft Monitoring & Control
TT&C	Telemetry, Tracking & Command
WG	Working Group

1. Introduction

Mission Planning is an activity that often requires interaction between multiple entities. This may be to support distributed planning, where the responsibility for different aspects of mission operations planning is spread over multiple entities, including the space segment. It may also be to facilitate collaboration between missions, or to allow the planning of payloads by multiple end-users or the planning of multiple payloads from different agencies hosted on the same spacecraft. Other missions, such as observatories, may make payloads available to a wider user community. Some planning responsibility may be delegated to the spacecraft itself and the corresponding capabilities hosted on-board. Currently all these interoperable interfaces are typically defined on a per-mission or per-agency basis.

The Mission Planning and Scheduling (MPS) Working Group (WG) of the Consultative Committee for Space Data Systems (CCSDS) has the objective of specifying generic, interoperable mission planning and scheduling interfaces, for all typical space mission use cases, including the ones identified above. This paper will provide an overview of the current progress of the standardization work in this area.

The MPS WG was formed in 2015, with the current participation of 8 national and multinational space agencies. The first activity of the MPS WG was to define the Mission Planning and Scheduling Green Book, which is an informative document describing the background and reference concepts typically found in space mission planning. It provides the interoperability scenarios and an analysis of representative mission types, as an input to the standardization work. The MPS Green Book was published in June 2018 [1].

Current work in the MPS WG is focused on the definition of the Mission Planning and Scheduling Blue Book, which is a normative document describing the proposed mission planning interoperability standard. This standard focuses on the MPS Services identified for supporting interoperability and defines an Information Model with the data structures required by the operations of these services.

Mission Planning and Scheduling are integral parts of Mission Operations and closely related to the other aspects of the overall Monitoring and Control of space missions. This close relation is recognized in the context of the CCSDS Mission Operations and Information Management Area (MOIMS), by the fact that the Mission Planning and Scheduling Services have been identified and included from the start among the envisaged Mission Operation Services to be specified in the scope of the CCSDS Mission Operation Framework [4].

2. Mission Planning Overview

This section provides an overview of the main functions, interactions, concepts and use cases of Mission Planning and Scheduling of space missions. It should be noted that in the wider context of space mission operations, the term Scheduling is sometimes used to refer to "Plan Execution". In the context of the Mission Planning and Scheduling standardization activity described in this paper, there is no distinction between the terms Planning and Scheduling and from here on only the term Planning is used.

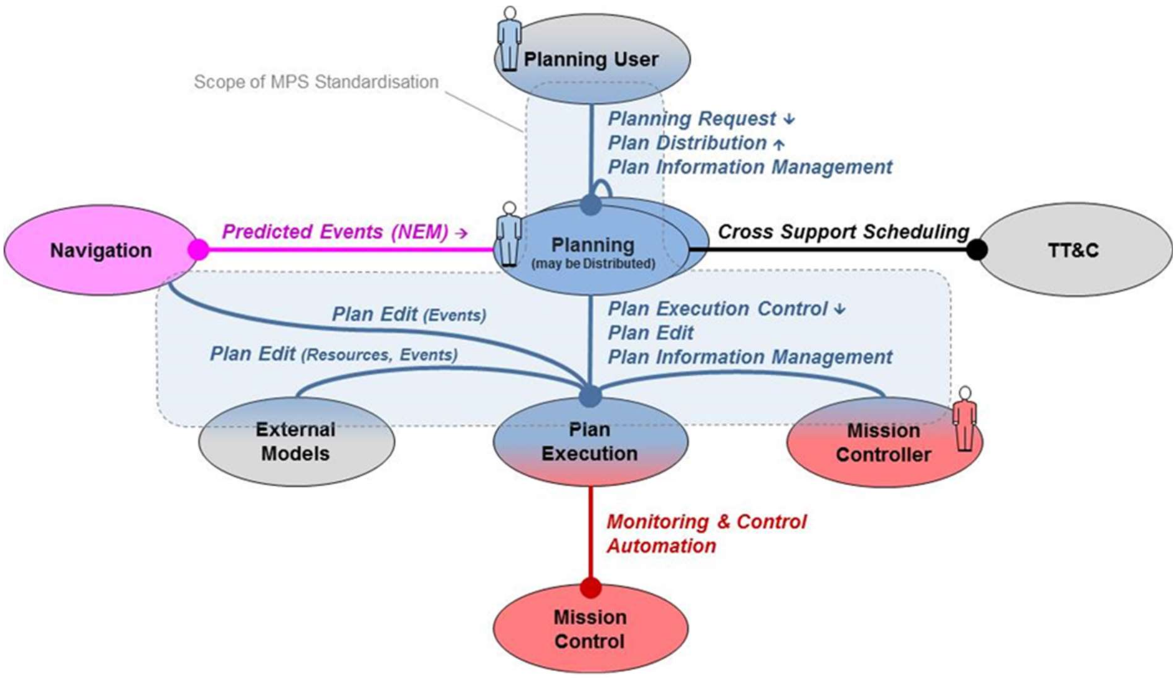


Fig. 1: Functions involved in Mission Planning

2.1 Main Functions and Interactions

Mission Planning encompasses application level functions of a space mission system that may be distributed across multiple organizations and physical nodes, both in the space and ground segments. The objective of standardization in this area is the interaction between these functions and others at application level, and not standardization of the Mission Planning functions themselves.

The scope of standardization includes both the format and model of data exchanged, as well as the semantics of the interactions for their exchange, captured by the associated service level interfaces. A generalized view of the functions involved in Mission Planning and their interactions with other functions is given in *Fig. 1*. The entities shown in blue are in the functional area of Mission Planning. The entities shown in different colors belong to other functional areas of mission operations, such as Monitoring and Control, Navigation, or Ground Station and Communication Network.

The following Mission Planning functions are identified:

- *Planning User*

  A generic function that is responsible for submitting requests to the Planning function and/or controlling the Planning process. It may also receive feedback on the status of planning requests, the generated plans and the status of the planning process. It is not a Planning function itself, but is a user of Planning data and services.

- *Planning*

  The function responsible for performing Mission Planning. Internally, it may be hierarchically organized and/or distributed. Planning requests are received from multiple Planning Users and feedback on their status provided. Planning Users may also perform high-level control of the planning processes supported by the function. The output of the Planning function are plans, which may be retrieved by Planning Users and distributed to Plan Execution functions.

  Planning is itself a user of the Navigation function and may receive predicted Planning Events related to orbital information, attitude or slew time information; and negotiates the scheduling of ground station support via Cross Support Services (CSS) [7][8].

- *Plan Execution*

  The function responsible for executing a Plan (or part of it). There may be multiple Plan Execution functions distributed between space and ground segments. It is not a Planning function itself, but it does support a common model of the Plan in its interface with Planning. It receives or retrieves distributed plans; allows external control of the Plan Execution process; and provides execution status of the Plan to Planning. Plan Execution may use underlying Mission Control Services to effect the execution of planned activities.

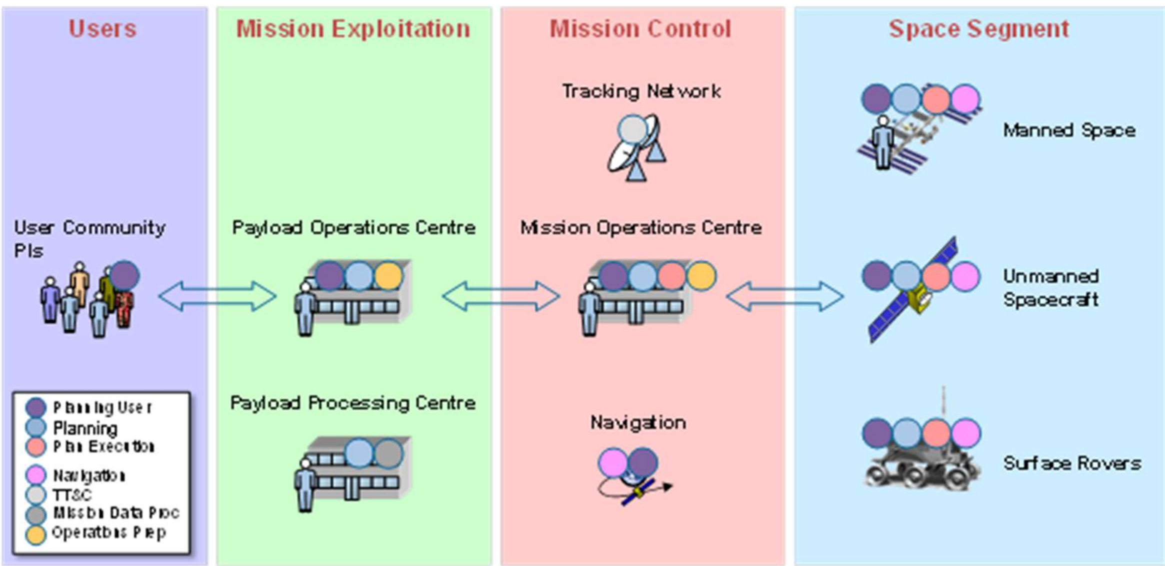


Fig. 2: Entities and Functions involved in Mission Planning

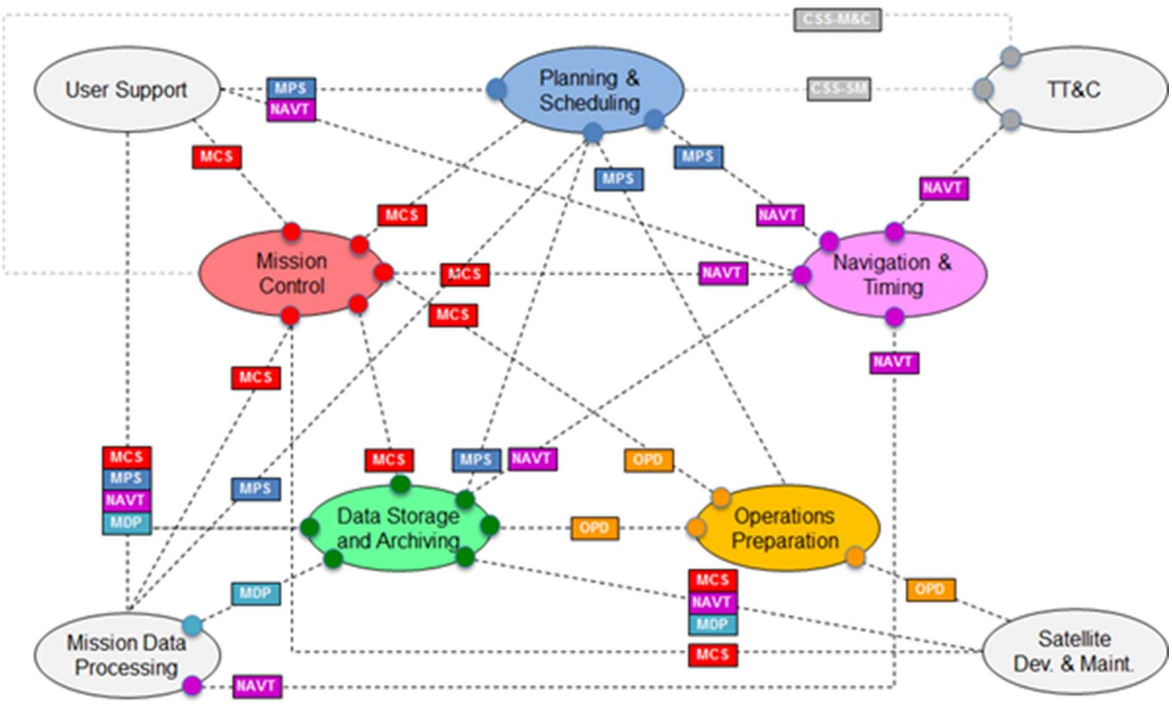
In a space mission specific deployment, there may be multiple copies of all the functions identified in *Fig. 1*. These functions may be distributed over a number of distinct entities, such as organizations and systems. There is not a fixed set of such entities, but typical examples include:

- User Community / PIs;
- Science/Payload Operations Centre;
- Payload Processing Centre;
- Mission Operations Centre;
- Flight Dynamics / Navigation;
- Ground Tracking Network;
- Unmanned Spacecraft;
- Surface Lander / Rover;
- Manned Space Vehicle.

As an example, *Fig. 2* illustrates potential deployment of each of the functions identified in the entities listed above. The circles indicate where the each of the functions are typically deployed in existing systems, or where they could potentially be deployed in the future. The arrows indicate the interactions in a typical deployment, but the potential distribution of functions indicated by the circles shows that all the functional interfaces shown in *Fig. 1* can be exposed to the boundaries between entities. It is where the interactions between the functions are exposed across one or more boundaries that there is the need for standardization within CCSDS, as a potentially interoperable interface between agencies.

2.2 Relationship to other CCSDS Standards

CCSDS is currently developing a Reference Architecture [3], in which all CCSDS standards can be identified, together with their role and to show how CCSDS standards relate to each other and support the deployment and integration of space systems. Mission Planning encompasses application level functions whose interfaces fall within the remit of the Mission Operations and Information Management Services (MOIMS) area of CCSDS.



CSS-M&C	Cross Support Services – Monitoring and Control
CSS-SM	Cross Support Services – Service Management
MCS	Mission Control Services
MDP	Mission Data Product
MPS	Mission Planning and Scheduling
NAVT	Navigation and Timing
OPD	Operations Preparation Data

Fig. 3: Mission Operations Functional Areas and their Interactions

Fig. 3 shows the main functional areas supporting Mission Operations and their principal interactions that are the potential subject of standardization by CCSDS. Functions and interactions are color-coded by area (Mission Planning and Scheduling being shown in blue). The interactions are annotated with text indicating the type of data transferred; the circle at one end indicates the function that is the service provider in the case of a service-based interface. At this level, the data types merely indicate the principal function with which they are associated, and so MPS data relates to all data formats that may be standardized for Mission Planning and Scheduling.

From the perspective of the Mission Planning and Scheduling functional area, interactions are shown with:

- User Support functions (principally for submission of Planning Requests and retrieval of Plans);
- Mission Control (to provide current status and to allow the execution of Plans through Monitoring & Control or Automation services);
- Navigation and Timing (for the provision of predicted events);
- TT&C (to schedule ground station contacts, using CSS Service Management, CSS-SM).

Examples of Mission Planning users are multiple functions that interact with Mission Planning for the submission of Planning Requests:

- Navigation & Timing for maneuvers;
- Operations Preparation for on-board software and configuration updates;
- Mission Data Processing for payload operations.

Finally MPS data may interact with Data Storage and Archiving, for the storage of planning data and its transfer to on-board file storage.

2.3 Reference Concepts

This section describes a number of planning concepts that can often be seen in typical space missions. All these concepts have been considered during the specification of the MPS Information Model and Services.

2.3.1 Hierarchical Planning

An approach to handle the complexity of the planning of a space mission is to divide the planning process over multiple planning cycles, starting with the planning of activities at a lower detail level and then to gradually increase to a higher detail level. This then leads to the concept of a hierarchical planning process.

Planning cycles and so-called planning horizons represent two things: on one hand the lead time by which planning products are computed and the planning process conducted at each level; on the other, the duration or applicability of the planned activities. As example, short-term planning may be conducted every week, covering the next month of planned operations (in this case the planning horizon is one month); or long-term planning may be conducted six months in advance for one week of operations (in this case the planning horizon is one week).

Some commonly used planning cycles are: Long-term Planning, Medium-term Planning and Short-term Planning. Typical space missions will be based on all or some of the three planning cycles as described above. Additional cycles could be considered, such as a very-short-term planning cycle, which could be arbitrarily short. This is in particular the case for the so-called tactical planning, e.g. of robotic assets for surface operations.

2.3.2 Distributed Planning

In some space missions, the planning may be centralized in a single function. In other space missions, the planning functions may be distributed over multiple entities on the ground or on-board, where each entity will be involved in a part of the overall planning. When these entities are fully autonomous and have their specific knowledge and responsibilities, one may speak of a federated planning concept.

In the distributed planning concept, the output of an entity acts as the input of another entity. The latter entity may then combine multiple inputs and produce a consolidated output to be sent to a next entity. This then results in a chain of planning processes, where the scope and fidelity of the planning information increases with each planning function in this chain. Distribution of the planning knowledge and responsibility across multiple entities results typically in a need for iterations; changes to the planning information, assumption or conflicts detected in one node cannot always be resolved locally and would require a feedback from the source entity in the chain.

2.3.3 On-board Planning

Mission Planning functions can be migrated partially or as a whole from the ground segment to the space segment. The drivers for such a migration are the need for increased automation and autonomy in the space segment. In particular for robotic exploration missions, the required level of on-board autonomy is generally higher, due to the long communication delays. Moving Mission Planning functions to the space segment allows for faster re-planning, as more accurate information becomes available on-board in real-time and can then be taken into account.

2.3.4 Goal Based Planning

As opposed to activity based planning, goal based planning typically utilizes more objective oriented Planning Requests. The main difference at the input level is expressed in terms of an objective (what) rather than "how". It is then left to the planning system to come up with "how" to achieve that objective, i.e. with planned activities. The MPS standard will support both activity based as well as goal based planning requests.

2.3.5 Manual, Automated and Mixed-initiative Planning

The planning of individual requests could be performed either manually or in an automated manner by the planning function, or a combination of the two, which is referred to here as mixed-initiative planning. The aspects of the mixed-initiative planning is even more relevant when considering the end-to-end planning process. Typically, the planning is conducted by mission planners, which have dedicated software and tools at their disposal. Although individual steps can be automated, the oversight of the planning process as a whole remains often under the control of the planners. In fully automated planning systems, the operator involvement is limited to the monitoring of the status of the various planning processes and to possibly intervene in case of anomalies.

2.3.6 Iterative Planning and Re-planning

The planning process in a typical ground segment may be highly iterative. This could be driven by a hierarchical planning concept as described above. Within a single planning cycle, there could be additional iterations due to the need for re-planning. The re-planning can be triggered by an event, such as new orbit predictions arriving from the navigation function, or reception of updated knowledge of the space and ground systems, including new configuration data to be used as input to the planning process. The re-planning could start using the current Plan as a baseline and update this Plan based on the new information that has become available, or the re-planning could restart without using any past planning information, ignoring the baseline plan. The evolution of a Plan through its life-cycle and maintaining consistent references to its previous instances is therefore incorporated in the MPS Information Model.

2.4 Use Case Scenarios

A number of interoperability scenarios involving difference space agencies can be envisaged, for example:

- *Spacecraft from one agency hosts a payload from another agency*

  This use case is driven mostly by the dependencies between the payload and the spacecraft platform. These determine the type and extent of the Mission Planning Services required. Typically, these dependencies can be of structural, thermal, attitude, power, data handling or instrument data processing nature.

  The payload requests typically use services from the platform. In some cases the use of such services implies resource sharing and allocation. This is e.g. the case for data storage on-board, data uplink and downlink, power and attitude. The payload agency needs from the platform agency a set of boundary conditions that shape the planning requests. Examples are constraints on power, data volume and downlink bandwidth, attitude and slew capabilities, thermal, etc.

- *Coordinated operations of satellites of different agencies*

  Another use case is the coordinated operations of satellites of different agencies. For example, in sensor web operations for disaster monitoring, it is often desirable to ensure spatial and temporal coverage of the affected area. In this case multiple agencies may have assets with varying capabilities to image, say a flooded area. A third party agency may be the governmental or NGO coordinating disaster relief. In these cases, the coordinating agency would provide service requests in the form of either specific observations or imaging coverage requests, such as e.g. in the OpenGeospatial Consortium standards.

The various use case scenarios applicable to the Mission Planning and Scheduling standardization process have been identified by performing a survey of a number of representative space missions of various CCSDS Member Agencies. The missions subject to the survey have been categorized into mission types, in an attempt to identify commonalities in the Mission Planning processes, e.g. in the areas of planning cycles, execution feedback, navigation services, planning requests, resources and constraints, and output of the planning phase. The full results of this survey, including the identified mission types, are described in the MPS Green Book [1].

3. MPS Information Model

While the MPS Information Model itself is not normative, the data formats and services derived from it and specified in the MPS standard are normative. It describes both the data actively exchanged by MPS Services and the data that is required as common configuration data by service providers and users.

A high-level overview of the MPS Information Model is given in Fig. 4. This shows the principal MPS data items and their interrelationships using standard UML notation. The rectangles in the diagram correspond to standard data items. The lines between them define the relationships between those data items. Mission Planning data items are shown in blue.

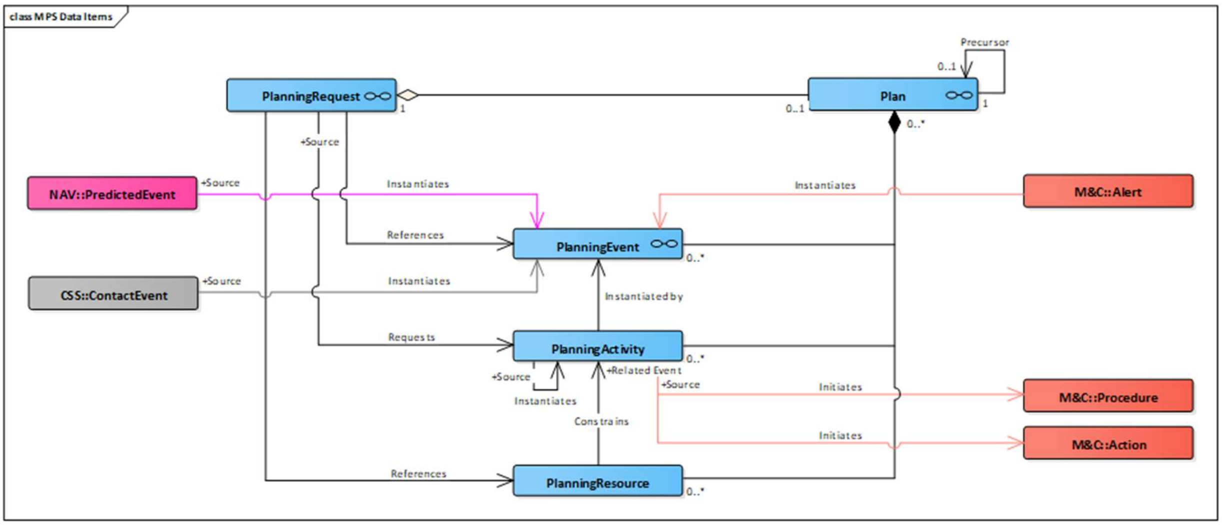


Fig. 4: MPS Data Items

The following principal MPS data items are shown in the diagram:

- Planning Requests;
- Plans;
- Planning Activities;
- Planning Events;
- Planning Resources.

The principal data items are described in more detail below. Each of these data items comprises a set of MO Objects with its own Object ID and in some cases version, following one of the MO Object patterns [6].

MPS Data Types are supporting data structures used in the context of the MPS Data Items and the MPS Service messages. The following MPS Data Types can be identified:

- Base Data Types (Boolean, Float, Double, Time, ObjectID, ObjectRef, …);
- Additional Data Types (e.g. Position and Direction Types);
- Expressions;
- Arguments;
- Constraints;
- Triggers;
- Repetitions.

Some aspects of the MPS Information Model are optional. These aspects are not required to be supported by a compliant MO MPS Service Provider, although this may limit the set of service capabilities and associated operations that can be supported. Optional aspects of the Information Model include:

- Planning Resources;
- Functions;
- Position and Direction Types;
- Constraints (other than represented with a text expression);
- Repetitions.

Planning Configuration Data is the set of identity and definition objects that together define the set of available data items that can be referenced in Planning Requests and Plans. This configuration data must be available to both communicating parties that exchange planning requests and plans. The transfer of planning configuration data to planning or plan execution functions is outside the scope of the current MPS services.

3.1 Planning Request

Planning Requests are the main input to the planning function. A Planning Request is a container for the information needed to be exchanged between the requester and the planner. It supports the specification of a request to plan one or more planning activities. Alternatively, it can support a request to use an existing Plan (already containing a number of planning activities) as an input to the planning process. It can constitute a one-off planning request, or request the repetitive planning of activities as a “standing order”.

The main characteristic of the Planning Request is that, being a container, it needs to hold references to, or instances of, the constituent information items that are required by the planner and agreed by the interacting parties for exchange at interface level. It has one or more planning activities as the basis of the request. In addition, the request may optionally reference planning events. Information about planning constraints on when a requested activity can or shall be planned may be exchanged as part of the Planning Request, by referencing constraints on the timing or position of Planning Activities, both absolute and relative to Planning Events or other Planning Activities, and on the state of planning resources.

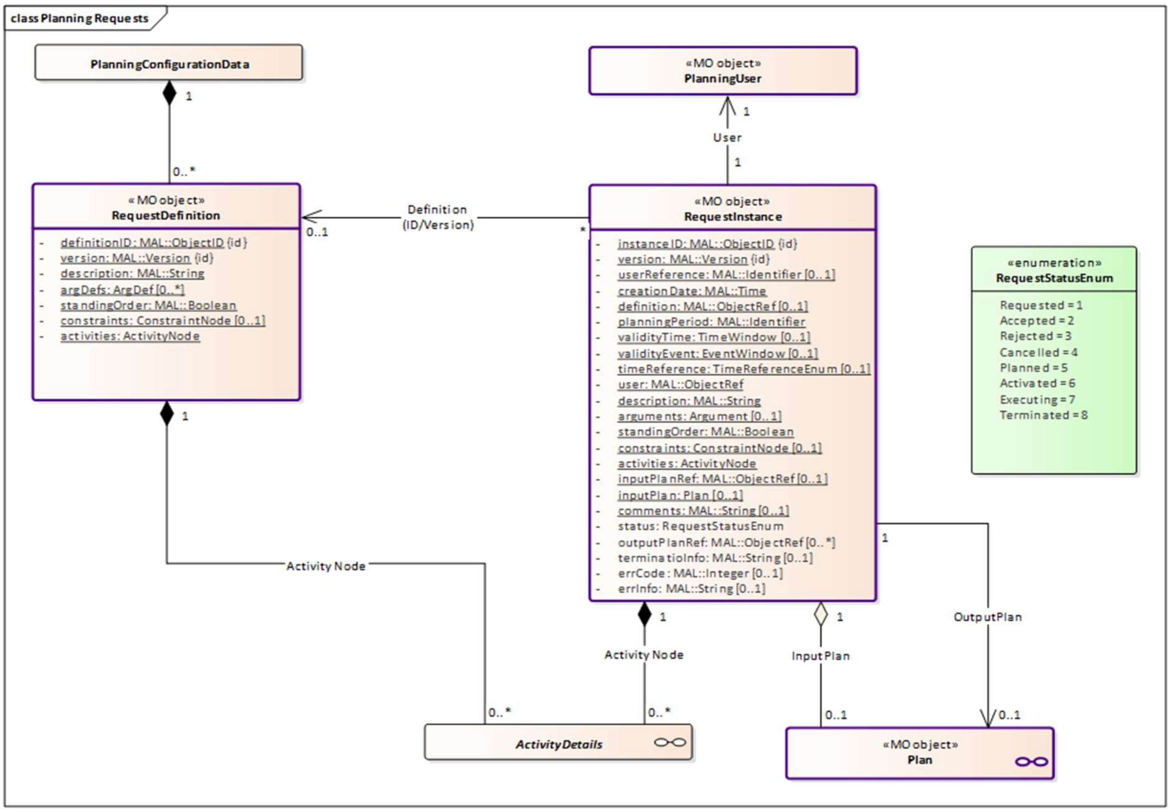


Fig. 5: Planning Requests class definition

The Plan definition is illustrated in Fig. 5. Planning Requests follow the MO Instance Object Pattern, comprising Definition and Instance classes of MO Object, although in this case Planning Request instances can be created without reference to a Planning Request Definition. Request Definitions provide a re-usable template for common Planning Requests from which specific Request Instances can be created and form part of the Planning Configuration Data for a mission planning system.

3.2 Plan

The Plan is the output of a planning process. The Plan is basically a container of one or more selected planning activities, optionally associated to planning events. In addition, the usage of planning resources may be contained in the Plan. The Plan may contain specific information from the planning process, which applies to the Plan as a whole. In the hierarchical and distributed planning concepts, the output of one planning function could be the input of another one. As such, a planning request could refer to an entire Plan.

Plans may be iterative, and therefore overlap with the previous Plan. This introduces the notion that a Plan may have an identified predecessor, and also that if a planning data item is contained in multiple iterations of the plan, then it should have the same unique identity in each successive iteration of the Plan to avoid ambiguity and duplication.

Plans comprise the following main elements:

- Plan Information: header data relating to the plan as a whole;
- Planned Items: the set of contained planning activities and planning events;
- Plan Revisions: summaries of the changes between this version of the Plan and another specified version of a Plan, usually its predecessor Plan;
- Plan Resources: value profiles covering the period of the Plan for a set of planning resources.

The Plan definition is illustrated in Fig. 6 below. The main elements are further detailed in dedicated data structures.

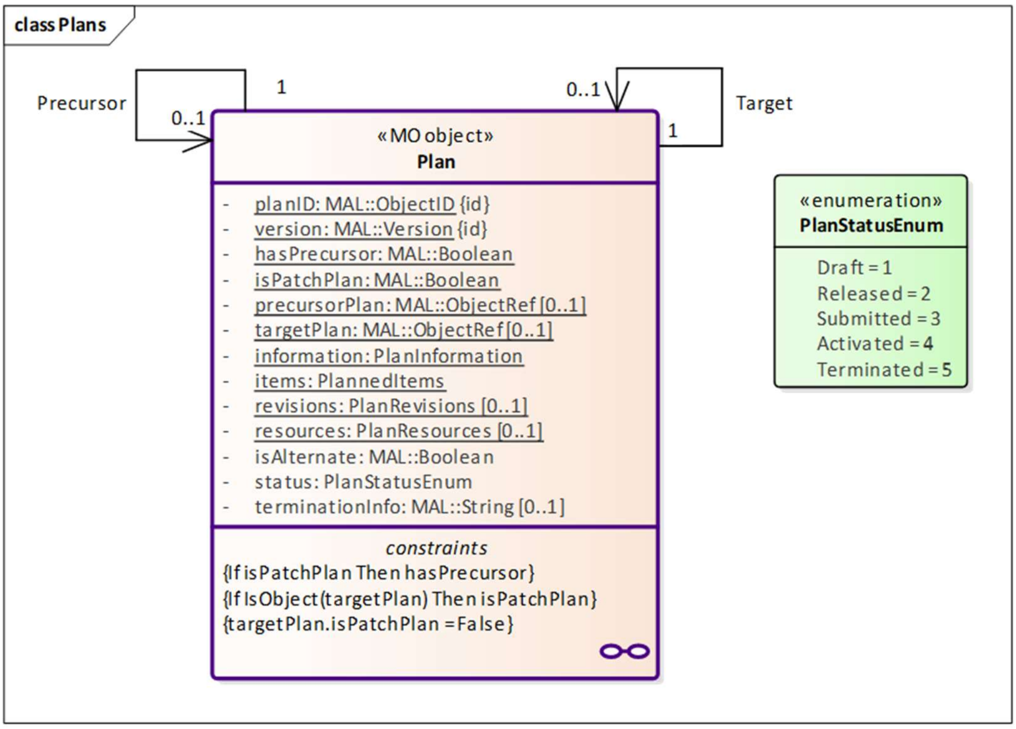


Fig. 6: Plans class definition

3.3 Planning Activity

A Planning Activity is the basic building block for the planning: a meaningful unit of what can be planned. As such, it has to be understood by the planning function. It could eventually be translated to something that can be executed by a plan execution function; this includes telecommands and automation procedures (that may represent any automated telecommand sequence, operational procedure, on-board control procedure, or function).

Planning Activities support hierarchy: a Planning Activity may be composed of one or more subordinate Planning Activities. A Planning Activity may define arguments (parameters), which could be used to instantiate a specific Planning Activity in a Plan, based on its generic definitions. Arguments of a Planning Request or Planning Event can be passed through to the arguments of Planning Activities resulting from these. Arguments can then similarly cascade down through a hierarchy of Planning Activities. A plan execution function may then flow down these arguments to any action or automated procedure initiated.

Planning constraints can also be associated with a Planning Activity, either generic constraints applicable to all occurrences (or instances) of the Planning Activity that are contained within its definition, or specific constraints associated with a particular instance that are defined in the context of the planning request. These planning constraints can be expressed in terms of the timing or position of a Planning Activity, both absolute and relative to Planning Events or other Planning Activities, and on the state of planning resources.

3.4 Planning Event

A Planning Event marks when a condition is being met. It is not envisaged to use it to express a condition itself, but rather to express the fact that it is fulfilled. Typical conditions, for which events are used to report their fulfilment, are temporal or positional. They may be used to represent predicted or planned events, such as predicted orbital events or planned periods of contact with a spacecraft, which are typically received as an input by the mission planning function, from an external function, such as Navigation.

Planning Events may be grouped hierarchically to represent a compound event, such as the start and end of a satellite pass over a ground station, or a satellite passing through eclipse (penumbra entry, umbra entry, umbra exit, penumbra exit). A Planning Event may define arguments (parameters) to convey additional information relevant to the planning process.

Planning activities may be linked to a related planning event. The start or end of the planning activity can be relative to the planning event, and the arguments of the event can be flowed down to the planning activity. Planning requests may also reference planning events, associating them with requested planning activities.

3.5 Planning Resource

A Planning Resource is an abstract status, modelling the state of the system being planned. It may be necessary to model some aspects of system state in order to:

- Trigger the execution of a Planning Activity;
- Constrain the execution of a Planning Activity.
- Define the effect that the execution of a Planning Activity has on the Planning Resource.

A Planning Resource is in effect a value of defined type that can evolve over time. A Resource Profile can be used to capture and communicate that evolution over time in the context of a Plan. If an event or constraint on a Planning Activity needs to be expressed in terms of the state of the system (rather than just time or position) then this corresponds to the state of Planning Resources.

A Planning Resource could in principle be considered as information that is internal to the planning system. However, some resources may be shared across multiple planning entities. As such, information regarding a resource may need to be communicated between entities, and therefore has to be referenced as part of a Planning Request or of the Plan, in terms of requested or consumed resources respectively. This may include the initialization or synchronization of Planning Resource values at specific points in the Plan.

4. MPS Service Specifications

The following MPS Services have been defined:

- Planning Request Service;
- Plan Distribution Service;
- Plan Execution Control Service;
- Plan Information Management Service;
- Plan Edit Service.

Each service comprises a set of service operations that the service consumer can invoke on the service provider. Service operations reference the data structures defined in the MPS Information Model described above. A compliant MPS system may support only a subset of these services. Service operations are grouped into capability sets. A compliant MPS system may only support a subset of capability sets for each supported service. However, once a capability set is supported, all the operations within the capability set shall be supported.

In support of legacy planning systems not able to support services, the MPS standard also envisages the exchange of planning information solely by means of data messages, based only on the MPS Information Model data structures, in particular with the Planning Request and Plan data structures. These data messages can then be encoded in (XML) files and exchanged by any file transfer means (e.g. FTP or email).

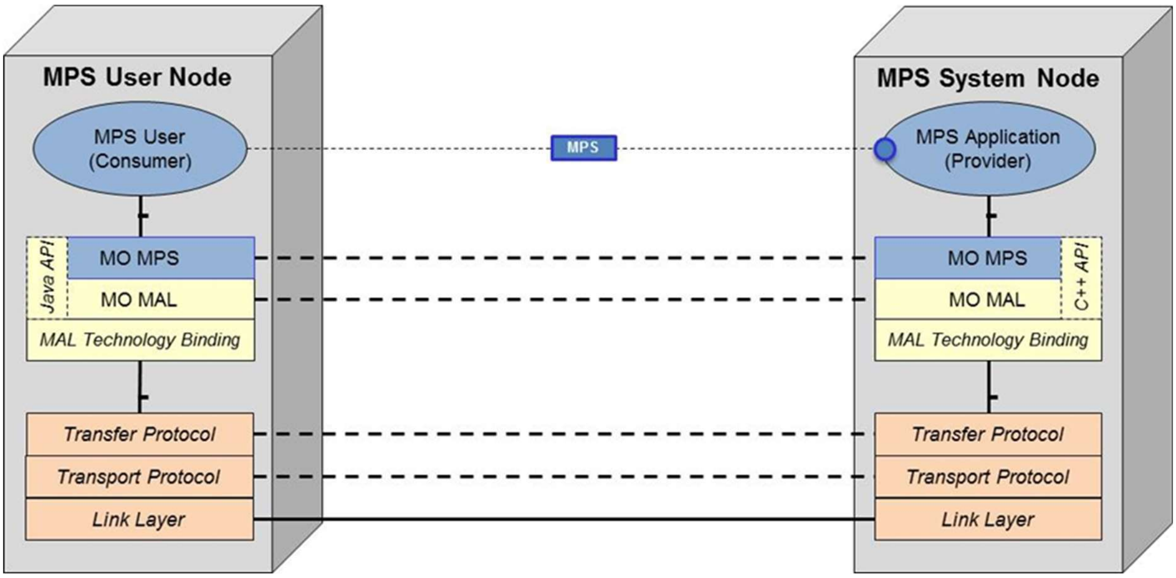


Fig. 7: MPS Services Generic Protocol Stack

Fig. 7 illustrates a generic deployment of MPS services using the Mission Operations (MO) service framework [4] and the Message Abstraction Layer (MAL) [5], with service consumer and provider functions hosted on different deployment nodes. The application level MPS service interaction is shown by the direct interface between service provider and service consumer functions, carrying MPS service messages that are defined in terms of data structures specified in the MPS Information Model.

4.1 Planning Request Service

The Planning Request Service is offered by the planning function of an MPS system to enable its users to submit, cancel and modify planning requests, as well as to receive feedback on their status. The service may be used by another planning function in a hierarchical or distributed MPS system, or by an MPS system user.

Planning Requests may include a set of requested Planning Activities or a reference to an existing Plan (the output of a Planning function in a hierarchical or distributed MPS system).

The service operations are defined in Table 1 below. Only the operations in capability set 1 are mandatory.

Table 1: Planning Request Service Operations

Operation	Description	Capability Set
submitRequest	Send planning request to service provider, optionally based on a planning request definition. The ID of the planning request instance created is returned.	1
getRequestSummaries	Request a list of available planning requests from the service provider, subject to a specified filter. The returned list is provided as a set of summaries comprising identity, descriptive header fields and status for each planning request instance passing the filter.	
getRequestStatus	Obtain the current status of one or more specified planning requests. The response is a list of planning request status updates, containing the status and other dynamic attributes of each requested planning request instance.	

cancelRequest	Send cancellation of a previously submitted planning request to service provider.	2
updateRequest	Send update of a previously submitted planning request to service provider. A new version of the planning request instance is created and its identity (ID and version) is returned.	3
monitorRequestStatus	Subscribe to receive planning request status updates for a filtered set of planning request instances. The consumer is notified of updates to the status and other dynamic attributes of subscribed planning request instances.	4
getRequest	Retrieve the full content of one or more specified planning request instances.	5

4.2 Plan Distribution Service

The Plan Distribution Service is offered by the planning function of an MPS system to enable its users to obtain the Plans output by it, as well as to receive feedback on their status. The service may be used by another planning function in a hierarchical or distributed MPS system, or by an MPS system user.

The service does not provide the capability to control the planning function itself or to generate plans. This capability can be supported if the planning function exposes a standard set of MO Monitoring & Control services. Submission of Plans to a plan execution function is supported by the Plan Execution Control Service.

The service operations are defined in Table 2 below. Only the operations in capability set 1 are mandatory.

Table 2: Plan Distribution Service Operations

Operation	Description	Capability Set
getPlanSummaries	Request a list of available plans from the service provider, subject to a specified filter. The returned list is provided as a set of summaries comprising identity, descriptive header fields and status for each plan passing the filter.	1
getPlan	Retrieve the full content of one or more specified plans.	
getPlanStatus	Obtain the current status of one or more specified plans. The response is a list of plan updates, containing the status and other dynamic attributes of each requested plan.	
monitorPlanStatus	Subscribe to receive plan updates for a filtered set of plans. The consumer is notified of updates to the status and other dynamic attributes of subscribed plans.	2
monitorPlan	Subscribe to receive a filtered set of plans, receiving the full content of the plan when published by the Provider.	3
queryPlan	Query to receive a filtered set of plans, based on an extended set of filter criteria, including on the planning activities and events contained within a plan.	4
getPartialPlan	Retrieve a subset of a plan, covering a more restricted period or only containing selected planning activities.	5

4.3 Plan Execution Control Service

The Plan Execution Control Service is offered by an MPS system's plan execution function to enable its users to submit (and revoke) Plans for execution; to control their execution at Plan, Sub-Plan and Activity levels; and to receive feedback on their execution status. The Plan Execution Control Service may be used by a planning function, or by an MPS system user responsible for mission operations.

Sub-plans are not defined as an MO Object in the MPS Information Model, but are specified by an Identifier associated with the constituent Activity Instances contained in a Plan. This can be used to sub-divide a Plan based on domain (spacecraft or subsystem), operational responsibility, or another criterion. Each Activity Instance can only be associated with a single Sub-plan. Control may be exercised via the service at the level of sub-plans.

The service operations are defined in Table 3 below. Only the operations in capability set 1 are mandatory.

Table 3: Plan Execution Control Service Operations

Operation	Description	Capability Set
submitPlan	Send a Plan to a plan execution function, making it available for execution.	1
revokePlan	Instructs a plan execution function to revoke a previously submitted Plan, making it unavailable for execution.	
getPlanStatus	Retrieve the current execution status of Plans.	
activatePlan	Enables the execution of specified Plans.	2
deactivatePlan	Disables the execution of a specified Plans, subject to an implementation specific deactivation mode.	
monitorPlanExecution	Subscribe to receive plan updates for a filtered set of plans. The consumer is notified of updates to the status and other dynamic attributes of subscribed plans.	3
monitorPlanExecutionDetail	Subscribe to receive updates that report changes in the detailed execution status for a filtered set of Plan contents at the level of planning activities, events and resources.	4
activateSubPlan	Enables the execution of planning activities associated with specified Sub-plans.	5
deactivateSubPlan	Disables the execution of planning activities associated with specified Sub-plans, subject to an implementation specific deactivation mode.	
getSubPlanStatus	Retrieves the current status of Sub-plans.	
monitorSubPlanExecution	Subscribe to receive updates on execution status of Sub-plans.	6
SuspendActivity	Request suspension of the execution of selected activities in one or more plans without changing the state of the plan(s), subject to an implementation specific suspension mode.	7
ResumeActivity	Requests the resumption of previously suspended activities in one or more plans without changing the state of the plan(s).	
getActivityStatus	Requests a detailed Report on the status of Activities at Activity, Sub-plan or Tag level.	8

4.4 Plan Information Management Service

The Plan Information Management Service is offered by the planning function of an MPS system to enable its users to list and retrieve available definitions for MPS data items, including: planning requests, planning events, planning activities, planning resources and MPS system configuration data. The service may also be offered by a plan execution function.

The service does not support the transfer of planning configuration data to planning or plan execution functions, which is outside the scope of the current MPS services. Nor does it support the insertion or modification of MPS data item definitions.

The service operations are defined in Table 4 below. None of the operations are mandatory.

Table 4: Plan Information Management Service Operations

Operation	Description	Capability Set
listRequestDefs	Request a filtered list of available Request Definitions.	1
getRequestDefs	Retrieve a set of available Request Definitions.	
listEventDefs	Request a filtered list of available Event Definitions	2
getEventDefs	Retrieve a set of available Event Definitions.	
listActivityDefs	Request a filtered list of available Activity Definitions	3
getActivityDefs	Retrieve a set of available Activity Definitions.	
listResourceDefs	Request a filtered list of available Resource definitions	4
getResourceDefs	Retrieve a set of available Resource definitions	
getSystemConfig	Retrieves system configuration data relating to the MPS System.	5

4.5 Plan Edit Service

The Plan Edit Service is offered by an MPS system's plan execution function to enable its users to modify Plans that have already been submitted for execution. It allows an external user or function to update the status of the Plan; insert, modify or delete planning activity and event instances; update the value of resources; and apply a time shift to a Plan.

This may be used by expert mission operations users in a non-nominal operational scenario to modify a Plan that is executing or about to execute in order to avert or recover from a failure. Where there is sufficient time, it is recommended to re-plan using the nominal planning process rather than to edit the Plan directly, as this circumvents any constraint checking performed by the planning function.

Another use of the service is for a third party functions to update elements of the plan to reflect information available in near-real-time. Examples are:

- Update of the input arguments of a planned activity instance to fine tune its behavior in response to currently observed status;
- Update of a predicted planning event instance that is already contained within a Plan, with refined timing or other details;
- The injection of instances of planning events detected in real-time and correlated to events for which a planned response is available;
- Update of a resource value to more accurately reflect a currently observed status.

The service operations are defined in below. Only the operations in capability sets 1 and 2 are mandatory.

Table 5: Plan Edit Service Operations

Operation	Description	Capability Set
updatePlanStatus	Update Plan status or isAlternate flag.	1
insertActivity	Insert a new Activity Instance into a Plan.	2
insertEvent	Inject a new Event Instance into a Plan.	
deleteActivity	Delete a specified Activity Instance from a Plan.	
deleteEvent	Delete a specified Event Instance from a Plan.	

updateActivity	Update a specified Activity Instance in a Plan.	3
updateEvent	Update a specified Event Instance in a Plan.	
updateResource	Make a discrete update to the value of a specified Resource at a specified time.	4
updateResourceProfile	Update the profile of a specified Resource over time.	5
applyTimeShift	Apply a time shift to a specified Plan or its sub-plans.	6

5. Prototyping Activities

As a proof of concept for the Mission Planning and Scheduling Services standard, two prototypes will have to be implemented. These prototypes shall independently demonstrate that the definitions found in the MPS Blue Book are comprehensive, self-explanatory, sufficient and implementable. ESA and DLR agreed to serve this task and will share a common test scenario covering the mandatory functionalities of the standard.

The prototype implementations will have to demonstrate that the interoperability can be achieved. Each prototype will act both as a service provider and as a service consumer. To be able to exercise the service provider and consumer operations, a testbed will be used on either side. To reduce the implementation effort, the goal is to work with a shared testbed, which is currently under development alongside the development of the prototypes. A proposed design for this testbed is depicted in Fig. 8 below.

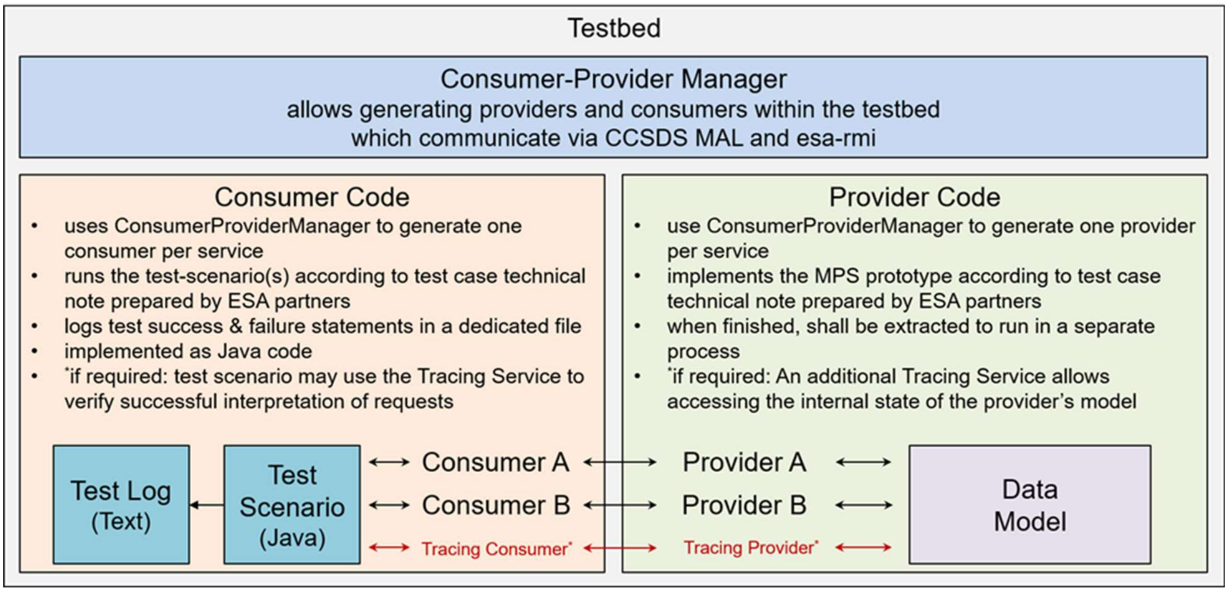


Fig. 8: Design Proposal for the Setup of the Testbed

6. Next Steps

Once the prototyping activities mentioned above will be completed and reported in a Yellow Book, and in addition the MPS Blue Book has been finalized by the WG and internally reviewed and agreed, then the Blue Book will be subject to public review by the CCSDS member agencies. When this public review is completed and any feedback from the CCSDS member agencies has been agreed and in case applicable, has been reflected in the Blue Book, then the Mission Planning and Scheduling standard can be published by the CCSDS Secretariat.

7. Conclusions

This paper has presented the ongoing work in the CCSDS Mission Planning and Scheduling WG with the definition of a mission planning interoperability standard, which should result in the publication of the MPS Blue Book once the steps described above will be completed.

The proposed standard is intended to support a wide variety of space missions and interoperability use cases, in line with mission planning concepts typically found in space missions. It will be based on an Information Model defining the data structures, used in the set of MPS Services supporting the interoperability between entities.

Although the full standard including the Information Model and Services Specification is quite extensive, for missions adopting the standard it is possible to limit the scope of the implementation. Only a core set of the data structures of the Information Model is mandatory; optional data structures do not need to be supported in a mission. In addition, an entity is free to support any of the Services defined in the standard. For each Service, only a limited number of operations are mandatory, defined with the Service capability sets.

In support of legacy planning systems not able to support services, the MPS standard also envisages the exchange of planning information solely by means of data messages, based only on the MPS Information Model data structures, in particular with the Planning Request and Plan data structures. These data messages can then be encoded in (XML) files and exchanged by any file transfer means.

As the normative part of the standard is only concerned with the interfaces between the different planning entities and not the planning functions themselves, adopting the standard to existing planning systems could be achieved in a non-intrusive way, as far as the planning information required to interact with other entities is available.

References

[1] Consultative Committee for Space Data Systems (CCSDS), https://public.ccsds.org/default.aspx
[2] Mission Planning and Scheduling. Report Concerning Space Data System Standards, CCSDS 529.0-G-1. Green Book. Issue 1. Washington, D.C.: CCSDS, June 2018. https://public.ccsds.org/Pubs/529x0g1.pdf
[3] Application and Support Layer Architecture. Report Concerning Space Data System Standards, CCSDS 371.0-G-1. Green Book. Issue 1. Washington, D.C.: CCSDS, November 2020. https://public.ccsds.org/Pubs/371x0g1.pdf
[4] Mission Operations Services Concept. Report Concerning Space Data System Standards, CCSDS 520.0-G-3. Green Book. Issue 3. Washington, D.C.: CCSDS, December 2010. https://public.ccsds.org/Pubs/520x0g3.pdf
[5] Mission Operations Message Abstraction Layer. Recommendation for Space Data System Standards, CCSDS 521.0-B-2. Blue Book. Issue 2. Washington, D.C.: CCSDS, March 2013. https://public.ccsds.org/Pubs/521x0b2e1.pdf
[6] Mission Operations Common Object Model. Recommendation for Space Data System Standards, CCSDS 521.1-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, February 2014. https://public.ccsds.org/Pubs/521x1b1.pdf
[7] Space Communication Cross Support − Service Management − Service Specification. Recommended Standard, CCSDS 910.11-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, August 2009. https://public.ccsds.org/Pubs/910x11b1s.pdf
[8] Cross Support Concept − Part 1: Space Link Extension. Informational Report, CCSDS 910.3-G-3. Green Book. Issue 3. Washington, D.C.: CCSDS, March 2006. https://public.ccsds.org/Pubs/910x3g3.pdf