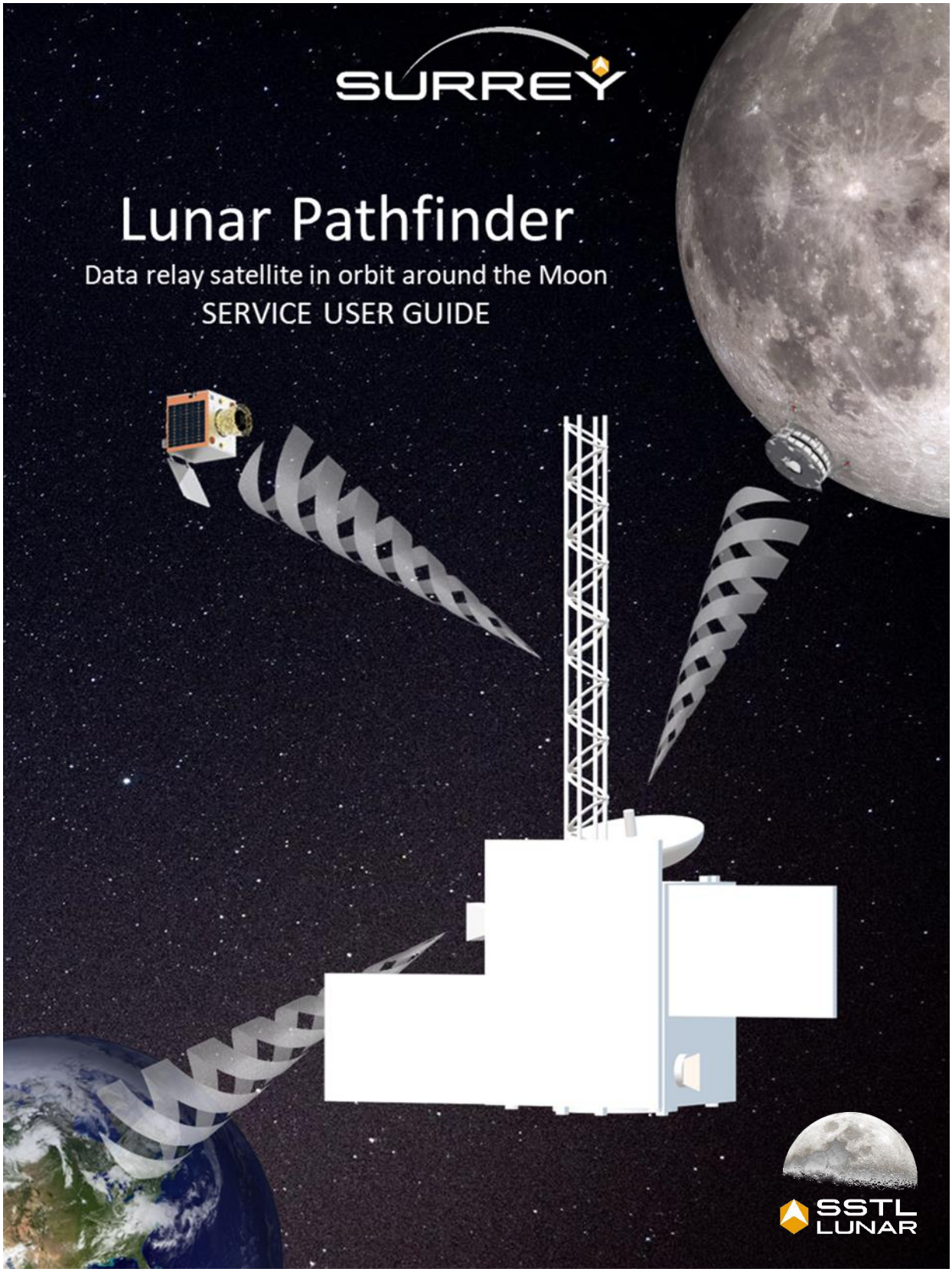
SURREY
Lunar Pathfinder
Data relay satellite in orbit around the Moon
SERVICE USER GUIDE
SSTL
LUNAR

Change Log

Date	Release
07/2020	Version 001 Release ST
07/2020	Version 002 Release ST
11/2020	Version 003 Release ST

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Contents

1. Introduction

This is the first issue of this Service User Guide. This document aims to inform organisations planning lunar mission. Future issues of this document will include greater detail on the service definition and information on pricing of services.

The purpose of this Lunar Comms user guide is to describe, to potential future users of the service, the approach taken by SSTL into delivering commercial services around the Moon, the communication services which will be made available to them, and the customer support before and after the launch of their assets.

This guide describes a list of services that can be offered on “catalogue”. Mission-specific needs and additional services can be discussed on a case by case basis.

1.1. Lunar comms and nav services – a phased approach

The Lunar comms and nav services endeavour, has the vision of setting up a sustainable infrastructure around the Moon, capable of supporting communication and navigation needs of lunar assets, in a reliable and cost-effective way.

By mutualising and commercialising the data-relay infrastructure, lunar assets will benefit from a cost-effective way of managing their communication and navigation needs, which in turn will free effort and resource to focus on the scientific value of their mission.

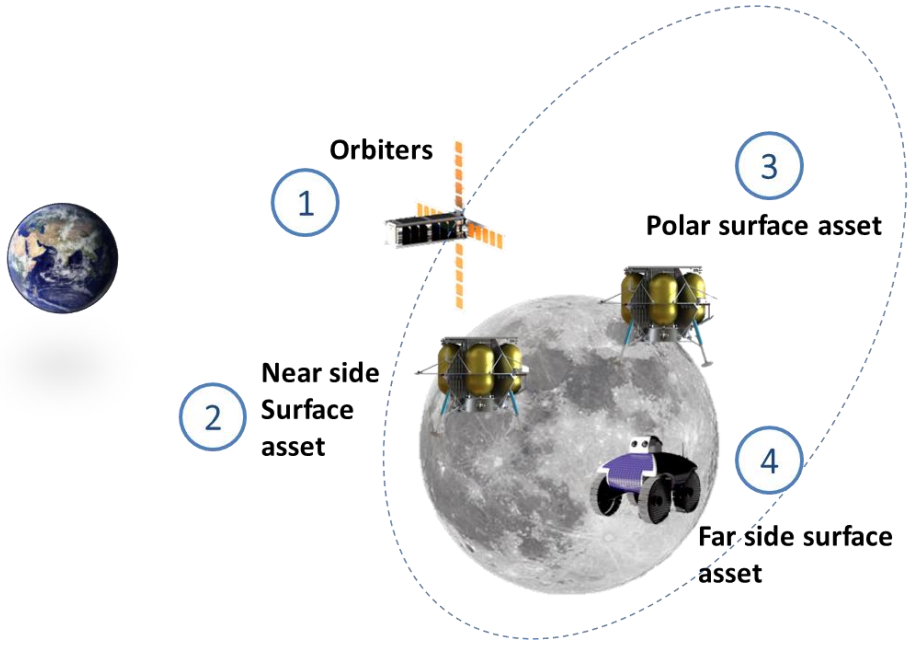


Figure 1.1-1 - Locations of customers

Depending on the location of the customer asset, as shown in Figure 1.1-1, customers will draw various levels of benefits from the data-relay services.

Surface assets on the far side of the Moon will require a data-relay spacecraft to communicate with the Earth, and Polar surface assets, potentially with limited direct to earth visibility, will also find the use of data-relay services a mission enabler. Rovers, constrained to remain within line of sight of the

lander to relay their communication, will find a new independence, both in how far they can go from the lander and how long they can survive beyond the lander's lifetime.

Near side surface assets and orbiters, which could manage with direct to earth communication, will benefit from the higher data-rate and lower performance requirements on their own communication modules, due to the proximity of the data-relay spacecraft. Significantly shorter distances to communicate over (4,000-8,000 km to Lunar Pathfinder vs. ~400,000 km for direct to earth or ~70,000 km for the Lunar Gateway), allow for the link budgets to be closed with low gain antennas or low power levels, representing a significant saving to for the Lunar asset.

The ambition for navigation services is to offer a cost-effective and high performance way for lunar assets to acquire localisation data, whatever their position on or around the Moon.

This ambitious enterprise is approached in 2 phases:

- Phase 1 – Lunar Pathfinder – a single spacecraft in lunar orbit, offering communication services to any lunar asset (surface or orbiter). Due to launch and enter operation in 2023, the spacecraft will be fully operational in 2023, for a duration of 8 years of service. This programme is supported by ESA under the commercial partnership programme.

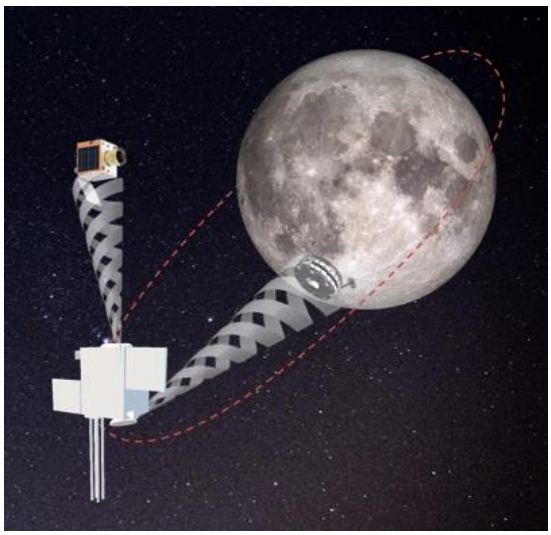


Figure 1.1-2 - Lunar Pathfinder (Phase 1)

- Phase 2 – Lunar comms and nav constellation – still at the study stage today – the ambition is to launch a constellation of several spacecraft capable of offering an enhanced communication service as well as navigation services.

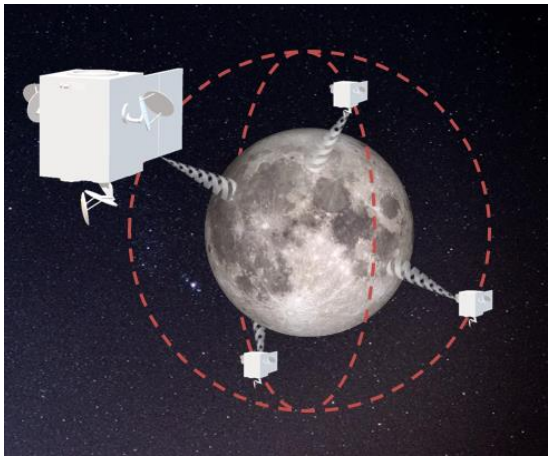


Figure 1.1-3 - Lunar comms and nav constellation (Phase 2)

1.2. Lunar Pathfinder – the first commercial communication services

Lunar Pathfinder will be the first spacecraft in orbit around the Moon to commercially offer communication services to Lunar assets, whether coming from companies, governments, universities, non-profit organisations or individuals, the aim is to offer a high-performance, competitively priced option to relay communications between the Earth and Lunar assets.

Lunar Pathfinder offers 2 simultaneous channels of communication to lunar assets: 1 in S-band and 1 in UHF. Communications are then relayed back to Earth ground station in X-band. Figure 1.2-1 shows links and associated bands and frequencies.

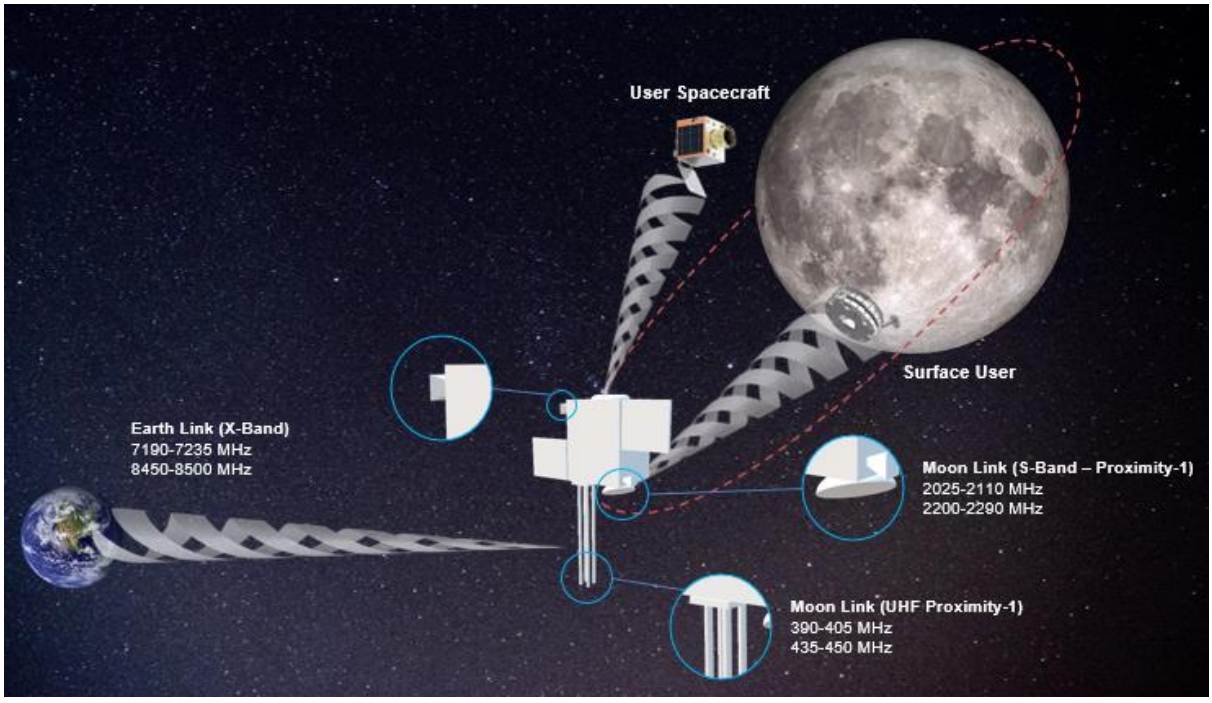


Figure 1.2-1 - Lunar Pathfinder earth and moon links

Lunar Pathfinder offers various levels of service packages depending on the lunar asset location and payload capabilities.

Depending on the chosen launch date Lunar Pathfinder will be fully operational for commercial services operations by mid to late 2023, for a duration of 8 years. During the commissioning period, the spacecraft can offer communication services, on a demonstration basis, but with restricted service levels. This will be possible as soon as the platform has been commissioned and the payload has been checked out to a certain level of functionality.

1.3. Lunar Pathfinder mission at a glance

1.3.1. Spacecraft

1.3.1.1. Mission Orbit

Lunar Pathfinder will operate in an Elliptical Lunar Frozen Orbit (ELFO), for an operational lifetime of over 8 years.

This orbit favours a long duration coverage of the lunar southern hemisphere, understood to be more attractive for early lunar missions. It covers the far side of the Moon and benefits from long access times to Earth to relay back customers' data.

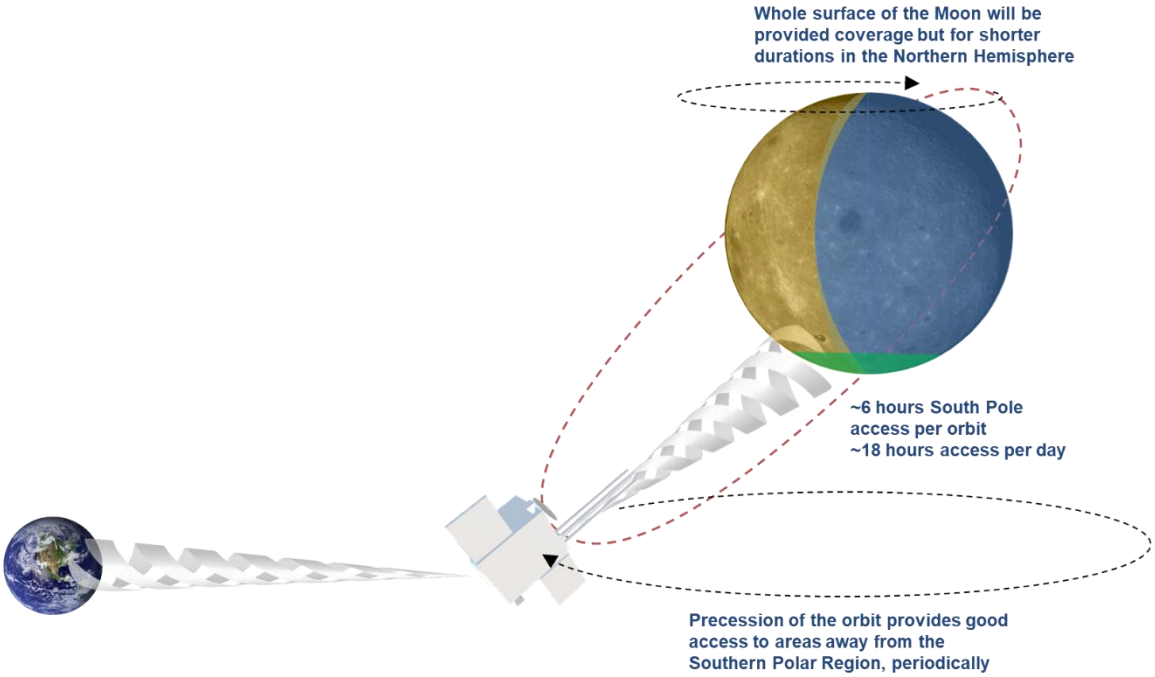


Figure 1.3-1 - Lunar Pathfinder orbit

1.3.1.2. Communication payload

The Lunar Pathfinder relay spacecraft is equipped with a Moon link payload, capable of operating 2 full duplex channels simultaneously:

- S-band (2025-2110 MHz (forward 0.5 - 128 kbps), 2200-2290 MHz (return 0.5 kbps to 2 Mbps)

- UHF (390-405 MHz (forward 0.5 - 128 kbps), 435-450 MHz (return 0.5 kbps - 2 Mbps)

The Moon link payload is used to send and receive to and from the lunar user assets using a Proximity-1 protocol.

The Earth link is realised in X-band (7190-7235 MHz (forward up to 30 kbps), 8450-8500 MHz (return ≤ 5 Mbps)).

The Proximity-1 protocol is designed to work with multiple assets in the same coverage area, and with a variety of assets of various performances.

Working with multiple assets within the same coverage area:

- All links will be controlled by the Lunar Pathfinder spacecraft, meaning that each transceiver will only operate on 1 RF channel at a time and multiple assets will be using this 1 channel.
- To establish a link, the spacecraft hails an asset by addressing it by its Spacecraft Identification (SCID). All assets will listen to this hail but only the asset with the right SCID will respond. Communication link will then be established. This is shown on Figure 1.3-2.
- This process can be automated to optimise operational costs, and ultimately service prices for the customers.

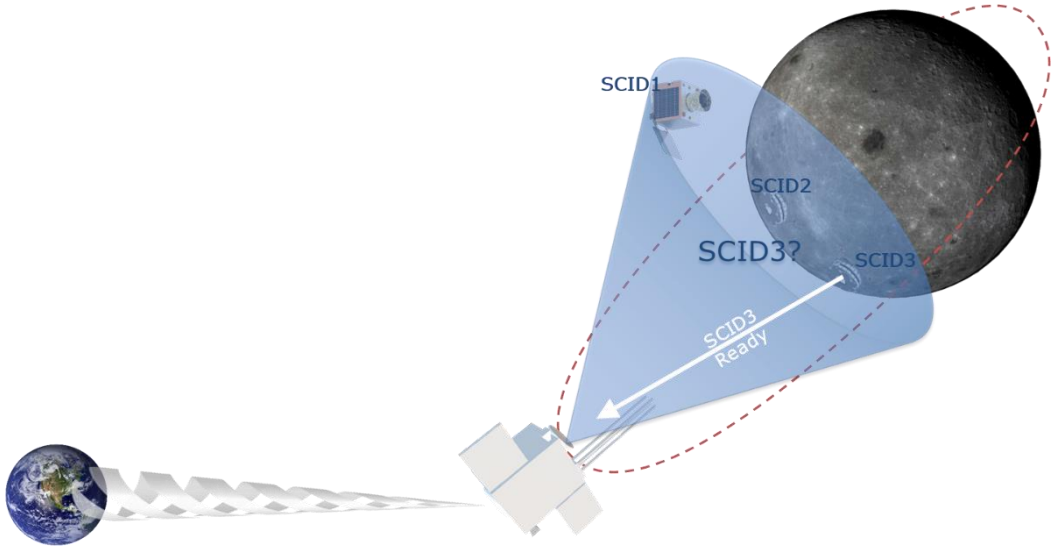


Figure 1.3-2 - Link establishment through hailing

Addressing a large spread of customer assets with various RF performances:

- Wide range of data rates (0.5-2048kbps)
- Links with assets of different performance RF systems and/or at different ranges to be supported on the same link
- Data rate to be dynamically adjusted over a link session as the signal strength changes to maximise data throughput, as shown in Figure 1.3-3 .
- The time when assets receive their allocation can be selected to provide better average data rate

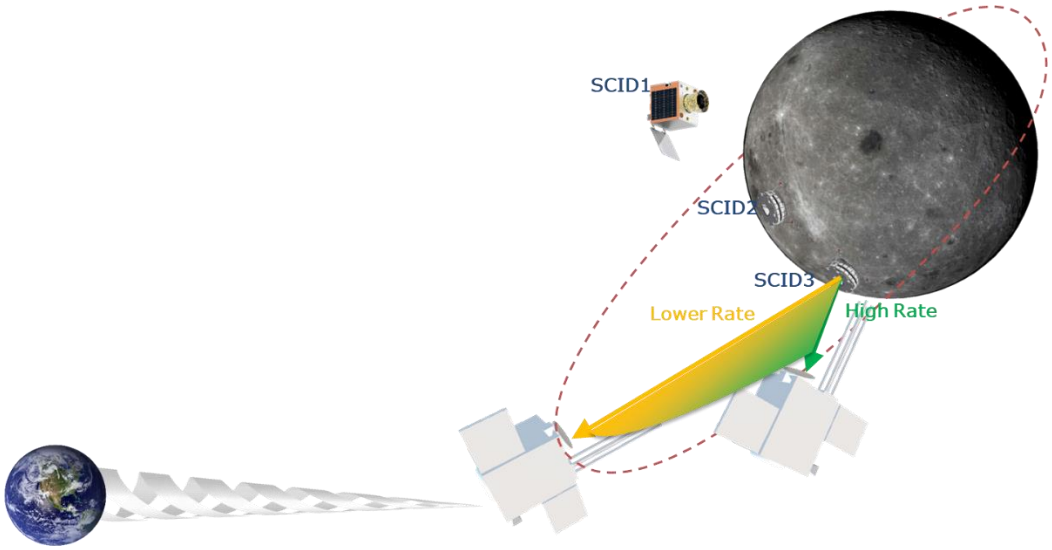


Figure 1.3-3 - Dynamic data-rate adjustment vs. range

The communication service works on a “store & forward” architecture, allowing flexibility regarding to relative position of the lunar assets, the data-relay spacecraft, and the Earth ground station. Data is stored in the payload until links are available:

- End to end link doesn’t need to be available simultaneously for data to be sent between the user’s Mission Operations Centre (MOC) and lunar asset data is stored at each node in the network until it can be sent on
- Commands and software patches ultimately destined for the asset can be sent to the data-relay spacecraft even when the asset is not in view of the Earth
- Data can be stored at the ground station until the next access to the data-relay spacecraft.

This approach brings additional flexibility and benefits to the users:

- Data can potentially be routed between lunar assets on sequential accesses without going via Earth
- Duration and schedule for ground station accesses can be varied based on amount of data to transfer and user operational requirements, thus reducing operational costs
- Provides operational flexibility to users as they can work normal hours rather than having to be available for end-to-end links

1.3.2. Ground segment

Depending on the service need, Lunar Pathfinder will use several ground stations, appropriately distributed around the Earth. The baseline ground station for the mission is with Goonhilly Earth Station (GES), in Cornwall, UK. In the feasibility study phase of the partnership, Lunar Pathfinder was designed to communicate with Earth via an X-band RF link, using GES 32 meter antenna (Goonhilly-6) located at 50.05°N 5.18°W.

Figure 1.3-4 - Aerial view of Goonhilly Earth Station with GHY-6 32m dish

The service is currently designed to pass all payload data through a single ground station in the early stages of the mission. The Earth ground stations network may be expanded to include ground station a sites in other parts of the world in the future. This will extend the contact time to Lunar Pathfinder and enable greater data throughput. This will be dependent on service needs.

2. Service description

2.1. Coverage maps

Lunar Pathfinder orbit was selected to favour coverage of the southern hemisphere of the Moon, particularly the polar region. Depending on the location of the asset, the coverage by Lunar Pathfinder will vary as shown in this section.

Small variations in the performance stated in this section are expected as a normal part of refine the mission profile.

2.1.1. Accessible Coverage

This section provides an assessment of the coverage of the lunar surface in terms of line of sight to Lunar Pathfinder. This means that some of these locations can be addressed by Lunar Pathfinder but that there may need to be a modification from Pathfinder's nominal operations to address these locations. A prime example would be locations near the North Pole.

An example of the coverage over a 14 Earth day period can be seen in Figure 2.1-1 and Figure 2.1-2. Figure 2.1-1 looks at the maximum revisit time over this period. Revisit refers to gaps in visibility of Lunar Pathfinder from an asset's location.

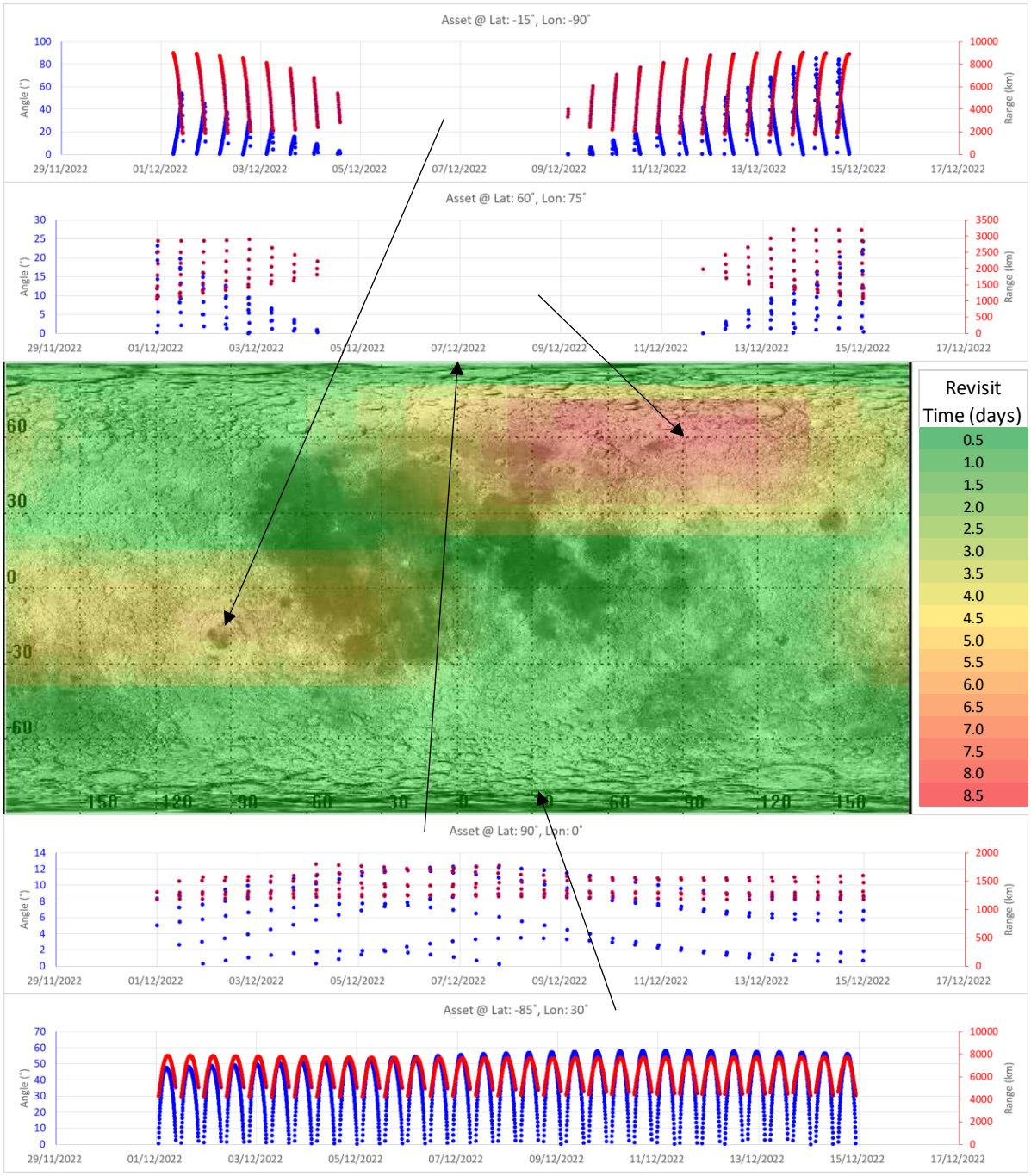


Figure 2.1-1: Maximum revisit time over a 14 Earth day period. Elevation and range of Lunar Pathfinder from 4 locations have also been plotted to further explain the nature of the coverage gaps.

Figure 2.1-2 show the total amount of time that Lunar Pathfinder is accessible during this period. The lower coverage time will be partially compensated, in the northern hemisphere, by the higher data rates achievable at shorter ranges.

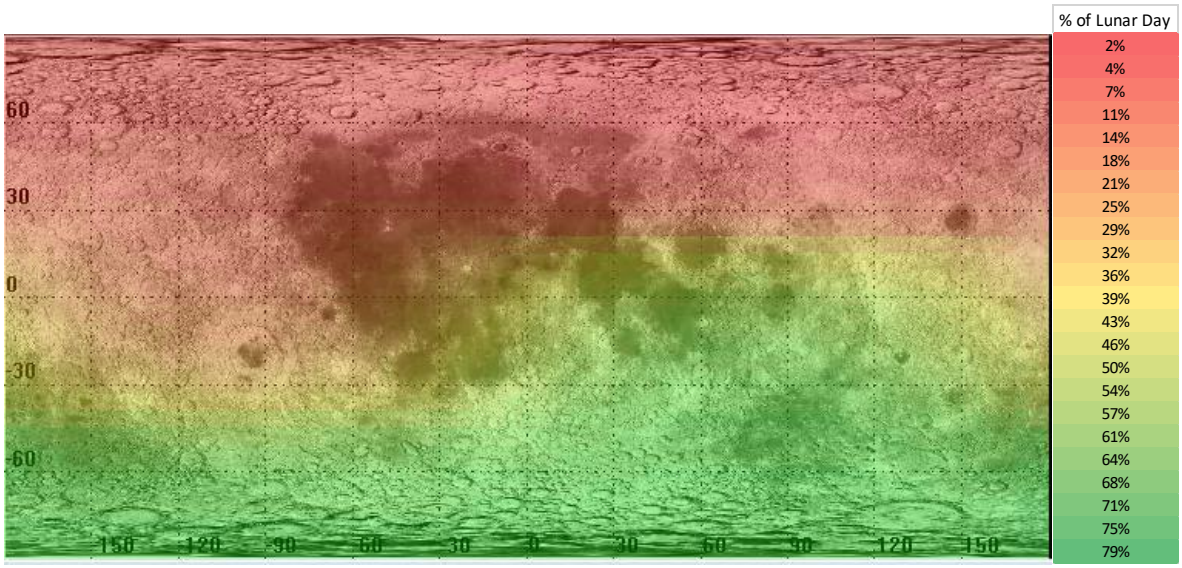


Figure 2.1-2: Example of total coverage time over a 14 Earth day period (% of the analysed time period, 14 days)

This pattern of coverage will rotate around the lunar surface as Pathfinder's orbit precesses. This means that if a mission is targeting landing locations in these intermediate latitudes, and has some degree of flexibility in their landing date, it may be advantageous to time their manoeuvre to maximise the opportunity to use data relay services provided by Lunar Pathfinder.

Figure 2.1-3 shows the maximum revisit time (the longest time between contacts) that can be expected at each location over a 1 year period. These are quite short over the southern hemisphere as Pathfinder's orbit provides long duration accesses each orbit. In the northern hemisphere though, the lower altitude of Pathfinder and the precession of its orbit will mean that some locations will experience gaps in coverage of several days. This will happen on a 28 day cycle as Pathfinder's orbit precesses.

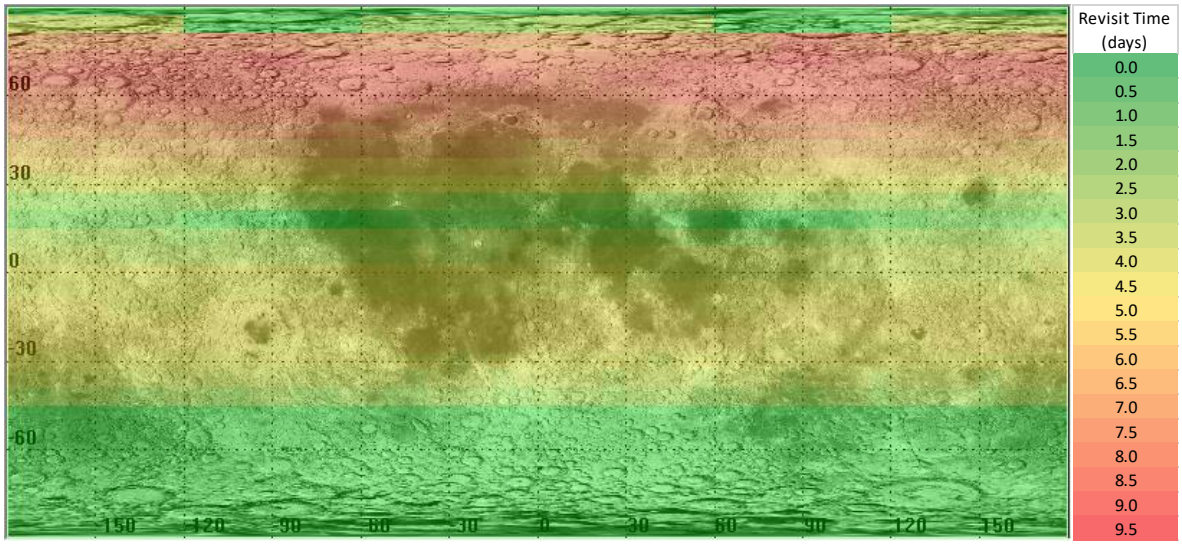


Figure 2.1-3: Maximum revisit time over 1 year

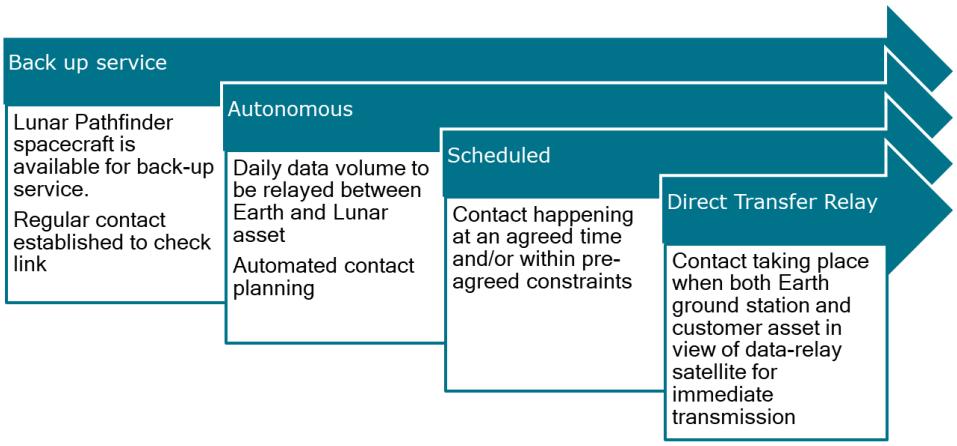
Figure 2.1-4 shows the average revisit times that can be expected at different locations on the lunar surface, this time, analysed over a 1 year time period. These revisit times are much lower than in

Figure 2.1-3 as most all locations will receive frequent accesses when not in the gap periods as can be seen in Figure 2.1-1.

Figure 2.1-4: Average revisit time over 1 year

2.2. Services options – tailored to your mission needs

Several options are available to customers when deciding the type of communication services best suited to their mission. From a dedicated service in "Direct Transfer Relay" to autonomous optimisation, service can be tailored to the mission needs.



All service packages include a pre-launch service, by which SSTL will work with the customer to ensure compatibility of the customer spacecraft with the Lunar Pathfinder spacecraft as well as compatibility of the ground stations.

Operational services are incremental, starting with a basic package called "back-up" service in which SSTL works with the customer in ensuring compatibility of their lunar asset and Lunar Pathfinder, and then offer periodic contact between the two to ensure availability of service if required.

In the “autonomous” mode, an agreed amount of data per day is relayed between earth ground station and relay satellite. This is called “autonomous” as Lunar Pathfinder optimises automatically when the customer asset is contacted for data transfer, within an agreed periodicity. This allows Lunar Pathfinder to automatically offer the best possible data-rates to customers whenever available.

The “scheduled” service builds upon the “autonomous” one, by adding priority service where, over a pre-agreed time period, only the asset in question will be hailed and provided data relay services. This service is ideal for users that have time critical events where they need a greater level of assurance on their communications link. During this time period the Moon Link payload will repeatedly hail the asset until it establishes a link.

The “Direct Transfer Relay” service builds upon the “scheduled” one, adding the operational constraint that Lunar Pathfinder must have line of sight of the customer asset and the earth ground station simultaneously, so that it can transmit data from one to the other quasi-instantaneously.

On the commencement of service, only “autonomous” and “scheduled” services will be available. The “back-up” service and “Direct Transfer Relay” will be added over time if customers are interested and the services are financially viable.

2.2.1. Back-up service

The “back-up” service is the bare minimum necessary to ensure that a lunar asset is able to use Lunar Pathfinder to transmit data, if needed, as a back-up.

It is assumed in this case that the customer has an alternative baseline solution to transmit communication to and from the Earth, but would be able to switch to Lunar Pathfinder if this baseline became unavailable.

This package includes:

- Pre-launch services (included in all packages to ensure compatibility, as described in paragraph 3.1)
- Operational services: regular hailing of the customer asset by Lunar Pathfinder to check the ability to establish a contact and open the communication route if necessary. No data other than hailing and response would be shared in this mode.

2.2.2. Autonomous service

The autonomous service package is the baseline service offered by Lunar Pathfinder, and the one assumed to be most attractive to customers who want to manage communication to and from their lunar asset in the most cost-effective way.

This package includes:

- Pre-launch services (as described in paragraph 3.1)
- Operational services: an agreed volume of data to be transferred between the customer and the customer asset, via Lunar Pathfinder, over an agreed period of time.

In this autonomous mode, the frequency, duration and time of the contact between the Lunar Pathfinder spacecraft and the customer asset is automatically optimised via algorithm. This way, the Lunar Pathfinder spacecraft capacity and availability is optimised in order to best serve all customers.

2.2.3. Scheduled service

Some missions may require a more dedicated service from Lunar Pathfinder, which is allowed through the scheduled service package. As an example, a mission might need tele-commands to be sent to their spacecraft at a very precise phase of operations, or to retrieve some housekeeping data at a certain frequency during a critical phase.

With this service, the customer can choose when and how the contact is established between the data-relay spacecraft and their asset.

This package includes:

- Pre-launch services (as described in paragraph 3.1)
- Operational services: an agreed volume of data to be transferred between the customer and the customer asset (like in the Autonomous package) but with a set of constraints allowing the customer to choose a period of time for the contact to happen between Lunar Pathfinder and the customer asset.

To service the additional constraint, the mission plan will give priority to the customers of the Scheduled Service package over the Autonomous Service package ones over the agreed period.

2.2.4. Direct Transfer Relay service

The Direct Transfer Relay service is the highest level of constraints within the Scheduled Service package. When allowable, it guarantees that, at the time the customer asset is contacted by the Lunar Pathfinder, the data-relay satellite has already established a link with an Earth Ground Station. This enabled Pathfinder to pass data to and from the asset as soon as it has been received by Pathfinder, minimising the delay between a user sending a command and the asset receiving and acting on them.

This package includes:

- Pre-launch services (as described in paragraph 3.1)
- Operational service: The link with the asset will be established in much the same way as in the Scheduled mode. Lunar Pathfinder will have a pre-established linked to the Earth Ground Station when establishing contact with the customer asset, at a pre-agreed time with the customer.

At the start of Lunar Pathfinder operations, Direct Transfer Relay service availability will be constrained by Earth Ground Station coverage. Starting with 1 ground station (located in Cornwall, UK), this service will be limited in availability until earth ground station coverage is ramped up.

2.3. Concept of operations

Lunar Pathfinder is capable of relaying various sorts of data

- TM/TC between customer asset and ground station
- Payload data between customer asset and ground station
- Point to point exchange of data between lunar assets without involving earth station, via Lunar Pathfinder. This service will not be available initially.

As explained in section 1.3.1.2, Lunar Pathfinder uses a CCSDS Proximity-1 protocol for communication with customer assets with Proximity-1 frames in which the assets data will be encapsulated.

Layer	Moon link
Data link	CCSDS Proximity-1 Data Link
Physical	CCSDS Proximity-1 Physical

The baseline assumption is that the Moon Link payload will not be encrypted. However, the customer data contained in the transfer frames can be encrypted by the customer.

Communication links between the customer asset and the data-relay spacecraft are established via hailing (see Section 1.3.1.2).

In “autonomous” mode, the spacecraft automatically schedules link sessions based on an algorithm run by the payload. In this mode, each asset receives their time allocation over a “service cycle”, agreed maximum allowable period between contacts of an individual asset.

The overall concept for the use of this system is that the user needs only minimal ground segment infrastructure to be able to control a lunar mission. A user needs a Mission Control Centre (MCC) with a computer with internet access from which to connect through a VPN to SSTL’s Lunar Services Mission Operations Centre (MOC). At each node in the system, data is stored until the next link becomes available. The following procedure describes the various steps of the comms service provision:

1. Uplink data sent to Lunar Services MOC
    - To command their spacecraft the user sends command files, or software patches, to the Lunar Services MOC, where it is stored until the next scheduled access to the Lunar Pathfinder payload.
    - The user is responsible for delivering these files to the Lunar Service MOC, with sufficient time for delivery to the asset prior to implementation (duration to be agreed between SSTL and customer).
2. Uplink data sent to Lunar Pathfinder
    - The commands are sent to the ground station from the Lunar Services MOC and then transmitted over the X-Band link to Lunar Pathfinder.
    - When the next data transfer session commences with the Lunar Pathfinder spacecraft, the commands are transmitted from ground and received by Pathfinder, and then be stored in the data recorder in Lunar Pathfinder’s payload.
3. Communication between Pathfinder to Asset
    - At the next access to the user’s asset, the data stored in the Moon Link payload are sent to the asset.
    - The link with the asset is established by the Moon link payload hailing the asset, receiving a response and moving onto a working channel.
    - How the data is delivered depends on the nature of the service:
        - If the link is through the autonomous service then the data may be transferred over more than one link session.
        - If the scheduled and Direct Transfer Relay service is being used then the link can be planned so that all of the data can be transferred during this access.
        - Back-up services most likely do not require the transfer of user but just a hail and a response to check that the asset is still contactable.

- TM and Payload data can be received by the Moon Link payload while the link is active:
    - The return link from the asset is expected to be the main driver for the duration of the link, as payload data is likely to form the bulk of the data transfer.
    - The data from the asset is be stored in the Moon Link data recorder until the next opportunity for transfer back through the Earth Link.

4. Asset data sent to GS
    - At the next opportunity of data transfer, the data stored on-board Lunar Pathfinder is transmitted to the ground station.
    - If both links (between ground segment and relay spacecraft and customer asset and relay spacecraft) are active at the same time it is possible for Direct Transfer Relay service to be used, upon request from the customer.
5. Asset data to users
    - Once the data is at the ground station, it is sent to the Lunar Services MOC over a VPN and is stored until it can be passed to the users.
    - The data is accessed by the users over a VPN link.

Figure 2.3-1 illustrates the basic principle of the process in which customer assets are contacted, data is stored and then forwarded back to Earth station.

Figure 2.3-2 shows the overall architecture, from the customer MOC to the customer lunar asset.

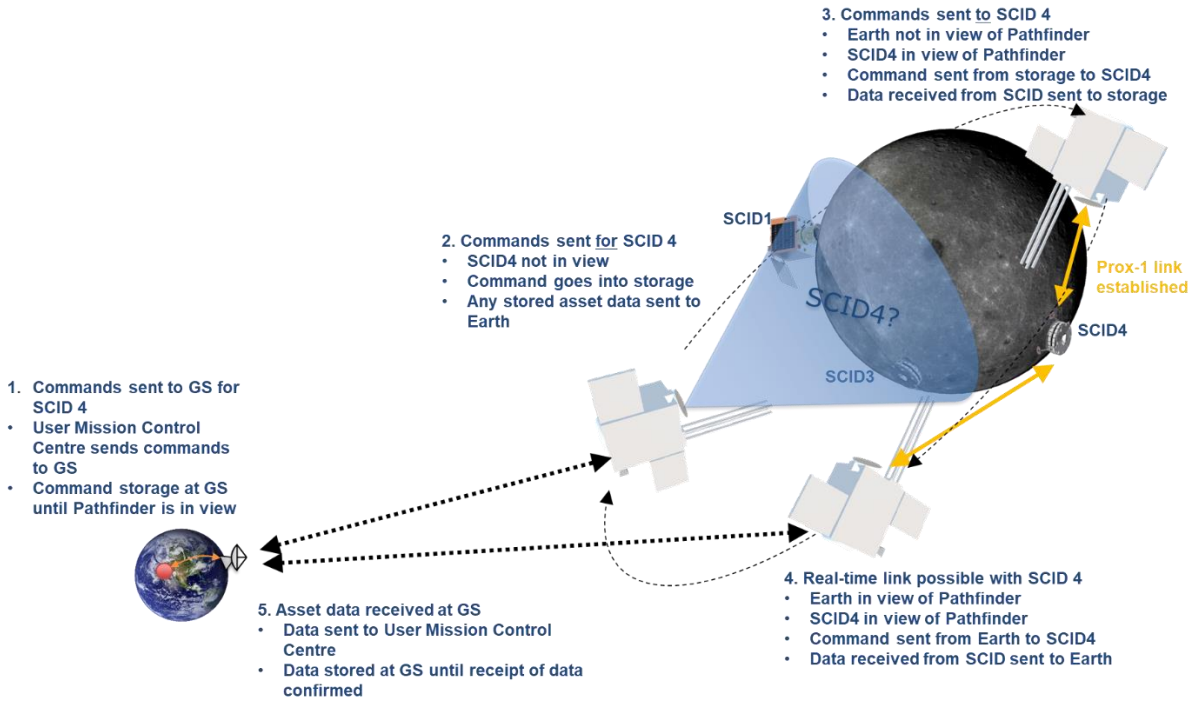


Figure 2.3-1 - Example of hailing/contact/data-transmission cycle

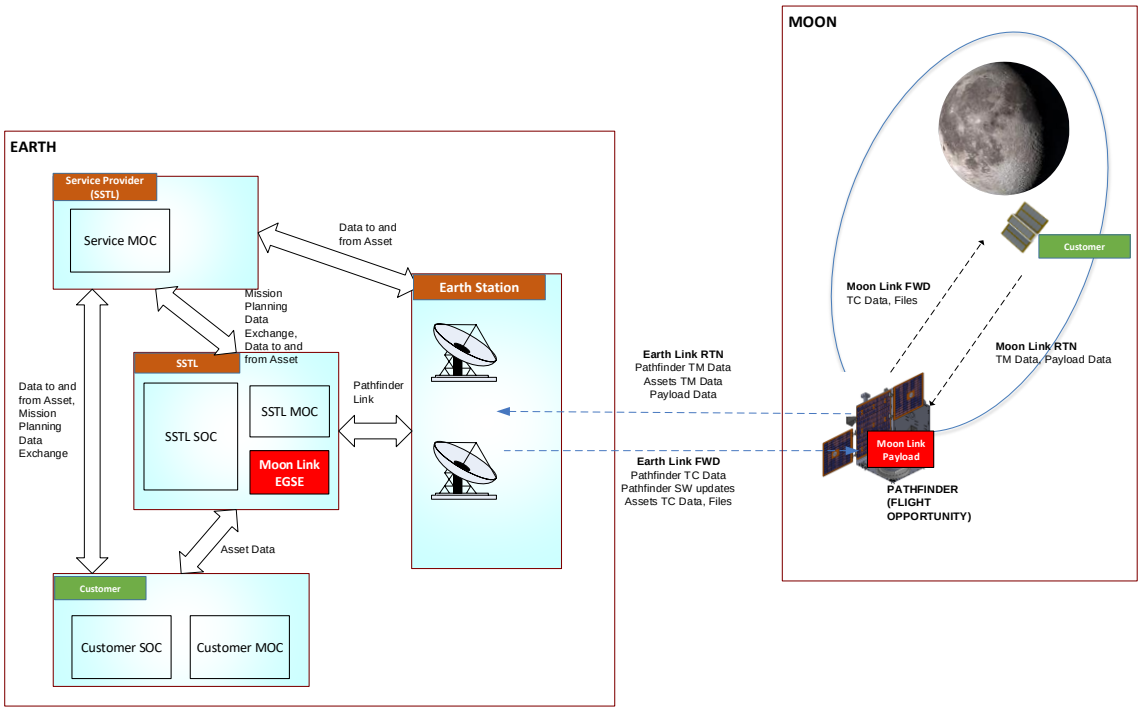


Figure 2.3-2 - Overall service delivery architecture

2.4. Data rates and service levels

The mission of Lunar Pathfinder is to relay an agreed volume of data within an agreed period of time, either allowing the autonomous algorithm to optimise contact time, frequency and duration during the agreed period, or by constraining it, depending on the nature of the service purchased.

Data rates are function of several elements: the RF performance of the Lunar Pathfinder spacecraft, the RF performance of the customer asset communication module and the distance between the customer asset and the Lunar Pathfinder spacecraft at the time of the contact. This means that data-rates can vary from one contact to another, but are predictable and taken into account in the optimisation of the contact time and duration.

2.4.1. Lunar Pathfinder spacecraft RF interfaces

The RF interface is shown in the following table.

	UHF Forward Link (OTM-U)	UHF Return Link (OFM-U)
Frequency	390 – 405 MHz	435 – 450 MHz
Modulation	PCM(SP-L)/PM	PCM(SP-L)/PM
Modulation index	1.047 rad	1.047 rad
Modulation index variation	± 5%	± 5%
Coding	Uncoded OR Convolutional (r=1/2, k=7) OR LDPC (r=1/2, k=1024)	Uncoded OR Convolutional (r=1/2, k=7) OR LDPC (r=1/2, k=1024)
Symbol rate	As per CCSDS 211.0-B-5	As per CCSDS 211.0-B-5
Useful data rate	As per CCSDS 211.0-B-5	As per CCSDS 211.0-B-5
	S-band Forward Link (OTM-S)	**S-band Return Link (OFM-S)**
Frequency	2025 – 2110 MHz	2200 – 2290 MHz
Modulation	PCM(SP-L)/PM	PCM(SP-L)/PM
Modulation index	1.047 rad	1.047 rad
Modulation index variation	± 5%	± 5%
Coding	Uncoded OR Convolutional (r=1/2, k=7) OR LDPC (r=1/2, k=1024)	Uncoded OR Convolutional (r=1/2, k=7) OR LDPC (r=1/2, k=1024)
Symbol rate	As per CCSDS 211.0-B-5	As per CCSDS 211.0-B-5
Useful data rate	As per CCSDS 211.0-B-5	As per CCSDS 211.0-B-5

2.4.2. Lunar Pathfinder orbital parameters

The Lunar Pathfinder operates in an Elliptical Lunar Frozen Orbit, or ELFO. This orbit has been selected to provide coverage of the whole lunar surface with long duration coverage of the lunar South Polar Region. This orbit provides other benefits such as long accesses to Earth and long term stability for the Lunar Pathfinder spacecraft.

The baseline orbit is described in the following table, these parameters are indicative and may be subject to change as the design progresses and when the launch date is set.

Item	Value
Semi major axis (km)	5737.4
Periselene altitude (km)	500
Aposelene altitude (km)	7500
Eccentricity	0.61
Inclination (deg)	57.82
Argument of Pericenter (deg)	90

The orbit is expected to naturally evolve over the course of the mission but will be maintained within acceptable bounds.

The orbit has been designed to primarily favour servicing missions at the Lunar South Polar Region as this location is of key interest due to the geological properties in the region and the presence of large permanently shadowed crates containing volatiles.

This being said, mission destined for the northern hemisphere are also able to access the service. These accesses are of shorter duration than in the southern hemisphere but at a much shorter range enabling links to be closed with higher data rates or with less RF power.

2.4.3. Examples of service performance, depending on customer asset RF performance and location

In this section several case studies have been analysed to provide examples of how the services can be used. The missions analysed are robotic missions including lunar landers and mission that could be delivered to orbit or the surface by landers.

A key assumption in these cases is that the EIRP and G/T stated in each case can be maintained throughout each access. In our initial discussion with prospective users, the specifics of their asset communication system and mission design will be taken into account, and a specific service package designed accordingly.

There is variability in the amount of data throughput/access time a mission can receive. This will be dictated by several factors, such as:

- User driven factors:
  - The amount of service requested
  - System limitations of the user asset: RF performance, power, etc.
  - Location or orbit of the asset
- Lunar Pathfinder driven factors
  - System utilisation: number of assets requiring services
  - System availability: downtime for orbit maintenance, momentum dumping, etc.
  - Pointing constraints

Working through the design of their service package with prospective users will guarantee that the customers' needs and specificities are understood and well served.

2.4.3.1. User case #1 – surface landers

This user case is geared towards customers wishing to use lunar comms services for surface landers. Whether institutional or commercial, landers typically offer transport and services to assets wishing to operate in lunar orbit or on the lunar surface. The services may be hosted experiments, delivery and support services for rovers, delivery of small orbital assets.

For this user case, we assume a typical mission duration of 7 to 14 days, until technology improvement make it more likely to survive the lunar night. The mission may be located anywhere on the surface of the Moon, but is likely to favour the South Pole for scientific research interest. The RF performance is expected to be within the following range: EIRP between 21.5 and 26.5 dBW, and G/T between -19.2 and -11.5dB/k.

User case assumptions:

Note: these values are there for example only and do not correspond to a specific mission – please contact SSTL to get an indicative report based on your specific mission parameters.

2 phases: orbital and surface operations

- 1st orbital phase includes: Initial capture, orbit lowering, low parking/phasing orbit and landing run. Once the lander has reached a Low Lunar Orbit (LLO) it enteres the normal service region of the Lunar Pathfinder system and is able to access the data relay services.
  During this first orbital phase, the need is assumed to be several short duration contacts to transfer commands and telemetry.
  Service level selected assumed to be scheduled accesses.
  Assumed use of omnidirectional low gain antennas.

Mission parameters – Orbital phase			
Orbit/Location:	LLO 100km altitude		
Duration		30	days
EIRP		9	dBW
G/T		-23.4	dB/K

- 2nd surface operation phase includes payload operation and deployment of assets.
  During this phase, the need is assumed to be long duration contacts to relay commands, telemetry and payload data.
  Assumed use of steerable high gain antenna.

Mission parameters – Surface Operations phase			
Orbit/Location:	S.Pole Lat: -90˚, Lon: 0˚		
Duration		13	days
EIRP		21.5	dBW
G/T		-19.2	dB/K

User case performance:

Performance of the service is characterised in

- Down time = this characterises the duration that the customer asset stays out of coverage from Lunar Pathfinder (mean and max durations). The customer asset needs to be able to wait for this amount of time between 2 consecutive contacts with Lunar Pathfinder.
- Data rate = this shows the mode and maximum data-rate which the customer asset should experience when transferring data to Lunar Pathfinder. As explained earlier the variation depends on the relative position of the customer asset and the data-relay spacecraft at the time of the contact.
- Contact time per day = this is the mean time that is required to move the agreed daily amount of data, given the data-rate performances.

Service performance – Orbital Phase			
Down time (hrs)	Mean	0.57	hrs
	Max	0.67	hrs
Data rate	Mode	123	Kb/s
	Max	1966	Kb/s
Data per day		500	Mb
Service performance – Surface Operations phase			
Down time (hrs)	Mean	2.53	hrs
	Max	2.58	hrs
Data rate	Mode	1966	Kb/s
	Max	1966	Kb/s
Contact time per day	Mean	467	mins
Data per day		60000	Mb

2.4.3.2. User case #2 – autonomous rover

This user case is geared towards customers wishing to use lunar comms services for autonomous rovers. A good example of this category would be the vehicles providing surface mobility for in situ sample analysis and sensing. They are capable of operating independently of the lander that delivered them to the lunar surface, and are likely to require a significant amount of data for navigating the surface of the Moon.

We assume a typical mission duration of 7 to 14 days, until technology improvement makes it more likely to survive the lunar night. The mission may be located anywhere on the surface of the Moon, but is likely to favour the South Pole for scientific research interest. The RF performance, of assets, is expected to be within the following range: EIRP between 12 and 26.5 dBW, and G/T between -21.6 and -11.5dB/k.

User case assumptions:

This particular example of a mission scenario assumes that the rover requires no communication services from the Lunar Pathfinder system prior to arriving on the lunar surface, for instance if it were delivered onto the surface by a commercial lander. This case shows the use of the Scheduled service package, as the customer would like to specify the precise time of contact between Lunar Pathfinder and the rover.

Mission parameters			
Orbit/Location:	Schrödinger Lat: -74.5°, Lon: 135°		
Duration		13	days
EIRP		13	dBW
G/T		-23	dB/K

User case performance:

Note: explanation of the terms in the user cases are provided in User Case #1 in section 2.4.3.1.

Service performance – Surface Operations phase			
Down time (hrs)	Mean	2.68	hrs
	Max	2.83	hrs
Data rate	Mode	492	kb/s
	Max	1966	kb/s
Contact time per day	Mean	529	mins
Data per day		20,000	Mb

2.4.3.3. User case #3 – tele-operated rover

This user case is geared towards customers wishing to use Lunar comms services for tele-operated rovers. The main difference with the previous user case is the involvement of a human operating the rover. The assumption for such a mission is that the main channel of communication would be the Lunar Gateway, and Lunar Pathfinder would provide additional services, and back-up.

The performance of this mission is assumed to be higher than the autonomous rover, with the ability to survive the lunar night and therefore able to sustain a longer mission time, and a higher performance comms module (continuous communication links, higher power, larger antenna, ability to produce a large amount of data).

User case assumptions:

Like for the previous user case, this mission assumes a delivery of the rover by a lander to the surface of the Moon. In this case on the South Pole.

Mission parameters			
Orbit/Location:	Lat: -90°, Lon: 0°		
Duration		100	days
EIRP		26.5	dBW
G/T		11.5	dB/K

User case performance:

Note: explanation of the terms in the user cases are provided in User Case #1 in section 2.4.3.1.

Service performance – Surface Operations phase			
Down time (hrs)	Mean	2.52	hrs
	Max	2.58	hrs
Data rate	Mode	1966	kb/s
	Max	1966	kb/s
Contact time per day	Mean	248	mins
Data per day		30,000	Mb

2.4.3.4. User case #4 – CubeSat

This case looks a CubeSat mission in a LLO with a 100km polar orbit. This type of orbit is likely to be popular for mission that want to use remote sensing to survey the lunar surface. These mission are likely to be delivered into these orbits by lunar landers.

A Lunar CubeSat mission has the potential to survive much longer than the initial surface mission as it doesn't need to survive the harsh conditions of the lunar night. A mission duration of 6 months has been analysed to assess the service delivery.

User case assumptions:

This mission assumes a delivery of the CubeSat by a lander to a LLO with an altitude of 100km.

Mission parameters			
Orbit/Location:	LLO 100km altitude		
Duration		181	days
EIRP		5.7	dBW
G/T		-3	dB/K

User case performance:

Note: explanation of the terms in the user cases are provided in User Case #1 in section 2.4.3.1.

Service performance – Surface Operations phase			
Down time (hrs)	Mean	0.58	hrs
	Max	0.75	hrs
Data rate	Mode	61	kb/s
	Max	1966	kb/s
Contact time per day	Mean	90 - 150	mins
Data per day		500	Mb

The large variation in data rates is due to the difference in ranges between the asset and Pathfinder when Pathfinder is at periselene and at aposelene. Due to their small sizes, CubeSats are often power limited and may not be able to support communications links for long periods. Higher performance CubeSats may be able to support longer contacts at higher average data rates. This could allow them achieve a few 1,000s of Mbits per day.

2.4.3.5. User case #5 – Lander on the North Pole

In the case of a lander at the North Pole the same assumptions to User case #1 are used, aside from the landing site being at the North Pole.

Mission parameters – Surface Operations phase			
Orbit/Location:	N.Pole Lat: 90˚, Lon: 0˚		
Duration		13	days
EIRP		21.5	dBW
G/T		-19.2	dB/K

This scenario assumes that the mission is receiving dedicated "scheduled" service. Indeed this specific location requires the operations of Lunar Pathfinder in order to be serviced.

User case performance:

Note: explanation of the terms in the user cases are provided in User Case #1 in section 2.4.3.1.

Service performance – Surface Operations phase			
Down time (hrs)	Mean	10.42	hrs
	Max	10.50	hrs
Data rate	Mode	1966	kb/s
	Max	1966	kb/s
Contact time per day	Mean	23	mins
Data per day		3000	Mb

The main difference with this scenario for User case #1 is that the contact time is much shorter but the data rate is consistently high due to the lower range of the Pathfinder spacecraft. The shorter contact time ultimately limits the data throughput of the lander.

2.4.4. Service Level Agreements

A set of service level agreements (SLA) will be in place for each of the service products offered by Lunar Pathfinder. The definition of these SLAs is still on-going but a non-exhaustive overview of those associated with each of the service is provided below:

- Back-Up
  - Number and schedule of contacts are executed
- Autonomous
  - Data throughput to and from an asset within a service cycle
  - Attempts to contact asset within service cycle
- Scheduled
  - Asset is given priority access during the scheduled time frame
  - Pathfinder makes every attempt to access the asset during this time frame
  - Maintained pointing to assets location if known/applicable
  - Availability of Pathfinder during access
- Direct Transfer Relay
  - As with Scheduled
  - Earth Link access in maintained throughout scheduler time frame
  - Latency of data to and from the asset

The content of the SLA will be common to each of the services but the specific details will be outlines in the Service package defined for each user.

3. Customer support and services

3.1. Pre-launch support and link commissioning for customer asset

Prior to contract signature for Lunar Comms services, SSTL will work with the prospective customer to define the services best suited to their needs.

Prospective customers will be asked to provide basic technical information about their mission, such as the user mission profile and communications link requirements. SSTL will then provide a high level estimate of the service that can be offered and associated performance.

SSTL will offer design support at various stages of the user's mission design.

- In the Definition Phase SSTL will provide ad hoc support to the user.
- A formal Intermediate Design review will be offered, in which SSTL engineers review documentation ahead of a workshop to assess the design of the user's mission and spacecraft regarding compatibility to the Lunar Pathfinder data relay service.
- Pre-launch testing will assess compatibility of the communications links between the user's asset and a representative transceiver. This testing can either be completed at SSTL's test facility or an SSTL team can be sent to the user's facility and conduct the testing there.
- Test Readiness Review with SSTL engineers will mark the start of a 2 ½ week testing campaign resulting in the generation of a Test Report. Following this a Test Review Board (TRB) will be held to assess the outcomes of the testing campaign. On successful completion of the Test Results Review the user's asset will be clear to use the system pending successful link commissioning in Cis-Lunar space.

After successful launch of the asset, and once it has reached the phase of its mission in which the Lunar Pathfinder services are due, activities will commence to commission the link between Lunar Pathfinder and the asset. This will be a short campaign, scheduled for the earliest opportunity in the user's missions before commencing the service package delivery. It will test the precise functionalities of the chosen service package. The specific tests will be dependent on the exact nature of this package and will pre-agreed through discussions with SSTL engineers during the design and testing phases.

3.1.1. Mission Planning Services

In the process of acquiring their service package SSTL Lunar can work with the user to various mission and link analyses to determine a detailed scope of the service package and the way in which it will be delivered to the user and their asset.

This is a service which can also be performed to assess new service requests, from the users while their asset is active, for complex mission scenarios. This will help to enable users to deal with the changing scope of their mission as they operate them.

These Pre-launch services can be contracted separately or as part of the full package with Relay Communications Services. If the Relay Comms Services are contracted, separately the user will still

have to have completed the Compatibility Testing before commencing the Relay Comms service package.

3.2. Engineering support and customer services

While the definition of engineering support and customer services are on-going, an overview of the functions that will be available will be covered in this section.

A helpdesk will be in place for users to contact to address urgent user requests that require immediate action. These could including:

- Request for priority access to their asset
- Reported issues with VPN connection
- Issues with the received data
- Etc.

Normal, non-urgent, requests can be submitted to order, and will be handled in normal working hours. In this category of requests: modification of the current service package (e.g. requesting more data throughput or extending their service period). Additional services or a change to a different type of service could also be requested, such as requesting a period of scheduled service to support critical operations.

Customers will receive service performance reports periodically. These reports will vary depending on the service type, reflecting the different service level agreements (SLA) associated with each. For example, with the scheduled service the report would contain data such as a log of the attempts made by Lunar Pathfinder during the requested time period, time at which the link was established, time that the link ended, etc. Back-up service reporting, in contrast, may be logs of attempts to contact the asset and confirmation of access.

Users will be notified of any issues with infrastructure effecting their service provision as well as any changes to the service.

As indicated, further details on the operational support are being worked through, and will be discussed in a further iteration of the documents.

4. Contact us

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