ESTRACK Management System Support for the CCSDS Space Communication Cross Support Service Management

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Over the last few years, services of the ESA Tracking Network (ESTRACK) have been automatically allocated by the ESTRACK Management System (EMS), more precisely by its planning and scheduling components ESTRACK Planning System (EPS) and ESTRACK Scheduling System (ESS). EMS, being the core component responsible for the ESTRACK service management, i.e. negotiation, allocation, configuration and scheduling of the services, has been analysed on conformity with the SCCS SM standard. The paper presents results of this analysis along with the high level architecture design for the initial implementation of the cross support according to the SCCS SM standard. The design overview focuses on the interfaces to the European Space Operation Centre (ESOC) internal ground segment systems such as the Flight Dynamic System and external proxy interface with corresponding workflows. After a brief overview of the standard and relevant EMS components, the initial deployment options, open issues and a tentative roadmap for the way towards the full support of the SCCS SM are discussed.

I. Overview

The Consultative Committee for Space Data Systems (**CCSDS**) Recommended Standard for Space Communication Cross Support Service Management (**SCCS SM**) published as Blue Book [1] in August 2009 is intended to provide standardised interfaces to negotiate, schedule, and manage the support of space missions by ground station network operators. ESA as a member of CCSDS has actively supported the development of the SCCS SM standard and is obviously interested in adopting it. Support of SCCS SM conforming interfaces and procedures includes:

- Provision of SCCS SM conforming interfaces to non ESA missions;
- Use of SCCS SM interfaces provided by other ground station operators to manage cross support of ESA missions;
- In longer terms potentially use of SCCS SM interfaces and procedures also internally for support of ESA missions by ESTRACK.

II. CCSDS Space Communication Cross Support Service Management

The CCSDS Space Communication Cross Support Service Management recommendation standardises the scheduling and configuration of space link and ground transfer services provided by a ground station network to a space mission.

The SCCS SM environment is illustrated in Figure II-1. In this model, Space Link Extension (**SLE**) transfer services and SCCS service management provide the interfaces between an SCCS Complex which provides transfer services and Telemetry, Tracking and Command (**TT&C**) space link services and a spaceflight Mission which uses

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those services. The spaceflight Mission consists of a single Space Element and the Mission Data Operations System (**MDOS**), which performs the Mission's ground-based functions.

The Utilization Management (**UM**) function of the MDOS coordinates and manages space link and transfer services on behalf of the service users within the MDOS. UM's role includes:

- Negotiating types of services, numbers of service instances, and the length of the Service Agreements with CM
- Providing configuration information for radio frequency, modulation, space link service, and space link extension transfer service
- Providing Trajectory Prediction information that allows the Complex to determine where the mission spacecraft will be at the requested periods of service provision
- Requesting periods of provision of space link services and space link extension transfer services
- Coordinating with Mission User Entities within the MDOS to enable the execution of SLE services and to collect status information

UM interacts with the Complex Management (**CM**) function of the Complex to acquire and operate the TT&C and transfer services needed by the Mission. CM's role includes:

- Negotiating types of services, numbers of service instances, and the length of the Service Agreements with UM
- Validating configuration, trajectory, and requests for services against service agreements
- Determining and scheduling internal resources in conformance with (validated) packages of services to be provided
- Providing configuration information to the resources of the SLE Complex to enable the production and provision of SLE services
- Monitoring and controlling its internal resources for correct operation in accordance with services requested

The interactions between UM and CM are the subject of SCCS SM, and the management information exchanges are carried out via the standard SCCS management services. The SCCS SM interfaces are highlighted in red in the figure.

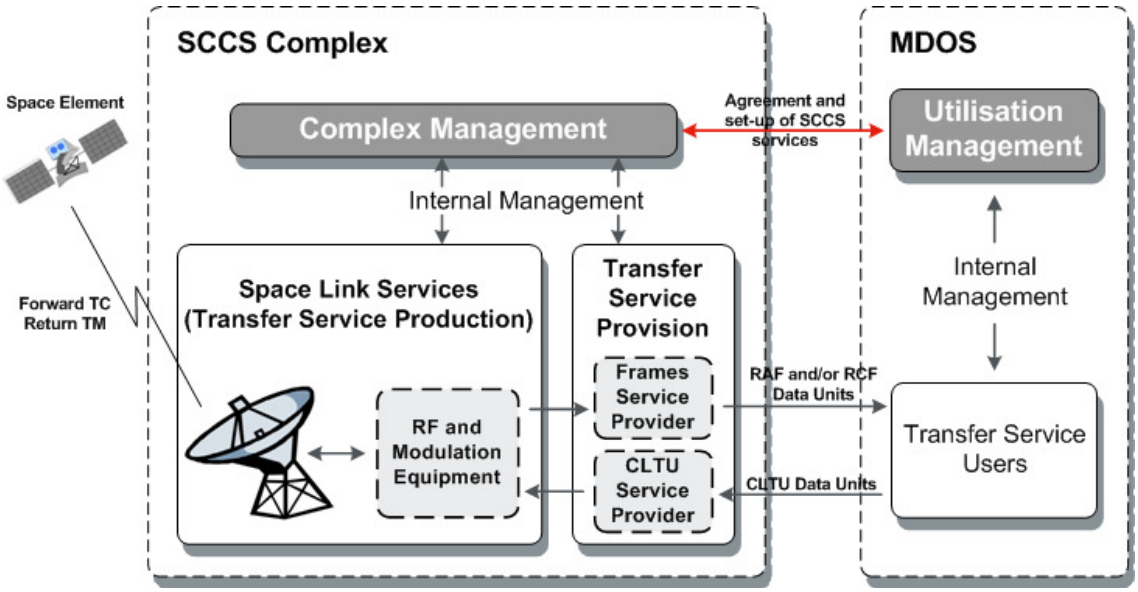

Figure II-1 SCCS SM Environment

SCCS SM is organized in terms of a set of service management *information entities* and the *management services* that manipulate them:

- Service Agreements
- Configuration Profiles
- Trajectory Predictions
- Service Packages

The management services are defined in terms of operations that are invoked by one SCCS-SM entity (UM or CM) and performed by the other (CM or UM). The entities and corresponding services are described below.

A **Service Agreement** defines the context of the support relationship between the Mission and the Complex during a particular mission phase. It defines the boundaries on the values of parameters of the other types of information entities - for example, allowed carrier and subcarrier frequency ranges and modulation schemes; number of service packages per unit time. The Service Agreement service only allows the Service Agreement to be queried, not defined.

Configuration Profiles define reusable configurations of space link and transfer service parameters. The service provides operations to add, delete, and query Configuration Profiles.

A **Trajectory Prediction** defines the course of the spacecraft over a period of time. A Trajectory Prediction can be either a single state vector to be propagated, or a set of vectors that form an ephemeris, conforming in either case to the Orbit Data Messages recommendation, CCSDS 502.0-B-2. The Trajectory Prediction service has operations to add, delete, and extend trajectory prediction information. It supports various modes of operation: it is possible, for example, to identify each separate prediction, and explicitly identify which prediction is used for which service package; on the other hand, a single named prediction can be refined and extended over time.

Exchange of **Service Package** scheduling information is the main focus of SCCS SM. There are two types of Service Package:

- Space Link Session (**SLS**) Service Package
- Retrieval Service Package.

The SLS Service Package schedules space link services and associated terrestrial data transfer services for a set of space link sessions (space-ground link contacts) whereas the Retrieval Service Package schedules an offline data transfer service for retrieval of data from a data store. The Service Package service is used to request the scheduling of SLS and Retrieval Service Packages, and to modify, query, or delete existing scheduled Service Packages.

III. The ESTRACK Management System

ESTRACK Planning System is responsible for dynamic allocations of services provided by ESTRACK to service requests of ESA's and external space missions. For that purpose EPS uses various planning and scheduling techniques based on constraint processing and optimisation algorithms. More details on the planning process can be found in [2].

Planning process inputs in EPS can be divided into three groups:

- Mission communication model
- Ground station services model
- Trajectory and other temporal mission specific information, e.g. events files supplied by the ESOC Flight Dynamics department

Mission communication requirements and ground station services are expressed as a mission model and a ground station model. Models are stored in the configuration database and can be changed or extended. The ground station model specifies the available ground stations and services they provide, e.g. telecommand uplink, telemetry reception, shadow tracking, range calibration, Delta-Dor etc. The mission model contains communication requirements expressed as Mission Agreements. A Mission Agreement defines required ground station services, called User Services, and their temporal aspects, Basic Standing Order Periods (**BSOP**). BSOPs specify the requested periodicity for User Service provisioning and can be expressed in different units: hours, days, weeks, orbits or some time periods. Additionally, Mission Agreement contains constraints attached to User Services, which define temporal aspects and the way the given User Service has to be used.

The EPS product is the ESTRACK Management Plan (**EMP**). Among others EMP contains Operational Service Sessions (**OSS**) representing the ground station services allocation to a particular spacecraft. Excerpts of the EMP are called plan views. Plan views are sent to the user missions as feed-back to their service requests and should be interpreted by their mission planning systems as station allocation plans. Missions can update and refine the plan by the means of OSS update requests. In addition to OSS updates missions are given another interface to govern the EMP generation process which is Standing Order refinement request. In contrast to OSS update requests Standing Order refinements do not target directly any of the OSS on the generated EMP but refines the mission service requirements model contained in the Mission Agreement and used for automated ground station services allocation.

The ESTRACK Scheduling System reads the plan produced by EPS and generates schedules for each of the facilities under management of the EMS. In addition ESS generates the required Service Instance Configuration Files for transmission to the Mission Operations Centre and to external provider systems.

Figure III-1 shows the operational context of the EMS.

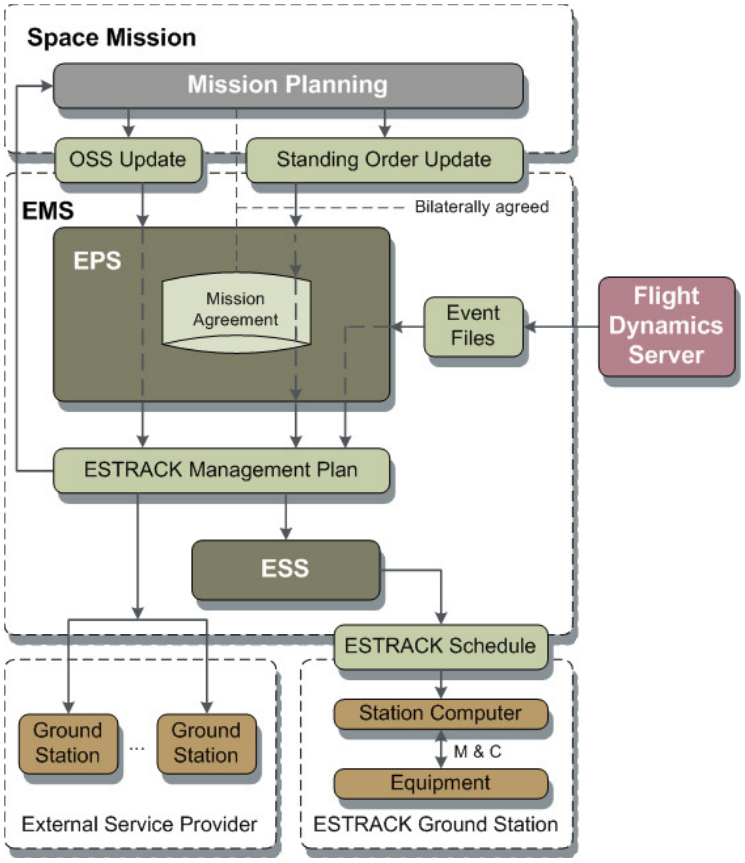

Figure III-1 ESTRACK Management System Context

IV. Initial Mapping and Deployment Options

SCCS SM defines a minimal compliance level which requires that

- EITHER the service provider can suggest service packages and the service user can accept them OR the user can specify service packages and the provider can accept them;
- Service packages can be deleted by the service user; and
- The provider must signal to the user when a service package had to be cancelled.

Table 1 shows operations of the Service Package Service which constitute the SCCS SM minimal specification compliance. All other services and operations are optional. Furthermore, a number of the operations allow for modification or extension by bilateral agreement. Complete table of the operations compliance levels can be found in [4].

Table 1 SCCS SM Minimal Specification Requirements

Operation	Bilaterally defined content allowed	Bilaterally defined exchange allowed	Required for minimal specification compliance
Create Service Package (CSP)	Partial	No	Alternative[4]
Delete Service Package (DSP)	No	No	Yes
Confirm Tentative Service Package (CTSP)	No	No	Alternative
Service Package Canceled (SPC)	No	No	Yes

Analysis of high level SCCS SM deployment options has shown that it is appropriate to distinguish the following application areas:

[4] Either CSP or CTSP must be provided. Implementations may provide both.

- Agreement of the parameters to be used for configuration of service production and provision which is supported by the SM Configuration Profile Service (excluding the Space Link Events Profile) and to some extent by the SM Service Agreement Service.
- Handling of Trajectory Profiles and derivation of the pertinent visibility events for the relevant ground stations and handling of spacecraft / mission events, i.e. the functionality assigned to Flight Dynamics at ESOC; these aspects are addressed by SM Trajectory Prediction Service and the SM Configuration Profile Service for the Space Link Events Profile.
- Actual scheduling of service packages addressed by the SM Service Package Service.

Within ESTRACK, EMS is directly concerned only with scheduling of service packages, whereas the other tasks fall into the responsibility of Ground Station Engineering and Flight Dynamics respectively. Enrolment of Service Management in each of these application areas can be handled independently.

Another outcome of the feasibility analysis of EMS support for SCCS SM standard is that Service Package Scheduling is the most urgent aspect for ESOC. Therefore, the first step to take would be to provide support for the minimal capability set within the Service Package Service. For cross support services the "specific period scheduling" approach is considered the most adequate but as EMS itself is based primarily on rule based scheduling, that option is a candidate for initial implementation as well. As EMS may play the role of a service provider towards external missions or my act as a service user towards external service providers on behalf of ESA missions, both roles must be supported.

In the area of configuration profile specification and management, extended system support can be envisaged. The specification of the configuration profiles aims at definition of a comprehensive set of configuration parameters in an equipment and mission independent manner. If this objective is achieved, then it should be possible to derive equipment specific configuration tables such as the Intermediate Frequency and Modem System (**IFMS**) configuration tables from these profiles in an automated manner. For equipment that does not support file based configuration tables appropriate Station Computer procedure parameters can be derived or the new Ground Station Monitoring and Control (**GSMC**) system configuration table feature may be used.

Of course such a system will require information about the equipment installed in the ground station and this information may vary across the versions of the equipment in use on a specific ground station. Most probably the conversion rules will also depend on the specific equipment and it cannot be excluded that there are variations for different equipment versions.

EMS support for the Trajectory Prediction service will be initially limited only to Extend Trajectory Prediction (**ETP**) message from this service which is enough to cover the functionalities provided by the Add and Delete Trajectory Prediction messages. Since EMS does not work with Orbit Parameter Message (**OPM**) and Orbit Ephemeris Message (**OEM**) defined to be the data formats for the Trajectory Prediction Service the data conversion service shall be provided by the ESOC Flight Dynamics or a bilateral agreement to use the event file interface shall be reached.

To provide initial support of the SCCS SM standard, a proxy based approach was chosen. Proxies will implement the SM services and convert SM Requests and Responses to and from interface files expected or generated by EMS. The proxy implementation approach was chosen instead of "native" implementation of the SCCS SM features in EMS in order to minimise changes to the EMS core.

Figure IV-1 shows the high level architecture of the infrastructure which ESOC envisages deploying for the initial SCCS SM support. Two proxies are foreseen to implement the Complex Manger role and the User Management role of SCCS SM. The first role provides space link services, the latter one requests space link services from external complex managers.

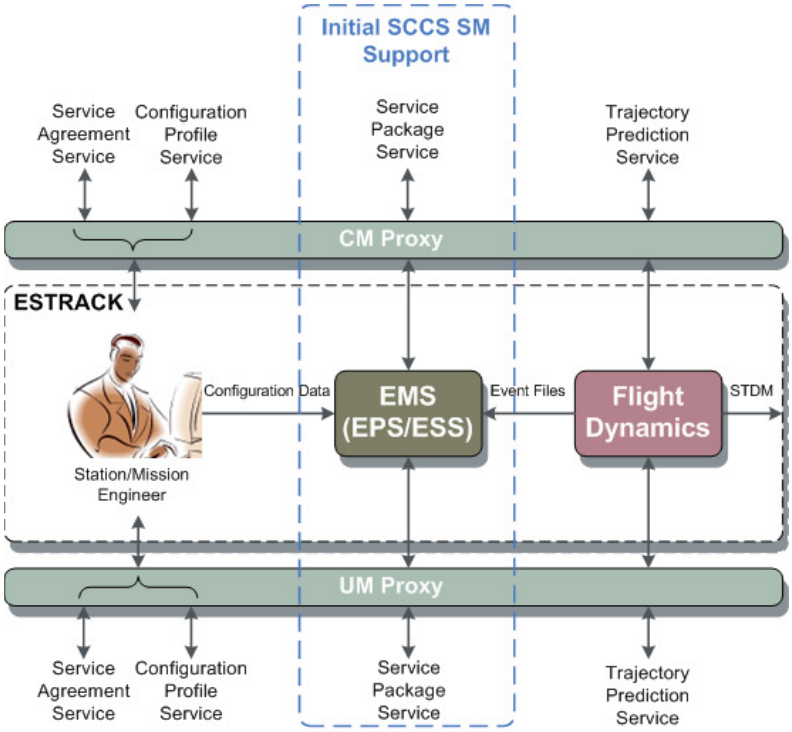

Figure IV-1 Support of SCCS SM via Proxies

The mapping of SCCS SM services to ESOC entities is described in Table 2. More details on the mapping between concepts, information entities and operations defined in SCCS SM and EMS can be found in [3].

Table 2 SCCS SM Service Mapping

SCCS SM Service	ESOC Entity	Description
Service Agreement Service	Station Engineer / Mission Engineer / EMS	The station engineer will use the Service Agreement to validate Configuration Profiles against the limits in the mission agreement.
Configuration Profile Service	Station Engineer / Mission Engineer	The configuration of the ESS / Station Computer and the relevant station equipment will be prepared to provide services adhering to these defined configuration profiles.
Service Package Service (limited to the minimal compliance level)	EMS (EPS/ESS)	The EMS will realise the SCCS SM service package service. For this purpose, the CM proxy maps the create service package operations to EMS OSS requests. In order to request SCCS SM service packages from external providers, the UM Proxy has to map the candidate OSSs of the ESTRACK management plan to SCCS Service Package Operations sent to external SCCS SM compliant service providers.
Trajectory Prediction Service	Flight Dynamics	In contrast to the SCCS SM standard, which relies on predicted trajectories, the ESOC systems rely on event files and Station Trajectory Data Message (**STDM**) files. Therefore the processing or generation of trajectory data is foreseen to be implemented by Flight Dynamics.

A substantial portion of the SCCS SM, namely the Configuration Profile Service which deals with the configuration of the ground station equipment, is initially foreseen to be realised as a manual engineering task. This is justified by the complexity inherent to the automation (or perhaps semi automation) of the task.

V. Proxy Interface Architecture

Figure V-1 shows the high level architecture of proxies implementing the mapping between SCCS SM messages and their counterparts in EMS.

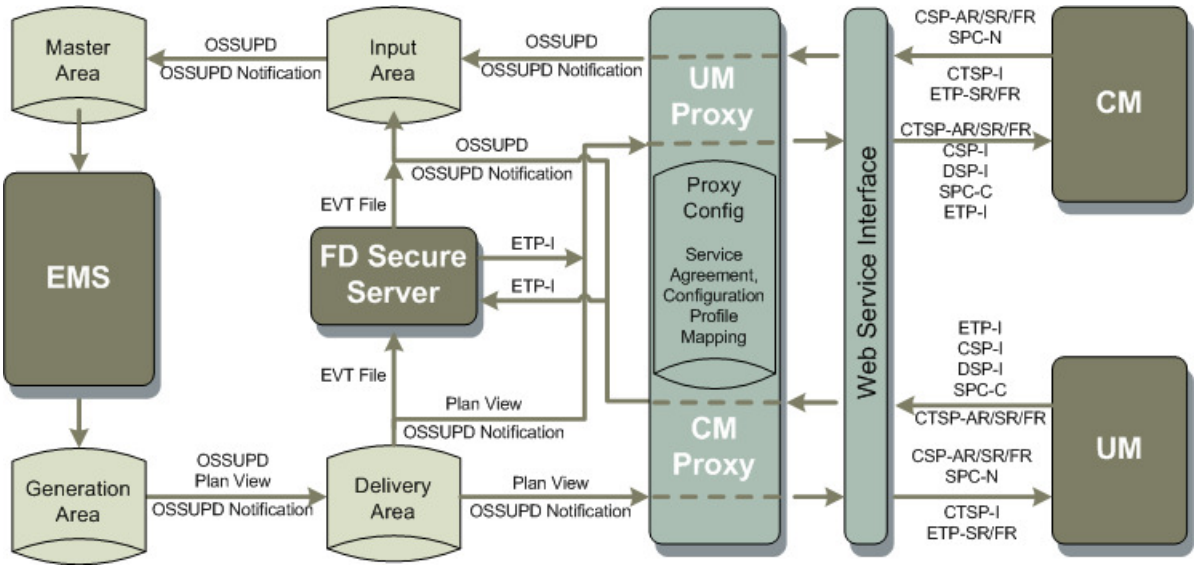

Figure V-1 High Level Architecture of the SCCS-SM Proxy in EPS/ESS[5]

The need for an editable, persistent proxy configuration is due to the requirement to support parameter re-specification, and to include Space Communication Service Profile into the CSP-SR message when re-specification is in effect. To satisfy this requirement the proxy should be able to map the configuration profile parameters from EMS to the parameters specified in Space Link Carrier Profile data set. Since the concept of configuration profiles is not formally defined in EMS, it is not possible to implement the mapping in automated manner. The mapping should be defined, validated and stored in the proxy configuration by EMS and ground station specialists. Additionally, proxy configuration will make it possible to support extended set of SCCS SM messages in the future without many changes in the proxy itself.

Although the mapping between EMS and SCCS SM messages cannot be implemented without changing the format of the EMS messages[6], most of the required adjustments are rather minor, e.g. enclosing an existent parameter to the message, and do not involve conceptual changes to EMS. The only mapping which requires special attention is the one between OSS Update and Create Service Package messages. The reason for this is the difference in representations of services which will be provided to users. OSS is the only information entity in EMS which represents of a set of services provided together to the user within a single continuous contact between a spacecraft and a single ground station, and at the same time can be accessed by users, i.e. created, queried, changed or deleted, via EMS external interface. Service Package, in contrast, can contain a number of Space Communication Services supported by different ground stations. Moreover, Space Communication Services within the same Service Package are not temporally constrained relative to each other. Therefore, a single Service Package can contain a number of Space Communication Services referencing different antennae and overlapping in time or temporally disjoined Space Communication Services referencing single or different antennae or no antennae at all.

It is worth to note that EMS working in the rule-based planning mode can produce a service allocation that would directly correspond to the SCCS SM Service Package but the request for such service allocation cannot be currently expressed in form of an OSS Update request. More precisely, if a single Space Communication Service Request within a Service Package Requests can only be implemented using handover between two stations the OSS Update mechanism will not be able to implement such a request. The reason for this is that the OSS Update implementation approach in EPS is not backed by the planning algorithm but solely by the consistency checking procedure. Even though it is not foreseen for the initial SCCS SM support to adapt the EPS planning engine to be able to produce a direct counterpart of the SCCS SM Service Package in response to an OSS Update request, it was

[5] Abbreviations used in the diagram can be found in Appendix A and Appendix B.

[6] Various EMS information entities, especially those defined in EMS ICD as XML files, e.g. OSS Update File, SOREF File, etc., will be referred to as EMS messages.

recognized by ESOC as a useful enhancement for EPS which would make sense and improve planning capabilities independently from the possible support for the SCCS SM standard.

OSS is not the only concept in EMS which represents service implementations in EPS. However, it is the only information entity which is accessible by the user via EMS external interfaces. In addition to OSS, EMS has an internal concept called Super Service Opportunity Window (**SSOW**) representing a possibility for a spacecraft to have a continuous contact on a set of ground stations if their visibilities overlap. Consequently, SSOWs are used to implement temporally overlapped OSSs on a set of ground stations where the duration of the overlap is controlled by the handover duration constraint.

In general, Service Package cannot be mapped to SSOW because of the temporal restriction imposed on the ground stations visibilities which constitute the SSOW (recall that a Service Package can contain temporally disjoint Space Communication Services). One of the conceivable approaches to enable a direct mapping would be to introduce in EMS a new concept based on the existent SSOW and make its entities accessible via public interface. This will enable EMS being in the UM role to map a request for a service implementation with handovers, i.e. SSOW, to a single Create Service Package Request. However it is not the only possible option, since the proxy can implement the required mapping without accessing SSOWs.

In the case when EMS is acting as UM, requests for single OSS without handover and for a number of OSS linked by handovers will be mapped by proxy to CSP-I message with single Space Communication Service Request. For that purpose, proxy should keep a table for mapping id of OSSs linked via handover to the id of the Service Package implemented and confirmed by a CM.

In the case when EMS is acting as CM, incoming Create Service Package Requests will be mapped by the proxy to a number of OSS Update requests. The number of OSS Update requests can be directly taken from the number of Space Communication Service Requests in the Create Service Package Request.

VI. Conclusion and Future Work

For the purpose of deployment of SCCS SM in ESTRACK it is appropriate to distinguish the following application areas:

1. Agreement of the parameters to be used for configuration of service production and provision;
2. Handling of Trajectory Predictions and derivation of the pertinent visibility events for the relevant ground stations and handling of spacecraft / mission events, i.e. the functionality assigned to Flight Dynamics at ESOC;
3. Actual scheduling of service packages.

Within ESTRACK, EMS is directly concerned only with scheduling of service packages, whereas the other tasks fall into the responsibility of Ground Station Engineering and Flight Dynamics respectively. Enrolment of Service Management in each of these application areas can be handled independently.

Service Package Scheduling is considered to be of highest priority, and within the Service Package Service support of the minimal capability set would be the first step to take. For cross support services the “specific period scheduling” approach is considered the most adequate but as EMS itself is based primarily on rule based scheduling, that option could be easily supported as well. As EMS may play the role of a service provider towards external missions or my act as a service user towards external service providers on behalf of ESA missions, both roles must be supported.

Analysis conducted within the ESA study of the EMS Support for SCCS SM [3] demonstrated that an initial implementation of SCCS SM support by EMS can be largely based on proxies that implement the SM services and convert SM Requests and Responses to and from interface files expected or generated by EMS. Changes to the current EPS software are only needed if SCCS Concepts such as service packages covering multiple space link sessions should be adopted for EMS because they are considered advantageous for support of ESA missions as well.

It is noted that the current version of the CCSDS Recommended Standard misses a number of features that are considered important for management of ESTRACK services and the most important of these have been compiled as recommendations for SCCS SM evolution.

However, it is also recognised that theoretical analysis and prototyping alone will not allow the elaboration of a standard that fully meets operational needs, and that initial operational experience is urgently needed to evolve the existing standard into a generally accepted and applied specification.

Appendix A

Acronym List

BSOP	Basic Standing Order Periods
CCSDS	Consultative Committee for Space Data Systems

CM	Complex Management
CSP	Create Service Package
CTSP	Confirm Tentative Service Package
DSP	Delete Service Package
EMP	ESTRACK Management Plan
EMS	ESTRACK Management System
EPS	ESTRACK Planning System
ESOC	European Space Operation Centre
ESS	ESTRACK Scheduling System
ESTRACK	ESA Tracking Network
ETP	Extend Trajectory Prediction
GSMC	Ground Station Monitoring and Control
IFMS	Intermediate Frequency and Modem System
MDOS	Mission Data Operations System
OEM	Orbit Ephemeris Message
OPM	Orbit Parameter Message
OSS	Operational Service Sessions
SCCS SM	Space Communication Cross Support Service Management
SLE	Space Link Extension
SLS	Space Link Session
SPC	Service Package Canceled
SSOW	Super Service Opportunity Window
STDM	Station Trajectory Data Message
TT&C	Telemetry, Tracking and Command
UM	Utilization Management

Appendix B

Abbreviation of Individual SM Messages

<OP>-A	<Operation> - Acknowledgement
<OP>-C	<Operation> - Confirmation
<OP>-FR	<Operation> - Failure Return
<OP>-I	<Operation> - Invocation
<OP>-N	<Operation> - Notification
<OP>-SR	<Operation> - Success Return

References

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[4] CCSDS 910.14-G-1, SPACE COMMUNICATION CROSS SUPPORT — SERVICE MANAGEMENT — OPERATIONS CONCEPT, Green Book May 2011