An International Standard Procedure for Managing Spacecraft Emergency Cross Support (SECS)

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Abstract In September 2019, the Interagency Operations Advisory Group (IOAG) Spacecraft Emergency Cross Support (SECS) Working Group presented the SECS Standard Operating Processes and Procedures (SOP) to the annual IOAG conference (IOAG-23). The SOP presents a harmonised approach for emergency recovery support entailing processes and services that reduce response times related to critical emergency situations. The implementation of these services will be achieved by:

- Encouraging member agencies to follow the guidelines outlined in the SOP
- Encouraging member agencies to establish arrangements that enable execution of SECS

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C. Cruzen et al. (eds.), *Space Operations*, Springer Aerospace Technology,
https://doi.org/10.1007/978-3-030-94628-9_1

The SOP provides guidance to agency Service Users, i.e. any agency mission, current or future, that may require additional support beyond their routine and contingency support, in order to recover from an Emergency Condition that threatens the life of the spacecraft. Initially, support is limited to IOAG member Agencies; however, the support, as defined, has the potential to expand the "service user" and "service provider" base. In addition, the IOAG is surveying interest from Commercial Service Providers for participation. The SECS SOP defines three specific categories of standard support that can be made available by service providers.

- Committed Support
- Acknowledgement Support
- Non-Registered Support

The SOP describes the "recovery" services that service providers may perform, covering a wide variety of contingency situations, including:

- Downlink or uplink engineering services for diagnostics (no real-time telemetry or telecommand transfer)
- Tracking data delivery and/or processing
- Full telemetry, tracking and command (TT&C) Services

These services require the support of various branches of a service provider's infrastructure, namely:

- Flight dynamics
- Ground stations
- Data communications
- Asset scheduling

The SOP deals with items of particular interest to mission managers, including what constitutes a spacecraft emergency, radio frequency (RF) licensing, points of contact, and the SECS asset database. As a "Proof of Concept", various demonstration exercises were performed utilising stations from multiple agencies tracking spacecraft which, although not actually in emergency, require preparation activities in line with a contingency acquisition. Completion of this SOP is a major milestone for this working group. The document focuses on emergency support for robotic missions. The working group plans to expand its scope to encompass emergency support for human spaceflight missions. More information on the IOAG can be found on the following website: https://www.ioag.org. The SOP can be located on the IOAG by following the "Documents" link then the "Public" link, or can be found directly on the website: https://www.ioag.org/Public%20Documents/IOAG%20Spacecraft%20Emergency%20Cross%20Support%20SOP.pdf.

Abbreviations

AOS	Acquisition of Signal
CCSDS	Consultative Committee for Space Data Systems
DSN	Deep Space Network
EbNo	Energy per Bit to Noise ratio
EsNo	Energy per Symbol to Noise Ratio
ESTRACK	European Space Tracking Network
FCT	Flight Control Team
GEO	Geostationary Orbit
IOAG	Interagency Operations Advisory Group
ITU	International Telecommunication Union
JPL	Jet Propulsion Laboratory
LEO	Low Earth Orbit
LEOP	Launch and Early Orbit Phase
MOCC	Mission Operations Control Centre
ODM	Orbit Data Message
OLP	Open Loop
RF	Radio Frequency
SECS	Spacecraft Emergency Cross Support
SGICD	Space to Ground Interface Control Document
SLE	Space Link Extension
SOP	Standard Operating Procedures
TC	Telecommand
TLE	Two Line Elements
TLM	Telemetry
TT&C	Telemetry, Tracking and Command

1 Introduction

The Spacecraft Emergency Cross Support Working Group (SECWG) SOP defines the grounds for declaring a spacecraft emergency as the following:

- Spacecraft emergency mode is the anomalous state of the spacecraft in which its persistence will cause the spacecraft's loss entirely or losing spacecraft's essential facilities (payload excluded).
- For human spaceflight missions, any of the above conditions or any external or internal conditions that could negatively affect the health and safety of the crew members.

Neither a ground segment failure by itself, nor loss of science or payload data, is considered a direct cause for declaring a spacecraft emergency.

1.1 Current IOAG Membership

IOAG Members
Agenzia Spaziale Italiana (ASI)
Centre National d'Études Spatiales (CNES)
Canadian Space Agency (CSA)
Deutsches Zentrum für Luft- und Raumfahrt (DLR)
European Space Agency (ESA)
Japan Aerospace Exploration Agency (JAXA)
National Aeronautics and Space Administration (NASA)
United Kingdom Space Agency (UKSA)
IOAG Observers
Australian Space Agency (ASA)
Chinese National Space Administration (CNSA)
Indian Space Research Organisation (ISRO)
Korea Aerospace Research Institute (KARI)
Roscosmos State Corporation for Space Activities (ROSCOSMOS)
South African National Space Agency (SANSA)
United Arab Emirates Space Agency (UAESA)

1.2 Consequences of a Lost Mission

The unplanned end of a mission results in a myriad of detrimental consequences.

- Losing significant financial investment in the spacecraft's development and its related infrastructure such as control systems and ground segment.
- The loss of data to the science community.
- Potential danger to other missions, if the spacecraft is positioned in an orbital trajectory that is also occupied by other spacecraft.
- Spacecraft operations often require a relatively large team of 1st, 2nd and 3rd line support personnel. Loss of a spacecraft can have serious impacts on the morale of individual personnel, the team and the community at large.

1.3 Current User Community

The Standard Operating Processes and Procedures (SOP) initially applies to IOAG member agencies, although the use cases might apply to non IOAG agencies in the future. The SOP could be considered as a catalogue of services and assets for any mission manager whether the project is in its planning stage or, if already in orbit, the project has identified a significant shortcoming in its operational strategy.

2 The Spacecraft Emergency Cross Support Working Group (SECSWG)

The IOAG was chartered to create a working group dedicated to the provision and standardisation of recovery cross support to spacecraft in emergency conditions, i.e. SECSWG. The Terms of Reference for the Working Group are as follows:

- Encouraging member agencies to follow the guidelines outlined in a SECS SOP when preparing for and coordinating cross support for a spacecraft emergency
- Encouraging member agencies to establish arrangements that enable the execution SECS SOP.

The current participating members in the Working Group are a subset of the IOAG membership, (i.e. ASI, CNES, DLR, ESA, JAXA, KARI, NASA). A major milestone for the Working Group was the presentation of the SOP to the IOAG for adoption and issue with the member agencies.

3 Support Scenarios

The amount of coordination and preparation for a service provider and a service user directly affects the available response time to support an emergency. Early coordination can significantly reduce the response time during an emergency; however, preparing a ground station for an emergency support that may never need incurs costs both to the user and the provider. Reflecting this, the SOP describes three types of service support scenarios that vary in the amount of preparation and investment prior to an emergency and the associated response times that can be expected.

3.1 Committed Support

A service user has contacted a service provider and, through established agreements, the provider has agreed that some of its assets can be used in the SECS process guaranteeing functioning pre-validated TT&C services. The service user has previously identified the assets that it considers appropriate to the recovery of the spacecraft, for example:

- The selected ground stations are tailored to support the spacecraft acquisition downlink and/or uplink

- RF licenses and International Telecommunication Union (ITU) filing have been confirmed
- The configuration has been validated for telemetry (TLM) recovery and/or command transmission
- End to end communications infrastructure has been validated for data transfer
- The service provider will periodically test the configuration and ground communications

3.2 Acknowledged Support

A service user has contacted a service provider, and the service provider agreed that some of its assets could be potentially used in the SECS process. Such identified assets were considered appropriate to the recovery of the spacecraft, i.e.

- The selected ground stations are tailored to provide the Service User with Engineering/Diagnostic services at a minimum.
- Standard TT&C services can be provided depending on the level of support readiness such as availability of ground communications lines, ITU filing and RF Licenses.
- The ground station configuration may not have been pre-validated and periodic testing will not be performed.

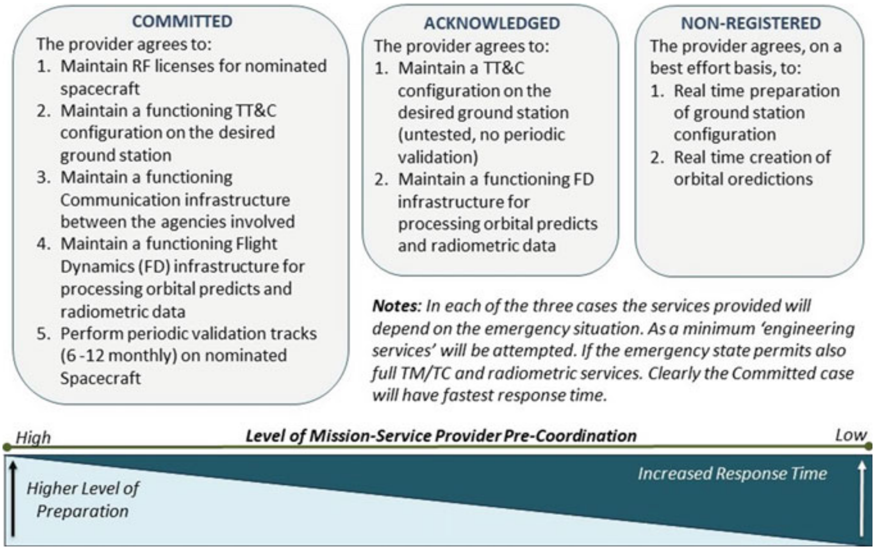
Effectively this means that a service user and service provider may negotiate the level of support readiness to an affordable level so that further standard TT&C services are available for emergency support.

3.3 Non-Registered Support

A service user that has not coordinated SECS services with a service provider prior to an emergency, i.e. ground segment and infrastructure, is not immediately available. Although workable, this approach dramatically increases the response time for emergency support.

3.4 Support Overview

The support scenarios can be thus summarised:



4 Categorisation of Services that Comprise Recovery Operations

While the general processes outlined in the SOP could apply to most emergency cases, they are generally for service users that comply with the applicable Consultative Committee for Space Data Systems (CCSDS) core standards as specified in the IOAG Service Catalogue#1 [1]. Non CCSDS compliant Users may be limited to engineering services, if available.

The SOP foresees the provision of four types of service, namely:

- Flight Dynamics Services
- Engineering Services
- Standard TT&C Services
- Network Services (Data Transfer)

4.1 Flight Dynamics Services

Committed and acknowledged support scenarios are expected to have established functioning infrastructure for transferring and processing of the spacecraft trajectory prior to the occurrence of an emergency. Thus, trajectory predictions can be created by the provider's flight dynamics and provided to the supporting station to initiate program track on the spacecraft. In the event of no pre-existing infrastructure, the service user is required to provide the service provider with the latest and/or expected trajectory predictions for the spacecraft in the CCSDS Orbit Data Message (ODM) format, recommended standard CCSDS 502.0-B-2 [2]. Any radiometric data collected by the supporting ground station will be delivered to the service user for processing and orbit determination. Alternatively, the service provider flight dynamics may be requested to provide orbit diagnostics and orbit determination. As mentioned previously all data transfer must conform to the CCSDS ODM Format.

4.2 Engineering Services

If a spacecraft is in an emergency condition, some functionality is lost due either to a system failure on the platform or non-nominal trajectory, which may prevent the provision of standard TT&C services. In such cases, the service provider can provide engineering services to determine the status, attitude, or orbit of the spacecraft to assist in the recovery from the anomalous condition.

4.2.1 Downlink Engineering Search Services

The Spacecraft Search Service category applies to cases in which the spacecraft trajectory is non-nominal, thus preventing ground stations from acquiring the downlink. These cases typically occur after launch, erroneous injection, or after a trajectory correction manoeuvre in which the on-board thrusters did not perform as predicted. The search techniques used to locate the spacecraft may include:

- Use of an antenna with wider beam-width, i.e., acquisition aid with smaller aperture but with link budget limitations
- Antenna scanning, predefined search pattern, e.g. conical scan
- Along track search, applying time offsets to antenna predicts
- Multiple trajectories, flight dynamics provide predictions corresponding to fixed error cases, e.g. ± 3 sigma against a nominal case.

If the search is successful, the first outcome of the service is confirmation that the spacecraft transmitter is "on". The antenna should then continue to track the spacecraft and collect passive measurements, e.g. antenna angles when in auto-track and raw 1-Way doppler, to allow computation of a new trajectory.

4.2.2 Downlink Engineering Signal Analysis Services

This category applies to cases in which the spacecraft downlink signal is non-nominal, e.g. the ground station cannot lock, demodulate or decode the received signal. Assuming the spacecraft transmitter is not functioning correctly, these services attempt to analyse the signal and provide the service user with useful information, e.g. spectrum analyser display, automatic gain control (AGC), energy per symbol to noise ratio (Es/No), energy per bit to noise ratio (Eb/No) recording etc. This data may assist the service user in preparing the recovery operations that are required. The diagnostic techniques that could be applied comprise:

- *Spectral Analysis:* The supporting ground station captures, records and displays (real time online) the spectrum of the received signal, thus confirming frequency, noise and modulation scheme.
- *Level Analysis:* Plotting the received signal level may help determine the attitude and signal-to-noise levels. Displaying level fluctuations could also give indications of the attitude and the spin rate of the spacecraft.
- *Lock Indications:* The supporting ground station can confirm, carrier lock, subcarrier lock, symbol lock, TLM Decoder lock and so on to determine up to what point the signal is processed correctly. Frame error counters in the decoders could be provided against the number of good frames received.
- *Open Loop Recording:* The supporting station records the digitised signal using an open loop recording system potentially allowing reconstruction of the TLM Stream.

4.2.3 Uplink Engineering Services

Uplink services apply to cases in which the downlink signal from the spacecraft is acquired, which is proof of life and proof of trajectory. Failure to acquire the downlink does not preclude this service; however, up-linking in the blind significantly increases the difficulty and complexity of recovery operations. The uplink engineering service attempts to increase the probability of the on-board receiver locking on to the uplink carrier utilising the following techniques:

- *Acquisition Sweep Range and Rate Adjustment:* The supporting station uses a sweep range wider than the nominal value and/or uses a sweep rate slower than nominal value to increase the probability that the receiver locks onto the uplink carrier. Another potential mode would be to sweep constantly or ramp the uplink frequency.
- *Acquisition Sequence Adjustment:* The supporting ground station uses an acquisition sequence longer than the nominal value to increase the probability that the on-board symbol synchroniser achieves bit lock onto the acquisition preamble.

4.2.4 Local Radiation Services

In situations of imminent danger to the spacecraft, the service user may request the service provider to radiate to the spacecraft despite having no communication link to the mission operations control centre (MOCC). This service can facilitate the spacecraft condition, i.e. if the spacecraft is coherent, the on-board lock can be confirmed by monitoring the downlink frequency tracking the uplink sweep.

4.2.5 Terminal Uplink Beam-Width Expansion

When the spacecraft trajectory has an extremely high uncertainty, radiation of an uplink signal from a standard aperture configuration may not be capable of acquiring the spacecraft during an emergency. This type of contingency event typically occurs when the LEOP of the spacecraft injection is flawed.

To expand the beam-width (coverage) of an uplink signal a smaller antenna, e.g. horn antenna, is fixed to the tracking antenna and connected to the station transmitter. This approach is primarily used on low earth orbiting (LEO) missions. The expanded Beam-width corresponds to a drastic limitation in uplink power; therefore. the link budget determines whether this technique can be effective.

4.3 Standard Services

The Standard Services available for SECS include the core services specified in the IOAG Service Catalog #1 [1], provided that the pre-conditions stated below are satisfied.

4.3.1 Return Data Delivery

Any core Return Data Delivery services specified in the IOAG Service Catalog#1 can be used as a standard SECS service provided that:

- The supporting ground station receives, demodulates and decodes telemetry on downlink correctly
- The ground link between station and MOCC is established using space link extension (SLE).

4.3.2 Forward Data Delivery

Any core Forward Data Delivery Service specified in the IOAG Service Catalof#1 can be used as a standard SECS service provided that:

- The supporting station already receives, demodulates and decodes TLM on the downlink correctly.
- The spacecraft receives the uplink signal correctly and executes the received Telecommands correctly.
- The ground link between the MOCC and the supporting station is established using SLE.

As mentioned earlier Forward services can potentially be provided without downlink acquisition, i.e. commanding in the blind.

4.3.3 Radiometric Services

Any Radiometric Service specified in the IAOG Services Catalog #1 (except for the Delta Differential One-Way Ranging (DDOR) service can be provided. This assumes that both the downlink and/or the uplink have been acquired correctly.

- 1-way doppler measurements, i.e. the downlink only has been acquired.
- 1-way doppler measurements, i.e. both the Downlink and Uplink has been acquired however the spacecraft on-board transponder is in non-coherent mode.
- 2-way doppler, i.e. both the downlink and uplink has been acquired and the on-board transponder is in coherent mode.
- Ranging, i.e. both the downlink and uplink has been acquired and that the on-board ranging transponder is compatible with the available ranging techniques available at the supporting station.

4.4 Network Services

Missions that have established a committed support agreement with a provider will have accepted the cost of having a permanent network infrastructure in-situ and can expect to receive telemetry as soon as the spacecraft is acquired. This also applies to the transmission of telecommands once the uplink has been acquired.

Missions that have an acknowledged support agreement may not be willing pay for permanent communications infrastructure. However they should have at least pre-agreed plans designed for the creation of an infrastructure with relatively low lead time such as Internet virtual private network (VPN) or perhaps the implementation of a "Bent Pipe" configuration should both User and Provider already have links established with a third party.

Unregistered missions that have no existing agreements will obviously have to accept that the lead time for the creation of links will be longer and depend on the network expertise of both parties a and the hardware that is available at both sites. If the creation of a VPN is not viable, it could be possible to purchase the communications services of a commercial "cloud" service to establish links on a temporarily. This may, however, raise security issues.

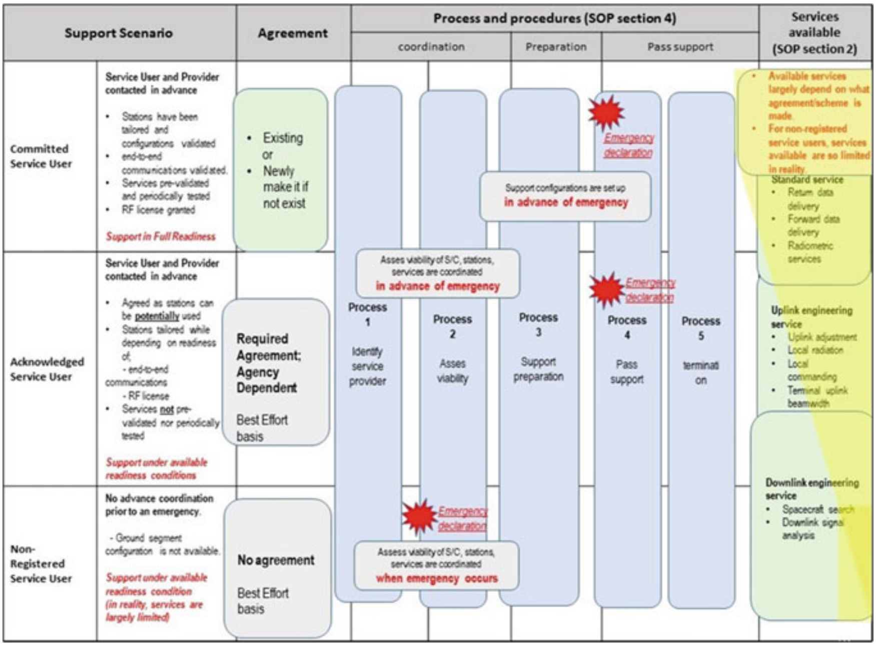
Baseline for Data transfer between a station and a Control Centre is the use of Space Link Extension protocols as defined by the CCSDS Standards(Space Link Extension (SLE) Multiple Blue Books encompassing possible Services [3].

5 Standard Operating Procedures

The targeted readership profile of the SOP is, fundamentally, for a mission manager and their team approaching launch and are designing the ground segment to cover the operational life of a the spacecraft taking into account not only routine activities but also potential emergency situations. Additionally it is useful for flight control teams that have identified a potential weakness in the current ground segment and may decide that it should be augmented with additional resources to deal with an emergency.

It also gives guidance to missions that are already in emergency and require emergency cross support to recover a spacecraft that is in imminent danger of being lost. The processes involved can be summarised as follows

1. Identify service provider
2. Asses viability of service provider for SECS
3. Support preparation
4. Pass support
5. Support termination.



5.1 SECS Asset List

Whatever the scenario, the SOP provides a list of assets that allows the mission to select resources that best fit their needs. The IOAG member agencies have identified a subset of candidate communication assets, i.e. ground stations which may be made available to provide SECS services.

Selection of a SECS asset (s) by a given mission is dictated by numerous factors such as compatibility, visibility and performance, e.g.

1. Site location (ensures required geometric coverage).
2. Typical station usage, e.g. LEO, GEO, Lagrange, Deep Space
3. Available spectral bands such as near earth S-/X-Band (range LEO to GEO), near earth S-/X-Band (range GEO to 2×10^6 km). or deep space S-/X-Band (range $>2 \times 10^6$ km)
4. Station specification such as figure of merit (G/T), equivalent isotropically radiated power (EIRP) and so on.

The asset information is provided in the SOP, however it is also planned to have the service user performance specifications of each ground station using a web accessible asset characteristic database.

The current asset Table is shown in Appendix 1.

5.2 *Points of Contact*

Each participating agency has nominated a list of contacts to coordinate and execute emergency cross support

5.2.1 Initial Point of Contact (IPoC)

The IPoC is the first person the service user contacts to coordinate SECS, regardless of which support scenario that is required. In general the IPoC is at the managerial level and corresponds to the function responsible for providing SECS. The IPoC coordinates any legal and administrative steps to prepare for SECS and oversee the technical preparations.

5.2.2 Operational Point of Contact (IPoC)

The IPOC provides the service user with the OPoC information. The OPoC is the real time interface during an emergency support. All support scenarios require that the OPoC is contacted to plan and execute all recovery operations.

A spacecraft emergency declaration is normally issued by the mission operations manager. This declaration cannot be triggered autonomously by mission operations staff "on console". Each service provider is responsible for validating requests for support per their respective internal agency procedures. Initial contact with the OPoC triggers the service provider's internal processes, e.g.

1. Authentication of emergency declaration
2. Commitment of resources required

3. Preparation of ground segment
4. Mitigation of operational impact on routine mission operations.

5.3 Information Exchange

The spacecraft specifications are critical for the preparations of the ground segment selected by the user and a template has been prepared to give guidance to the user regarding what is required. Typically this information would be found in the mission space to ground interface control document (SGICD). The template is shown in Appendix 2.

5.3.1 Preparatory Activities

Clearly for both committed and acknowledged scenarios the service providers and service users execute the activities prior to any emergency. The non-registered scenario requires that they be executed at the time of the service request on a best effort basis. Support preparation is coordinated between the user, the OPoC and the ground station personnel. Table 1 lists the preparatory activities.

5.3.2 Service Provider Information Exchange During Emergency Support

The following assumes that the interaction at the management level, via the IPoC, is complete, i.e. the service provider agrees to make the requested assets available for emergency support. The actions are also dependant on the categories of the required SECS services.

- Service provider confirms the receipt of the latest orbital predicts and report on the computed tracking times and ephemeris for each contingency pass which can be provided.
- Service provider asses and mitigates any scheduling conflicts concerning the use of the requested asset
- Service provider provides confirmation of acquisition of signal (AOS), i.e. proof of life
- Service provider provides an orbit diagnostic in the ODM format, if applicable.
- Service provider transfers TLM frames, if applicable.
- Service user confirms transmission of commands, if applicable.
- Service provider provides radiometric data, if applicable.

Table 1 Spacecraft emergency support preparation

Step	Action description	Committed	Acknowledged	Non-registered
1	Service user: provide the spacecraft specifications which contains the service user configuration data to the service provider	Required	Required	✓
2	Service provider: configure ground stations for the pre-selected specific services	Required	Required	✓
3	Service provider: obtain RF license	Required	May be required	–
4	Both: determine ground communication line routing path between service user MOCC and service provider, including security aspects	Required	May be required	–
5	Both: test and validate ground communication line routing path	Required	✓	–
6	Conduct periodic end to end validation and testing (6–12 months)	Required	–	–
7	Both: agree upon parameters and techniques for engineering services	✓	✓	✓
8	Both: establish and maintain functioning FD infrastructure	Required	May be required	–
9	Service user: provide spacecraft trajectory file (s)	✓	✓	✓
10	Both: establish operations concept for offline data transfer	Required	May be required	✓
11	Both: exchange contact information	Required	Required	✓
12	Service provider: provide instruction regarding next steps to the OPoC	Required	Required	✓

Required = Completed prior to Emergency, ✓ = Completed at the time of Emergency

5.3.3 Service User Information Exchange During Emergency Support

The service user provides a pre-pass voice briefing to ensure that all parties are aware of the objectives and any limitations for the upcoming pass. They also confirm that the current ODM or two line element (TLE) is the latest version.

After starting the track and acquiring the spacecraft, the flight control team (FCT) provides updates to the provider in real time throughout the service. The FCT confirms the receipt of good TLM Frames, then summarises the health of the spacecraft and condition of the operational transponder. The FCT should provide advance notice of any recovery operations that could cause a loss of signal (LOS), a change in frequency or a change in TLM or TC Rates.

5.3.4 Termination of Support

When the services user declares the end of the spacecraft emergency and recovery of the mission, the service user will provide a debriefing message describing the contingency and the effectiveness of the recovery operations. The service provider will produce a report on the assets and services that participated in the recovery and specific outputs of the scheduling and statistics systems.

6 Proof of Concept

6.1 Committed Scenario

On February 10th, 2020, ESA launched its solar orbiter mission (SOLO) to study the Sun. Routine Science operations will be conducted solely from the ESA 35 m Deep Space Network comprising of Cebreros (Spain), New Norcia (Australia) and Malargue (Argentina). In the event of a critical Spacecraft Contingency and by extension a spacecraft emergency, the ESA/NASA Cross Support agreement can trigger SECS from the Jet Propulsion Laboratory (JPL) deep space network (DSN), in particular, support from the 70 m antennae and their high power amplifiers. As previously stated the following have been implemented and will be regularly validated:

1. Points of Contact
2. Flight Dynamics Infrastructure
3. End to End Data Communications Infrastructure
4. Station Configuration
5. Periodic Validation Test Plan
6. RF Licensing and ITU Filing
7. Voice Communication
8. SLE Configuration (Return All Frames (RAF) & Command Link Transmission Unit (CLTU)
9. Scheduling Interfaces.

6.2 Acknowledged Scenario

Between JAXA and CNES, the agreement for spacecraft tracking cross support has been concluded and this agreement can trigger the SECS from both agencies. For the purpose of exercise and demonstration of emergency support capabilities, the Downlink Engineering Search and Signal Analysis Services stated in Sects. 4.2.1 and 4.2.2 were performed under the simulated acknowledged scenario. In this exercise, CNES declared a loss of on-orbit CNES satellite and requested JAXA to search for the satellite by providing the nominal orbital information which was intentionally time-offset for this exercise. JAXA configured its stations at short notice and initiated search tracking with the antenna scanning and the predefined search pattern for the first tracking pass and then applied the time offsets to the antenna predicts for the second tracking pass. Figures 1 and 2 of the Spectrum Analyser display and the

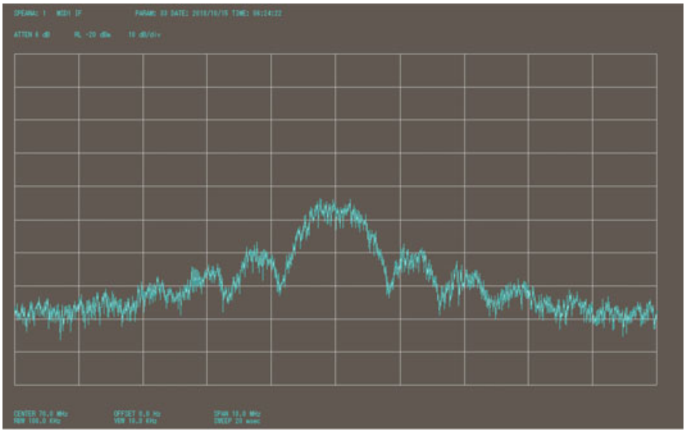


Fig. 1 Satellite spectrum

Fig. 2 AGC Level (RHC/LHC) and antenna pointing Az/El error profile

AGC level were provided to CNES to verify the correct downlink signal of the CNES satellite. With this exercise, both agencies demonstrated the usefulness of the SECS SOP.

6.3 Non Registered Scenario

Every ESA ground station is furnished with a subset of Spacecraft IDs for test and simulation purposes, namely NETSAT. For the purposes of this exercise Cebreros and NETSAT were selected. The target for acquisition was the HAYABUSA II (ISAS/JAXA) spacecraft. The HAYABUSA II SGICD was used for the spacecraft specifications. The orbital predicts which were already available for the Malargue Station were translated to NETSAT.

The NETSAT configuration tables for the Downlink, Uplink and Radiometric subsystems, e.g. Frequency Plans, Doppler Predictions, Demodulators, Decoders and TLM Recording etc., were created. This was time consuming and the lead time would typically be a minimum of 1 man day. The exercise was considered to be closed loop only, i.e. an open loop configuration was not created.

The station mimic was made available on the Web streamer providing a real time display of the station operations, if it were required by the MOCC.

The goal was to acquire the spacecraft and record station performance parameters. A communications infrastructure between Cebreros and the HYB2 MOCC was not available, therefore the TLM frames were recorded on the Cebreros SLE Servers which could be retrieved manually by FTP and transfer to the User MOCC offline.

The spacecraft was successfully acquired at 512 sps. The downlink signal strength was marginal and there were many BAD frames, however some were flagged as GOOD and could have been processed by the MOCC if necessary. The recorded frames were retrieved to the European space operations centre (ESOC) but were not forwarded to the MOCC.

The following diagram provides a snapshot of the Cebreros station acquiring HYB2 downlink. The charts in the bottom left corner display the Carrier Levels on Receiver 1 and 2 (Figs. 3 and 4).

Although the uplink chain was configured, the X-Band transmitter was not switched “on” since there was no emergency and Cebreros did not possess an RF license.

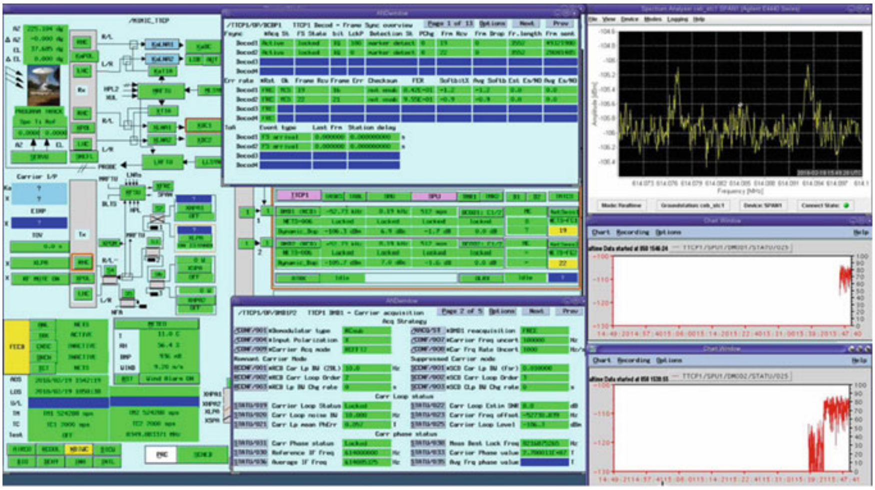


Fig. 3 Snapshot of Cebreros contingency acquisition of test target Hayabusa-2 downlink

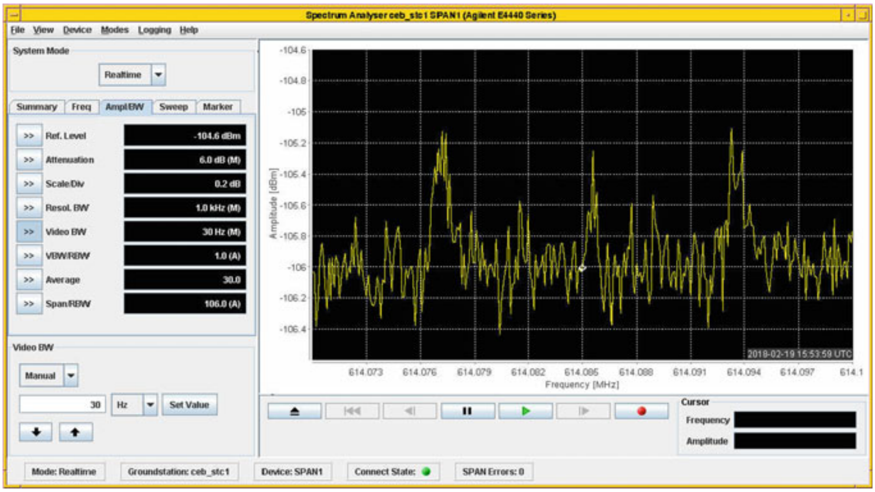


Fig. 4 Hayabusa-2 downlink spectrum (proof of concept acquisition)

7 Addition and Validation of New Terminals to the Asset List

With the completion of the refurbishment of the "Goonhilly-6 (GHY6)" 32 m in Cornwall, southwest England, the station has undergone validation testing for support of a deep space mission (ESA Mars Express) and a high earth orbit (ESA Integral). A full spectrum of support activities were exercised, i.e. telemetry, telecommand and tracking (TT&C) services. The testing was performed in both Xray Band (X-Band) and Sierra band (S-Band) The Communications infrastructure was validated using the SLE. It is planned to validate the station for Lagrange point (ESA GAIA) and Lunar (ISRO GAGANYAAN) orbits second half of 2021.

When the second issue of the SOP is released, GHY6 will be added to the asset list under the auspices of the United Kingdom Space Agency (UKSA) which is a member of the IOAG.

8 Discussion

The SOP cannot predict the nature of every spacecraft emergency, it contains however a list of potential situations, involving both signal processing problems, trajectory problems, or worst case both in parallel.

Recovery of a spacecraft will very often require transmission of an Uplink signal from the provider. Committed or Acknowledged support assumes that RF Licensing and ITU filing has been discussed and finalised if considered necessary.

RF Licensing is an extremely sensitive issue and conforming to ITU regulations is considered mandatory. The asset table in Appendix 1 indicates which countries categorically refuse to radiate without a license. The table also lists assets that would radiate should the spacecraft be in imminent danger of loss of mission.

In the event of a non-registered user approaching a service provider for assistance in recovery operations an uplink may well be requested. Paragraph 4.9 of the ITU regulations states the following:

No provision of these regulations prevents the use by a station in distress, or by a station providing assistance to it, of any means of Radio communication at its disposal to attract attention, make known the condition and location of the station in distress and obtain or provide assistance.

This means no ITU regulation prohibits a ground station from providing support to a spacecraft or an astronaut in a life threatening situation!

9 Conclusions

The fruits of the work of the standards groups is evident by the ability to leverage those standards with a spacecraft emergency where rapid call up of support is needed with a high confidence that the interface will be compatible. The team has worked to develop a standard operating procedure that leverages those standards, and defines a set of terms and processes that enable coordination of support as rapidly as possible. The value of some minimum levels of coordination cannot be understated as it is recognized that time is likely of the essence during a spacecraft emergency and pre-coordination for authorization, as is defined under the committed and acknowledged scenario's, will likely yield the best opportunity for saving the mission.

Future work will continue to refine the SOP and help to broaden the mission set to human space flight missions and also engage commercial providers.

Acknowledgements The support and guidance of the IOAG leadership, in particular, Michael Schmidt is acknowledged in encouraging the progress and benefits of this effort.

Appendix 1 (Current SECS Assets Table)

Agency	Size	Location	Antenna ID	Typical Station usage[1]	S-band		X-band		Conditions to take into account for providing support		Remarks
	(M)				Max EIRP (dBm)	G/T (dBK)	Max EIRP (dBm)	G/T (dBK)	Available Support services[2] (specify if any constraint)	Is Uplink RF license required for Emergency support? [3]	
ASI	10	Malindi, KEN		LEO	98.0	21.3	-	-	IOAG SC#1 core services (TLM, TC, RNG)	An S-band full coverage annual license is available	It supports Arianespace launches from Kourou CSG (A5, VEGA) and SpaceX launches. SLE compliant
	13	Malindi, KEN		LEO	99.0	21.3	-	-	IOAG SC#1 core services (TLM, TC, RNG)	An S-band full coverage annual license is available	It supports Arianespace launches from Kourou CSG (A5, VEGA) and SpaceX launches. SLE compliant
CNES	11	Kourou, GUF		LEO, G	101.0	22.5	-	35.5	All	-	
	10	Kerguelen Islands, FRA		LEO, G	101.0	21.5	-		All	-	
	11	Aussaguel, FRA		LEO, G	101.0	22.5	-	35.5	All	-	
	6.4	Aussaguel, FRA		LEO	85.0	17.0	-		All	-	
	11	Hartebeesthoek, ZAF		LEO, G	101.0	22.5	-	35.5	All	-	
	13	Kiruna, SWE		LEO, G	98.0	22.5	-	34.0	All	-	
	13	Inuvik, NT, CAN		LEO, G	98.0	22.5	-	34.0	All	Required	
DLR	15	Weilheim, DEU		LEO, G, L, H	108.0	26.7	-	-	All	-	
	15	Weilheim, DEU		LEO, G, L, H	109.0	27.8	-	-	All	-	
	30	Weilheim, DEU		H, D	-	-	-	44.0	All	-	also L-Band DL
	7.3	Neustrelitz, DEU		LEO	-	17.0	-	31.0	All	-	
	7.3	Neustrelitz, DEU		LEO	90.0	17.0	-	31.0	All	-	
	7.3	Neustrelitz, DEU		LEO	90.0	17.0	-	31.0	All	-	

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Agency	Size	Location	Antenna ID	Typical Station usage[1]	S-band		X-band		Conditions to take into account for providing support		Remarks
	(M)				Max EIRP (dBm)	G/T (dBK)	Max EIRP (dBm)	G/T (dBK)	Available Support services[2] (specify if any constraint)	Is Uplink RF license required for Emergency support? [3]	
	11.5	Neustrelitz, DEU		LEO	93.0	22.0	-	36.0	All	-	also Ka DL
	9	O'Higgins, ANT		LEO	92.0	19.5	-	32.0	All	-	
	13	Inuvik, NT, CAN		LEO	100.0	22.4	-	35.9	All	Required	
ESA	4.5	New Norcia, AUS	NNO2	LEO	-	-	101.5	28.0	All	-	Includes 0.75 m Acquisition Aid
	15	Kiruna, SWE	KIR1	LEO, G, L, H	102.9	29.5	-	39.2	All	-	
	13	Kiruna, SWE	KIR2	LEO, G, L, H	98.3	22.8	-	36.5	All	-	
	15	Kourou, GUF	KRU1	LEO, G, L, H	105.0	29.4	114.0	42.0	All	-	
	35	Cebreros, ESP	CEB1	G, L, H, D	-	-	139.0	52.4	All	Required	also K & Ka DL
	35	New Norcia, AUS	NNO1	G, L, H, D	128.0	39.2	138.7	51.2	All	Required for S-band[4]	
	35	Malargue, ARG	MLG1	G, L, H, D	-	-	139.5	52.1	All	-	also K & Ka DL and Ka UL
KARI	13	Daejeon, KOR		LEO	88.0	23.0	-	36.0	Engineering service only	Required	SLE is not operational yet
	9	Daejeon, KOR		LEO, G	85.0	19.0	-		Engineering service only	Required	SLE is not operational yet
	7.3	Daejeon, KOR		LEO	83.0	19.5	-	34.0	Engineering service only	Required	SLE is not operational yet
	11	Jeju, KOR		LEO	83.0	20.0			Engineering service only	Required	SLE is not operational yet
NASA	4.7	Wallops Island, VA, USA	LEO-T	LEO	89.2	17.0	-		All	-	
	11.3	Wallops Island, VA, USA	WG1	LEO,G,L,H	94.6	23.6	-	34.5	All	-	
	11.3	Fairbanks, AK, USA	AS1	LEO,G,L,H	94.6	22.0	-	35.2	All	-	

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Agency	Size	Location	Antenna ID	Typical Station usage[1]	S-band		X-band		Conditions to take into account for providing support		Remarks
	(M)				Max EIRP (dBm)	G/T (dBK)	Max EIRP (dBm)	G/T (dBK)	Available Support services[2] (specify if any constraint)	Is Uplink RF license required for Emergency support? [3]	
	9.1	Fairbanks, AK, USA	AS2	LEO,G,L,H	89.0	21.2	-	36.2	All	-	
	11	Fairbanks, AK, USA	AS3	LEO,G,L,H	95.7	22.9	-	35.2	All	-	
	18.3	White Sands, NM, USA	WS1	LEO,G,L,H	102.0	29.6	-	-	All	-	
	11.3	Kennedy Space Center, FL, USA	KUS	LEO,G,L,H	87.0	17.2	-	-	All	-	
	11.3	Ponce De Leon, FL, USA	PDL	LEO,G,L,H	87.0	17.2	-	-	All	-	
	70	Canberra, AUS	43	D,L,H	135.6 (2110 -2118 MHz) 127.4 (2090–2091 MHz)”	49.8	145.8	61.5	All	-	In all cases for all stations the JPL Frequency Spectrum Mgr will follow up post support for license if needed. (2090–2091 MHz) Emergency only
	70	Goldstone, CA, USA	14	D,L,H	135.6 (2110 -2118 MHz) 127.4 (2090–2091 MHz)”	49.8	145.8	61.5	All	-	(2090–2091 MHz) Emergency only
	70	Madrid, ESP	63	D,L,H	135.6 (2110 -2118 MHz) 127.4 (2090–2091 MHz)”	49.8	145.8	61.5	All	-	(2090–2091 MHz) Emergency only (2110 -2118 MHz) Emergency only
	34	Canberra, AUS	34	D,L,H,G	128.7	40.8	139.5	54.2	All	-	LEOP support for Geosynchs S or X Band
	34	Canberra, AUS	36	D,L,H,G	108.8	40.8	139.5	54.2	All	-	LEOP support for Geosynchs S or X Band
	34	Canberra, AUS	35	D,L,H,G			139.5	54.2	All	-	LEOP support for Geosynchs X Band only

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Agency	Size	Location	Antenna ID	Typical Station usage[1]	S-band		X-band		Conditions to take into account for providing support		Remarks
	(M)				Max EIRP (dBm)	G/T (dBK)	Max EIRP (dBm)	G/T (dBK)	Available Support services[2] (specify if any constraint)	Is Uplink RF license required for Emergency support? [3]	
	34	Goldstone, CA, USA	24	D,L,H,G	128.7	40.8	139.5	54.2	All	-	LEOP support for Geosynchs S or X Band
	34	Goldstone, CA, USA	25	D,L,H,G			139.5	54.2	All	-	LEOP support for Geosynchs X Band only
	34	Goldstone, CA, USA	26	D,L,H,G	108.8	40.8	139.5	54.2	All	-	LEOP support for Geosynchs S or X Band
	34	Madrid, ESP	54	D,L,H,G	128.7	40.8	139.5	54.2	All	-	LEOP support for Geosynchs S or X Band
	34	Madrid, ESP	55	D,L,H,G			139.5	54.2	All	-	LEOP support for Geosynchs X Band only
	34	Madrid, ESP	65	D,L,H,G	108.8	39.4	139.5	53.2	All	-	LEOP support for Geosynchs S or X Band
JAXA	10	Katsuura, JPN		LEO, G	101.0	22.5	-	-	All (see note1)	Required	**Note1:** For Radiometric Services, the Pseudo-Noise [PN] Ranging Systems is available only from DS stations but not conform to the CCSDS standard. JAXA LEO stations have presently no plan to implement the PN ranging system. Therefore, only satellite transparent mode is available in the regenerative mode and JAXA's internal format is used for this service **Note2:** "Engineering service only" stations are not connected to SLE
	20	Katsuura4, JPN		LEO, G, L	97.7	27.7	-	39.0	All (see note2)	Required	
	10	Masuda, JPN		LEO, G	101.0	22.5	-	-	All (see note1)	Required	
	10	Okinawa, JPN		LEO, G	101.0	22.5	-	-	All (see note1)	Required	
	18	Okinawa2, JPN		LEO, G	104.8	25.5	-	-	All (see note1)	Required	
	10	Mingenue, AUS		LEO, G	101.0	22.5	-	-	All (see note1)	Required	
	10	Santiago, CHL		LEO, G	101.0	22.5	-	-	All (see note1)	-	

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Agency	Size	Location	Antenna ID	Typical Station usage[1]	S-band		X-band		Conditions to take into account for providing support		Remarks
	(M)				Max EIRP (dBm)	G/T (dBK)	Max EIRP (dBm)	G/T (dBK)	Available Support services[2] (specify if any constraint)	Is Uplink RF license required for Emergency support? [3]	
	10	Kiruna, SWE		LEO, G	101.0	22.5	-	-	All (see note1)	*(being confirmed)*	
	10	Maspalomas, ES		LEO, G	101.0	22.5	-	-	All (see note1)	-	
	20	Uchinoura, JPN		LEO, L, H	110.0	32.8	-	43.0	Engineering service only	N/A	
	34	Uchinoura, JPN		LEO, L, H, D	115.0	38.4	138.7	50.0	All (see note1)	Required	
	11	Uchinoura, JPN		LEO	103.6	23.8	-	-	Engineering service only	N/A	
	64	Usuda, JPN		L, H, D	-	40.0	143.0	49.5	All (see note1)	Required	

[1] Typical Station usage

This section shows the type of satellites most-typically operated by the ground station. Service User may refer to this section to ensure the suitability of assets in terms of frequency band and/or antenna drive speed when identifying which antenna(s) can be used.

Example:

LEO = Low Earth Orbit; G = Geostationary; L = Lunar or its vicinity including Lagrange Point;

H = High Earth Orbit including Highly Elliptical Orbit; D = Deep Space

[2] Available support services (specify constraints, if any)

Availability of the SOP services. Specify constraints, if applicable.

Example:

All = All Services may potentially be available; however, availability of specific services need to be coordinated with Service Provider.;

Engineering services only (because no real-time interface, such as SLE function, is available at the ground station)

Specify constraints, if any (if any of Core SC#1 functions is not available for standard TT&C services)

[3] Is RF uplink license required for emergency support?

Specify if RF license must be obtained prior to providing uplink services.

Example:

Required: = formal RF license process is required for this station

"-" = Ground station does not require formal RF license for emergency support; however, real-time coordination with relevant administrative bodies may be required. Ground stations do require RF uplink license for uplink services during non-emergency situations, such as periodic testing.

Antenna ID: CCSDS station ID

[4]Full allocation not available

N/A: Not applicable

Appendix 2 (Spacecraft Specification Template)

DOWNLINK

Carrier Frequency (Hz)
*(*Minimum requirement for 2.2.2 and 2.2.3 (A))* ____________________

Polarization
*(*Minimum requirement for 2.2.2 and 2.2.3 (A))* ☐ RHC ☐ LHC

Spacecraft Antenna EIRP
(for Deep Space Link Budget) ____________________

Antenna Pattern
(*for Deep Space Link Budget)* ____________________

Coherent Turn-around Ratio ____________________

Modulation Type
*(Possibly TLM Rate Dependent *Minimum requirement for 2.2.2 and 2.2.3 (A))* ____________________

Subcarrier Frequency (Hz)
(possibly TLM Rate Dependent) ____________________

Modulation Index
(possibly TLM Rate Dependent) ____________________

TLM Coding ____________________

(possibly TLM Rate Dependent) ____________________

TLM Symbol Rate (sps) ____________________

TLM Info Rate
(bps) ____________________

Randomizer ☐ Yes ☐ No

Coded Channel Access Data Unit (CADU)
CADU=ASM+Data+Trailer *(possibly Coding Dependent))* ____________________

Sync Marker
(possibly Coding Dependent) ____________________

TLM Transfer Frame
Length ____________________

Virtual Channels
(only House-keeping no Science) ____________________

Ranging ____________________

Others *(to be added as required)* ____________________

UPLINK

Uplink Frequency (Hz) ____________________

Polarization (RHC/LHC) ☐ RHC ☐ LHC

Antenna Pattern *(for Deep Space Link Budget)* ____________________

Antenna Gain *(for Deep Space Link Budget)* ____________________

Spacecraft G/T *(for Deep Space Link Budget)* ____________________

OB RCVR Pull In Range *(for Deep Space Link Budget)* ____________________

OB RCVR Tracking Range *(for Deep Space Link Budget)* ____________________

OB RCVR RF Power Dynamic Range *(for Deep Space Link Budget)* ____________________

Required Ground Station EIRP *(for LEO MEO, & GEO s/c)* ____________________

Modulation Type ____________________

Subcarrier Frequency (Hz) *(possibly TC Rate Dependent)* ____________________

Modulation Index ____________________

TC Coding ______

TC Rate ______

CLTU min length (Octets) ______

CLTU max length (Octets) ______

TC Protocol (PLOP1/PLOP2) ☐ PLOP1 ☐ PLOP2

TC Format Standard ______

TC Pseudo Randomizer ______

Idle Pattern Length ______

Uplink Sweep Profile ☐ Sweep range and speed ☐ For Deep Space ☐ Wide Band ☐ Intermediate Band ☐ Narrow Band

Others *(to be added as required)* ______

RANGING TYPE

Ranging Major Tone Frequency *(or OB BW)* ______

Modulation Type ______

TX Tone Modulation Index (Uplink) ______

RX Tone Modulation Index (Downlink) ______

Standard RNG Code Lengths *(or OB BW)* ______

Ranging Channel Equivalent Noise Bandwidth ______

On board transit time ______

GROUND IMPLEMENTATION

Communications ______

SLE Services ______

Service Instances ______

Voice ______

References

1. IOAG Service Catalogue #1, Issue 2, Revision 2 16/09/2020
2. CCSDS Orbit Data Messages 502.0-B-2 Nov 2009
3. CCSDS Standards: Space Link Extension (SLE) Multiple Blue Books encompassing possible Services