# ISRU-DM: Communications Service Executive Summary (CS-ESUM)

**PREPARED BY**

Chris Saunders, Matt Cosby

**REVIEWED BY**

Matt Cosby

**APPROVED BY**

Gary Lay

**CUSTOMER APPROVAL**

**PROJECT**

ISRU Demonstration Mission: Mission Definition

**WORK PACKAGE NUMBER**

SSGZ

**SSTL REFERENCE**

0327499

**CUSTOMER ID NUMBER**

CS-ESUM

**REVISION**

1

**REVISION OR RELEASE DATE**

2nd November 2018

**STATUS**

*ISSUED*

**DRL NUMBER**

NA

**CLASSIFICATION**

NA

**Surrey Satellite Technology Limited**
Tycho House
20 Stephenson Road
Surrey Research Park
Guildford, Surrey
GU2 7YE, UK
**Tel: +44 1483 803803**
**Fax: +44 1483 803804**
**Email: sstl@sstl.co.uk**

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# DISTRIBUTION LIST

| Name | Organisation | No. of copies | Release Date |
|---|---|---|---|
| David Binns | ESA/ESTEC | 1 | 2nd November 2018 |

# DOCUMENT REVISION STATUS

| Last Edited Date | Revision / Release Number | Status | Edited By | Pages / Paragraphs Affected | Change Ref |
|---|---|---|---|---|---|
| 2nd November 2018 | 001 | 1st Issue | C. Saunders | All, first issue | |
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| | | | | | |

# 1 INTRODUCTION

## 1.1 SCOPE

This document is the Communications Service Executive Summary (CS-ESUM), a deliverable for the In-Situ Resource Utilisation Demonstration Mission (ISRU-DM) definition study. It has been prepared by Surrey Satellite Technology Limited (SSTL) and Goonhilly Earth Station (GES) for the European Space Agency (ESA) under contract 4000123270/18/NL/JK.

The ISRU-DM mission aims to perform the first demonstration of ISRU on the Moon, via the production of water or oxygen from raw lunar material (i.e. regolith, ice etc.) At agency-level the phase-0 level study was also performed to understand the technical and programmatic feasibility of undertaking the ISRU-DM mission via the provision of commercial services from industry. To this end the study was split into three 'segments', the first studying the ISRU payload itself, the second studying the transportation and delivery of the ISRU payload to the lunar surface, and the third studying the provision of a communications service to the ISRU payload once on the Moon. SSTL and GES have been working as part of this 3rd Segment, and this report contains a summary of the work done in this area for the ISRU-DM study.

More details on the service design description and the interfaces between different elements of the mission are given in [RD-1] through [RD-4], which provide more detail on the proposed service capabilities and performance. The objectives and requirements of the mission are given in the two ESA documents [AD-1] and [AD-3].

## 1.2 APPLICABLE DOCUMENTS

Applicable Documents identified in the following text are identified by AD-n, where "n" indicates the actual document, from the following list:

AD-1. *Statement of Work, Lunar ISRU Demonstration Mission Definition Study*, ESA SOW 15th Sep 2017

AD-2. *Concurrent Design Facility Studies Standard Margin Philosophy Description*, ESA-TECSYE-RS-006510, Issue 1, Revision 2

AD-3. *Design Rationale and High-Level Requirements for the Lunar ISRU Demonstration Mission (DRM)*, ESA ESA-HSO-K-TN-0010

## 1.3 REFERENCE DOCUMENTS

Documents referenced in the following text, are identified by RD-n, where "n" indicates the actual document, from the following list:

RD-1. *Communications Service Description Document (CS-DD)*, SSTL Document 0315640, Oct 2018

RD-2. *Communications Service Interface Requirements Document (CS-IRD)*, SSTL Document 0320164, Oct 2018

RD-3. *Response to ESA Request for Information: "Technologies, Science Payloads, and Commercial Services for Lunar Missions"*, SSTL Document 0319529

RD-4. *Lunar ISRU P/L Payload Interface Definition Document (PL-IDD)*, LIMS-TN-OHBI-002, Issue 2, 3rd Aug 2018

RD-5. Ely, T., *Stable Constellations of Frozen Elliptical Inclined Lunar Orbits*, The Journal of the Astronautical Sciences, Vol.53 (3), 2005

## 1.4 ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| CCSDS | Consultative Committee for Space Data Systems |
| CLMSS | Commercial Lunar Mission Support Services |
| DSA | Deep Space Antenna |
| DTE | Direct To Earth |
| DTN | Delay Tolerant Network |
| ESA | European Space Agency |
| ESTRACK | European Space Tracking Network |
| GES | Goonhilly earth Station |
| HTTP | Hyper Text Transfer Protocol |
| IP | Internet Protocol |
| ISRU | In-Situ Resource Utilisation |
| ISRU-DM | In-Situ Resource Utilisation Demonstration Mission |
| LOS | Line of Sight |
| MOC | Mission Operations Centre |
| NASA | National Aeronautics and Space Administration |
| P1 | Proximity-1 |
| PI | Principal Investigators |
| POC | Payload Operations Centre |
| PUS | Packet Utilisation Standard |
| RCC | Relay Control Centre |
| RS | Relay Satellite |
| SLE | Space Link Extension |
| SNUGS | Service-based Next-generation User Ground Segment |
| SSTL | Surrey Satellite Technology Limited |
| TC | Telecommand |
| TM | Telemetry |
| TTCP | Telemetry Telecommand Control Processor |
| UHF | Ultra-High Frequency |
| UK | United Kingdom |
| USLP | Unified Space Link Protocol |
| UTC | Universal Coordinated Time |

# 2 LUNAR MISSION SUPPORT SERVICES

Surrey Satellite Technology Limited (SSTL) and Goonhilly Earth Station (GES) are currently working in Partnership with European Space Agency (ESA) in response to the ESA call *"Space Exploration as a Driver for Growth and Competitiveness: Opportunities for the Private Sector"*. This has led to the definition of a **"*Commercial Lunar Mission Support Services*" (CLMSS)** partnership that aims to develop a set of commercial services that will be offered to both ESA and the wider open market as a commercial offering. The long-term aim is to be provider of services that support institutional and commercial development and utilisation of the lunar environment and its surrounding space ([RD-1] and [RD-2]):

***"Commercial Services to Support the Exploration of the Moon and the Sustainable Development of the Lunar Economy"***

In general, the SSTL and GES partnership offers the possibility of supporting both Direct To Earth (DTE) and Relay Service (RS) communications between a lunar lander and the Earth, through a combination of dedicated ground and space segments. The former is a direct communications link between the lander and a ground terminal, whilst the latter incorporates an orbiting relay spacecraft to form a link between the lander and the spacecraft, and then between the spacecraft and Earth. The complete ground and space architecture allows flexibility in the services that can be offered to customers, as well allowing and enabling new innovative mission concepts for lunar exploration.

# 3 ISRU-DM MISSION SUPPORT

## 3.1 LANDING SITE

Early in the project, Shackleton Connecting Ridge, was selected as the landing site to be assumed for the study, which has the potential for long periods of near constant solar illumination (a so-called "peak of eternal light"). However, the site also suffers periodic outages of the line of sight to Earth, meaning that long duration missions (i.e. beyond one lunar day) may have to use a combination of DTE and relay communications. The Segment 2 (delivery) team have reported that a preferred baseline landing date is 8th Sep 2025.

## 3.2 SERVICE DESCRIPTION

In terms of the Space Segment elements, the service will consist of:

- Provision of a UHF-band local proximity links between the relay spacecraft and the Segment 2 lander. This will implement the CCSDS defined 'Proximity-1' service for user-relay links
- X-band link between the Relay Spacecraft and the GES ground segment for forward and return links between the relay spacecraft and the ground.

In terms of the Ground Segment, the service will consist of:

- Option for DTE communications at either S or X-band. This is based on a network of three deep space ground stations that is planned by GES to be operational by 2022 (see section 3.2.2).
- The space segment mission operations centre at GES in Cornwall.
  - The co-location or otherwise of the lander and ISRU payload operations teams is TBD. This needs to be assessed both at mission level, and in the frame of existing infrastructure elsewhere that could be used. For example it is anticipated that the Segment 2 delivery team will have their own mission operations centre for their lander operations.
  - The operations concept is based around a dedicated Application Programming Interface (API) that is made available to customer and to the Goonhilly ground station itself. This allows a transparent interface to the customer, whilst also allowing ground station configuration changes to be managed without disruption to the customer.

### 3.2.1 Performance Summary

Table 1 shows a high-level summary of the communications coverage that can be provided to the ISRU-DM mission. In addition, based on the current level of understanding of the lander architecture, an assessment of the likely data rate that could be achieved is given. S and X-band is assumed for DTE, and for relay a UHF system is proposed. The UHF TM data rate of 256 kbps shown in the table is considered a worst case as it assumes a simple mono-pole antenna on the lander. If for example a helix antenna was used on the lander, simulations show that rates of >1 Mbps should be feasible through the UHF relay link.

| Dates | Coverage Type | Data Rates |
|---|---|---|
| Landing (8th Sep 2025) to 20th Sep 2025 | - Direct Line of Sight to Ground Segment<br>- Continuous visibility | - S-band TM: 20 kbps<br>- S-band TC: 64 kbps<br>- X-band P/L TM: 1024 kbps |
| 20th Sep 2025 to 5th Oct 2025 | - No Direct Line of Sight to Earth<br>- Relay satellite provides store-and-forward and quasi bent-pipe link to Earth<br>- 8 hrs coverage time per pass, twice per day | - UHF TM: ≥256 kbps<br>- UHF TC: ≥64 kbps |
| *For the South Pole landing site, the coverage pattern repeats every lunar month, with ~12 days where the Earth is visible (corresponding to the top row in the table) and ~16 days where the relay satellite must be used to communicate with the lander (corresponding to the bottom row in the table)* | | |

**Table 1: Summary table of data rates for ISRU-DM mission. Details of the link budget assumptions are given in [RD-1]**

### 3.2.2 Ground Station Direct To Earth Coverage

Direct to Earth communications coverage to the lander is based on a network of three deep space ground stations that is planned by GES to be operational by 2022. These comprise:

- Goonhilly Site in UK (already exists, currently in funded ESA DSA-equivalent upgrade)
- Site in Malibu, California (preliminary site identified)
- Site in Perth, Australia (preliminary site identified)

Both the Malibu and Perth sites have been identified by the GES team, but formal acquisition has not yet started. This is planned for 2019, with an in-service date of 2022. The sites are therefore used as a representative example of a commercial network, of the type that should be operational by the time of the ISRU-DM mission. Each station will have the equivalent capability to a typical ESA or NASA Deep Space Antenna (e.g. 30 m diameter antenna, S and X-band operation, several kW of uplink RF power available). GES also plans to implement (and has already demonstrated) SLE cross-support with other networks (e.g. ESA ESTRACK, NASA DSN, JAXA, ISRO). For the current one week mission (the current baseline mission in the MRD) it is considered feasible to dedicated ground support over this period (subject to further clarification in later mission phases). The three ground stations form the coverage pattern as shown in Figure 1

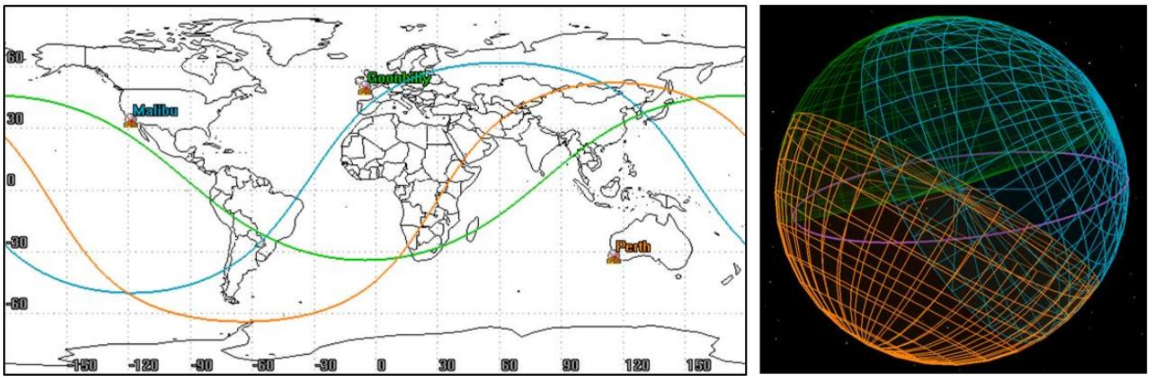


**Figure 1: Three GES ground station locations. The figure shows 2D and 3D representation of the coverage of the Moon from the three GES sites when assuming 5° minimum elevation on ground.**

Figure 2 shows the visibility of the proposed Shackleton Connecting Ridge landing site to these three stations over a period of 15 days starting on the 8th Sep 2025. Here 'visibility' is taken to mean when a LOS between at least one of the ground stations and the lander exists at an elevation angle of >5° at the ground station. Uninterrupted continuous visibility starts at 21:33 UTC on 8th Sep 2025 and lasts until 08:18 UTC on 20th Sep 2015. There are two implications to this:

- 1. Landing should ideally be delayed until after 21:33 UTC on 8th Sep 2025 if continual coverage is needed.
- 2. The core required mission duration of 7days (as expressed in [AD-3]) can easily be fit into a continuous coverage block of time from the ground stations (continuous coverage lasts ~12 days).

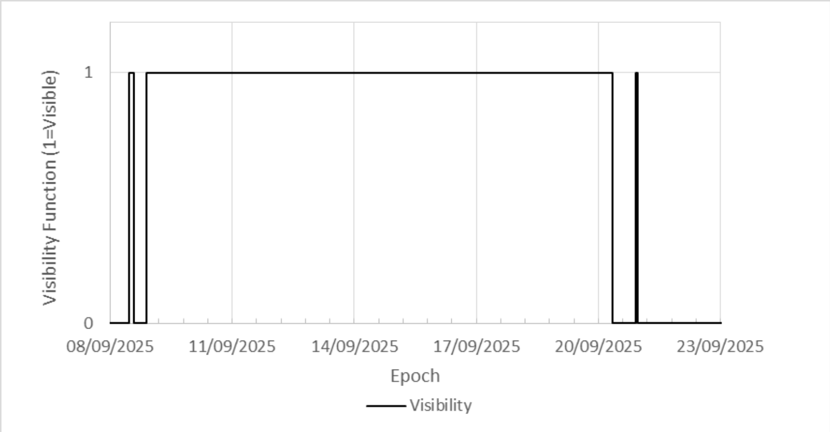


**Figure 2: Visibility of the Shackleton Connecting Ridge to the three GES ground stations over a period of 15 days starting on 8th Sep 2025 (the baseline landing date). The minimum required mission duration of 7 days can be accommodated within this window.**

Similar periods of continuous ground visibility window repeat every ~16-17 days, but in the intervening time there is no direct ground visibility possible. This pattern repeats indefinitely, so a similar scenario would occur if the landing date for the mission was to change from the current baseline.

### 3.2.3 Relay Satellite Coverage

Use of a relay spacecraft as part of the communications architecture has several potential benefits:

- It can extend the potential visibility time of the lander beyond the ~10-12 day blocks of time available when just using a DTE architecture.
- If the lander touches down in a non-nominal location (e.g. behind blocking terrain, on a slope, inside a crater etc.) then the use of a relay satellite allows a second possible communications link to be established if the primary DTE LOS is lost or is not available.
- It can be used to provide coverage to the lander prior to the landing, in case the lander has no visibility to the Earth. This could be the case for example if the lander needs to perform an orbital manoeuvre when it is out of direct line of sight to the Earth.

The relay satellite will use a particular type of stable-inclined elliptical orbit [RD-5]:

- Orbit Period: 12 hours (semi-major axis: ~6140 km)
- Eccentricity: 0.55
- Inclination: ~50°
- Argument of Periapsis: 110° (apoapsis in the Southern hemisphere of the Moon)

The orbit is illustrated at Figure 3. An orbit period close to 12 hours is attractive in the sense that two complete revolutions of the Moon will be completed within a single Earth day. With a 12 hour orbit, the spacecraft provides ~18 hr of coverage visibility to a Southern polar user over a 24 hour period. This occurs in two block of ~9 hours of coverage, with a ~3 hr gap when the satellite passes though periapsis. On average therefore, this provides ~75% coverage availability of the South Pole.

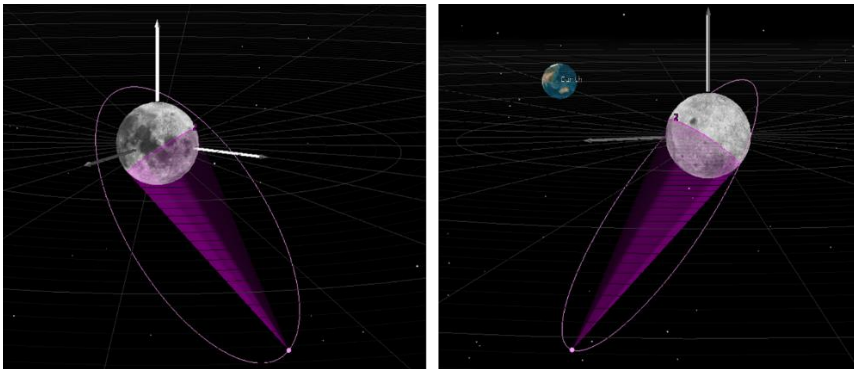

**Figure 3: Relay Satellite Orbit**

Simulations of the ISRU-DM mission scenario show that the use of the relay satellite improves the amount of potential coverage time (i.e. time when a communications line of sight to the lander is available) from ~35% to ~82% of a year, on average.

### 3.2.4 Example ISRU-DM Mission Scenario

The segment 1 payload team have provided an Interface Description Document (IDD) [RD-4] which contains a proposed payload operations timeline and the minimum payload data rate that would be required as shown at Figure 4. Five production 'runs' ('batches') are planned as the nominal mission on the lunar surface.

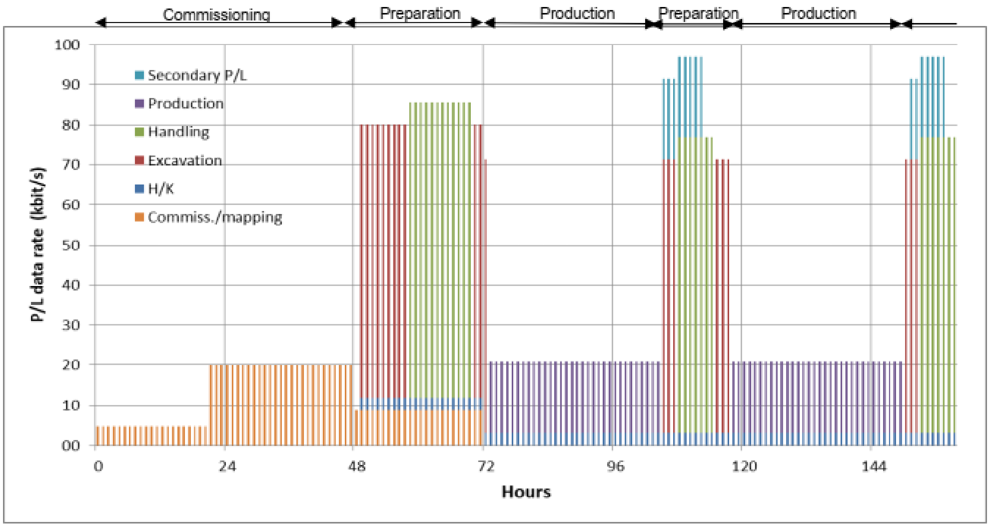


**Figure 4: Minimum payload data rate needed according to the Segment 1 Payload IDD [RD-4]**

It is noted in [RD-4] that continuous data link coverage is required when the following activities are performed:

- The commissioning phase immediately after landing,
- The 'preparation phases' in *each* ISRU production 'batch' and;
- The *first* batch production.

Continuous data link coverage is not strictly required for the 'production phases' except for the first one (i.e. the first batch), although it is expected that this would be welcomed if it were available.

Continuous coverage with the ground is needed for the first 108 hours (2.5 days) when on the surface (this covers the commissioning, the 1st preparation phase and the 1st production phase). Five complete production batches are estimated to be completed in just over 12 days of elapsed time (302 hours in total). Figure 5 shows how the proposed ISRU payload time-line fits into the ground station visibility pattern. It can be seen that the if the landing occurs when the ground visibility window opens, then all of the periods when continuous ground contact is mandatory can be accommodated within a single block of time when the three GES stations are visible. As shown in [RD-1], with sensible assumptions on the lander equipment performance, and the use of the GES ground segment, data rates of 1 Mbps DTE are possible with good margin.

Figure 5 shows that with the current payload time-line, the production and cooling/unloading phases of the 5th batch would occur after the ground visibility window has closed. This period could be covered by the relay satellite, and as already noted the relay could then be used to maintain contact with the lander, until the next period of continual DTE visibility opens some ~16 days later. As continuous contact with Earth cannot be guaranteed from the relay satellite (e.g. through temporary Moon blocking of the line of sight) this may require some changes to the payload operations, or could simply take the form of periodic lower-level monitoring of the payload in between direct Earth visibility periods.

For a nominal mission the following can be taken as a baseline (subject of course to further study in later mission phases):

- The landing should occur close to the opening of one of the continuous ground visibility windows (i.e. after 21:33 UTC on 8th Sep 2025)
    - For the next 12 days, during this period it should be possible to generate at least 1 Mbps data downlink rate to Earth using X-band on a continuous basis. This is sufficient to encompass 4 complete batches of ISRU processing, and the preparation of a 5th batch under continuous ground supervision.
- For the remainder of the 5th batch and for the period between continuous ground visibility windows, then a relay satellite can be used offering data rates of at least 256 kbps. This is expected to be sufficient for, as a minimum, monitoring of the payload until the next direct ground visibility window opens some 16 days later, whereby a fresh set of ISRU processing batches could be initiated.

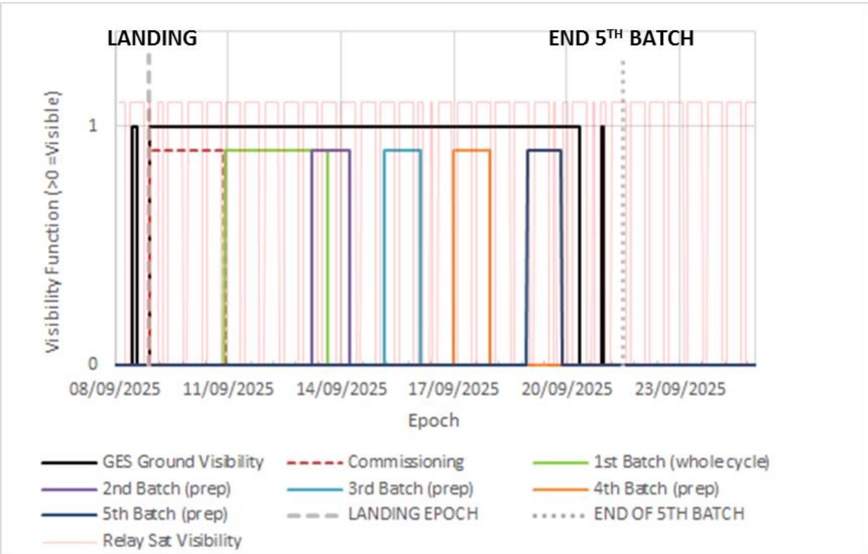


**Figure 5: Visibility of the Shackleton Connecting Ridge to the three GES ground stations compared to the requested payload time-line indicating where continuous coverage is needed (i.e. the preparation phases of each batch). Also shown is the repeating visibility pattern of the relay satellite – note, here the relay satellite is assumed 'visible' if it has simultaneous line of sight to both the ground segment and the lander.**

# 4 OPERATIONS INTERFACE

Part of the potential service provision elements of the ISRU-DM mission includes the operational aspects of the mission. This is a complex piece as there are three elements of the mission in which 'operations' could be considered (the operations of the relay spacecraft, the operations of the lander, and the operations of the ISRU payload).

## 4.1 OPTIONS FOR THE ISRU-DM MISSION

At the Mission Integration exercise at ESTEC, it was agreed that the communications architecture should be flexible enough to be able to handle the following configurations of the Payload Operations centre (POC), Mission Operations Centre (MOC) and the Relay Control Centre (RCC):

1. The POC, MOC and RCC are co-located in a single location for the mission duration.
2. The POC and MOC are co-located in a single location and the RCC is in a different location for the mission duration.
3. The POC, MOC and RCC are in three separate locations for the mission duration.

Of the different options, the second seems like the most sensible to baseline at the current time. Nevertheless, the communications architecture must be compatible with the following space segment configurations, which are dynamic, during the mission duration:

1. The Lander communicates to the Goonhilly Ground station directly.
2. The Lander communicates, via a relay, and the relay communications to the Goonhilly Ground station, directly.
3. The Lander communicates to a ground station (such as an ESTRACK station), that is not Goonhilly, directly.
4. The Lander communicates to a ground station (such as an ESTRACK station), that is not Goonhilly, via the relay satellite.

## 4.2 OPERATIONAL CONCEPT

The architecture shown in Figure 6 is proposed. This defines the Packet as the cross-support entity, with the transfers of these packets in files on the terrestrial network. The translation of this packet into frames is handled by Goonhilly Earth Station. This architecture also has the advantage of allowing a migration to a Delay Tolerant Network (DTN) architecture in the future, where packets are replaced with Bundle Protocol (BP). It has been proposed, although not agreed, that DTN will be rolled out to NASA, ESA and other space agencies networks within the 2022/2023 timeframe. Therefore, it is prudent to ensure that any ISRU communications architecture proposal is compatible with DTN, as both timescales could align.

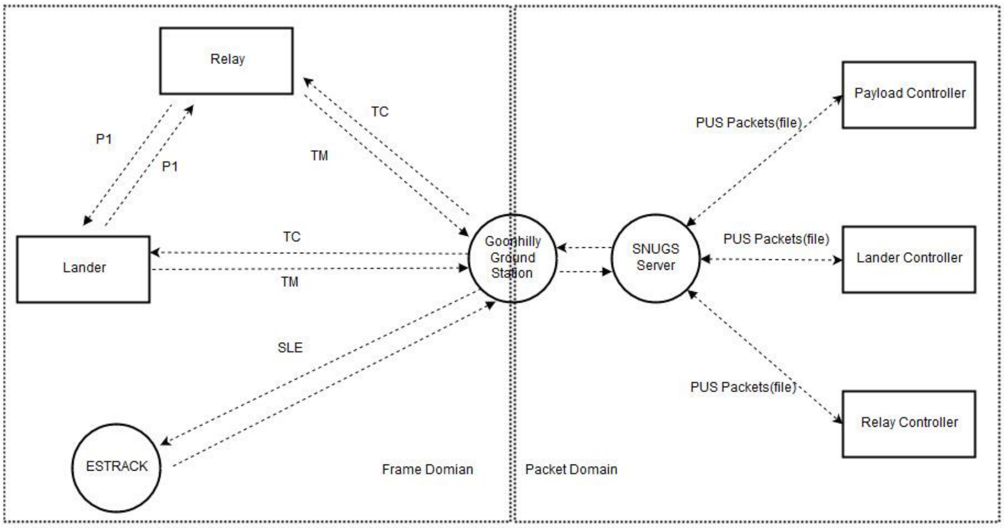


**Figure 6 Proposed Communications Architecture**

# 5 CONCLUSIONS AND SUMMARY

SSTL and GES have performed a study for ESA exploring the services that SSTL and GES can bring to the ISRU-DM mission, in the frame of supplying communications and operations functionality.

The proposed SSTL and GES service consists of both space and ground segment elements to allow both DTE and Relay communications services to the ISRU mission.

In terms of the Space Segment elements, the service will consist of:

- Provision of a UHF-band local proximity links between a Relay Spacecraft and the ISRU lander. This will implement the CCSDS defined 'Proximity-1' service for user-relay links
- X-band link between the Relay Spacecraft and the GES ground segment for forward and return links between the RS spacecraft and the ground.
- The spacecraft will be in an ~1000 x 8000 km elliptical orbit, inclined at ~50° and with the apoapsis over the Southern hemisphere.

In terms of the Ground Segment, the service will consist of:

- Option for DTE communications at either S or X-band. This is based on a network of three deep space ground stations that is planned by GES to be operational by 2022. These comprise
    - Goonhilly Site in UK (already exists, currently in funded ESA DSA-equivalent upgrade)
    - Site in Malibu, California (preliminary site identified)
    - Site in Perth, Australia (preliminary site identified)

The ground segment can support DTE rates of 1 Mbps or higher at X-band if a typical medium gain antenna is used on the lander. With the three ground stations identified, virtually continuous coverage of the Moon is possible. However, for a lander at Shackleton Connecting Ridge, the Earth is only visible for periods of ~10 days every lunar month. Therefore, as the basis of landing at this site is to exploit the long periods of solar illumination, the relay spacecraft can provide additional connectivity during the 'long gaps' between DTE coverage. With the proposed UHF proximity service, a data rate of ~0.25 Mbps or higher can be achieved using a simple mono-pole antenna on the lander, and moderate Tx power (5W). If a higher gain antenna was used on the lander, then >1 Mbps can be supported.

Using either DTE or the Relay, the available data throughput capacity has significant margin with respect to the expected data production rate of the payload. This margin could be exploited to provide additional services to the payload, or to increase the rate and/or volume of telemetry produced. This will need further iteration with the Segment 1 team during subsequent mission phases.

The use of the relay significantly improves the available contact time with the lander from ~35% when just DTE is used, to ~82% of a year, on average, when DTE and Relay services are used in combination. This has the potential to significantly increase the utilisation of the ISRU payload, and to increase the value derived from the mission, especially given the potential for long-term (>one lunar day) survival of the lander at the Shackleton Connecting Ridge landing site.