SURREY

Lunar Pathfinder

Data relay satellite in orbit around the Moon

SERVICE GUIDE

Change Log

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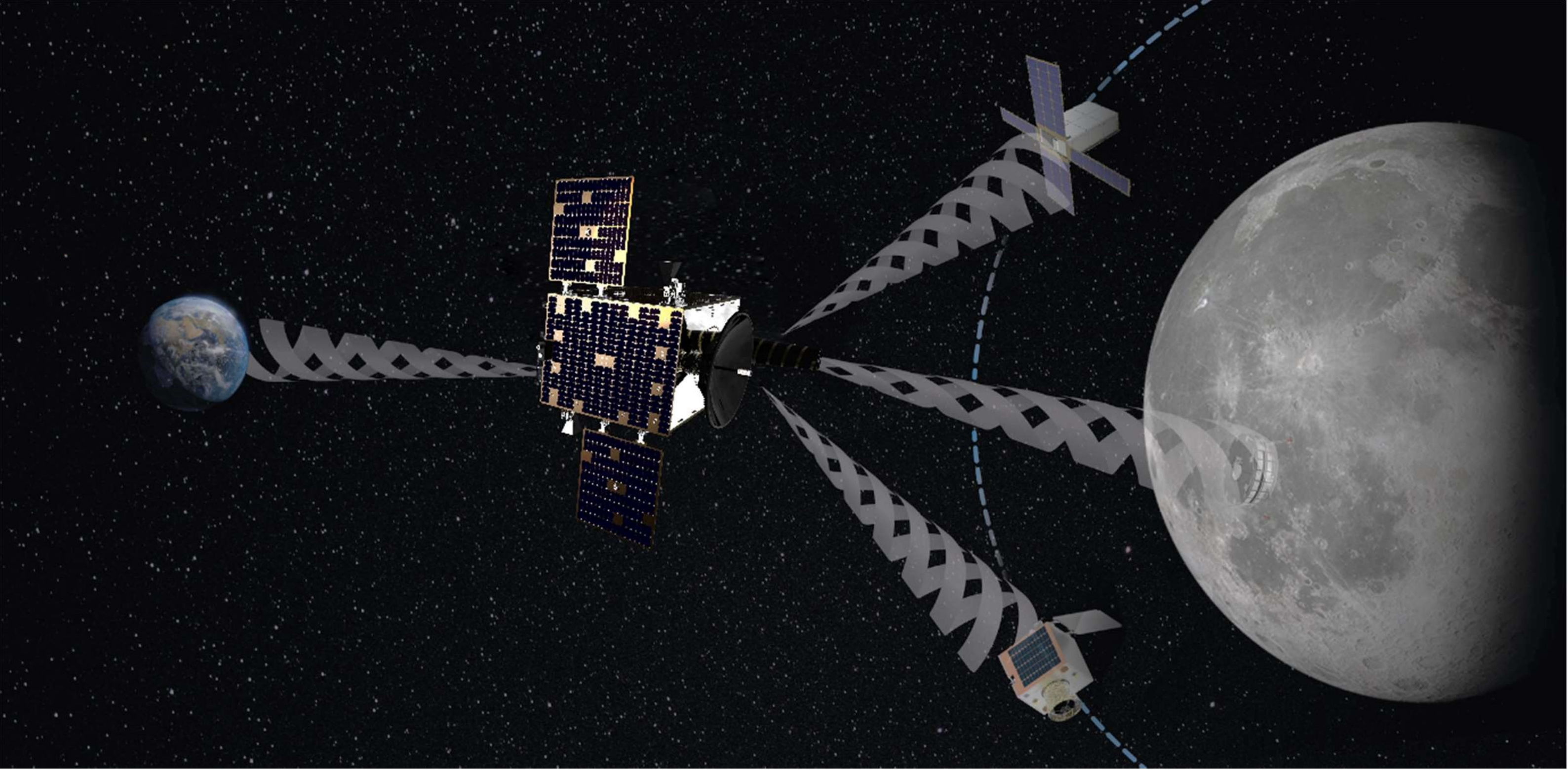


Chapter 1

Introduction

1 Introduction

1.1 About Us

SSTL Lunar is a brand of Surrey Satellite Technology Ltd, used for the provision of services around the Moon. Services will initially comprise of relay communication services from the Lunar Pathfinder spacecraft with commencement of services in-orbit anticipated in 2025. The SSTL Lunar team is very active in the market place and information can be found on the SSTL website, including news items, as well as in the frame of conferences and webinars such as IAC, GLEX, Moon Village Association, European Lunar Symposium etc.

1.2 Service Guide Overview

This document aims to present details of SSTL's Lunar Pathfinder satellite and its suite of communication services available to service customers.

The end-to-end service is described, from the pre-launch services, to the portfolio of communications services offered, performances expected and customer support available. 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..

Performance, such as coverage and data-rates of the link between user asset and Lunar Pathfinder, which varies depending on the location and capabilities of the user asset, can initially be assessed using the Lunar Mission Builder App, which can be found on the SSTL website.

A table of additional documentation provided to the customer as part of the on-boarding process, including the version number of the latest issues, can be found in Section 8.1 – Relevant Documents.

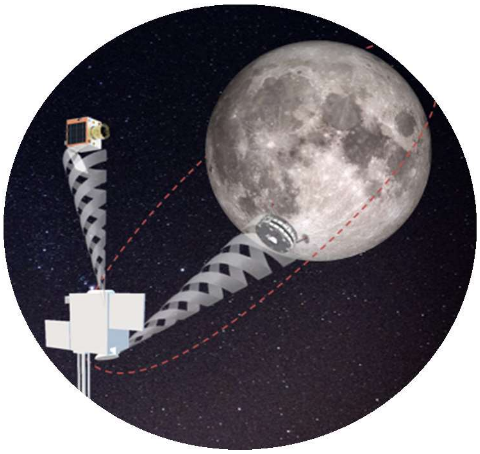
Future issues of this document will include greater detail on the service definition and information on pricing of services. It is recommended to check the SSTL Lunar Website for the latest versions of the Service Guide and the Relevant Documents.

1.3 Lunar Communications and Navigation Services – A Phased Approach

A rejuvenated interest in returning to the Moon has catalysed an armada of missions that aim to energise a thriving lunar ecosystem. In order to support these endeavours and realise this vision of a lunar renaissance, the necessary infrastructure must be put in place.

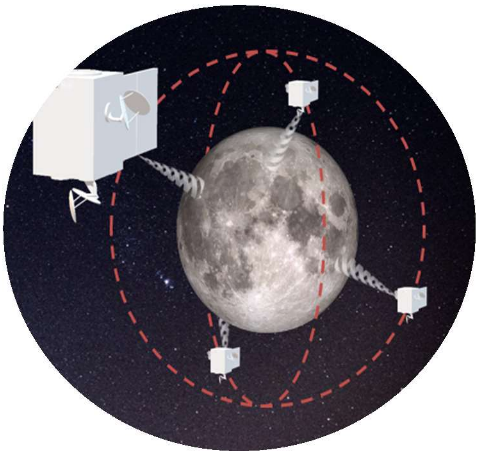
One of the key pillars of this infrastructure will be a Lunar Communications and Navigation network - a high performance, cost-effective service that is capable of providing for the communication and navigation needs of lunar assets. The service liberates users from the burden of a costly and complex independent solution, while providing more robust communications, navigation, and networking capabilities. This will unlock opportunities across a number of nascent lunar markets, empowering the genesis of a sustainable lunar and cis-lunar economy.

This ambition will be realised in a two-phase approach:



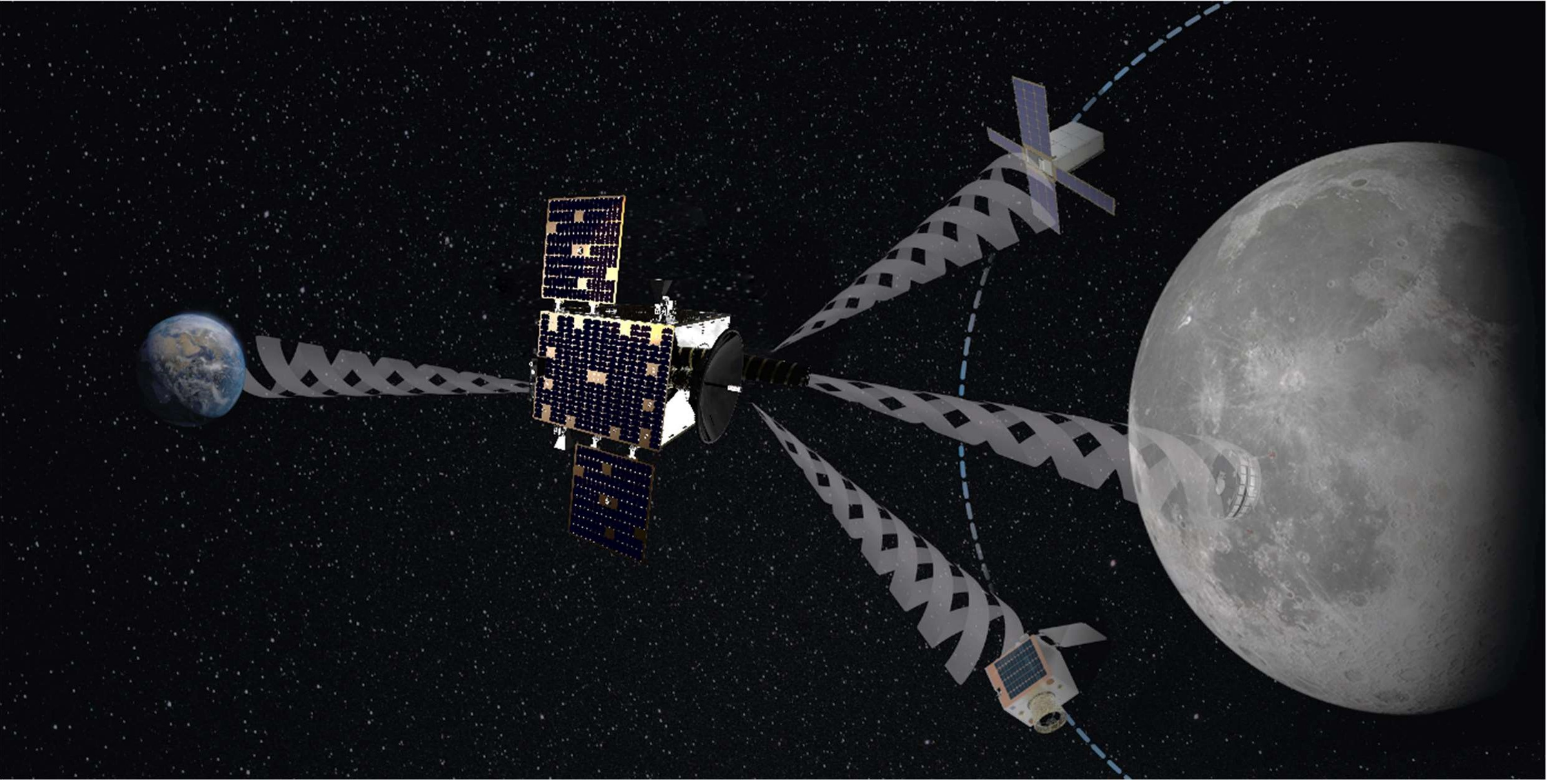
Phase 1:

Lunar Pathfinder - A single spacecraft in lunar orbit, offering communication services to any lunar asset (surface or orbiter). Due to launch end Q4 2024, the spacecraft will be fully operational in 2025 with a service duration of 8 years. This programme is supported by ESA under a commercial partnership programme.



Phase 2:

Moonlight – A constellation of satellites in lunar orbit which will provide communication and navigation services. Still in study phase, under ESA's Moonlight initiative, the constellation will offer an enhanced communication solution while providing lunar navigation capabilities.



Chapter 2

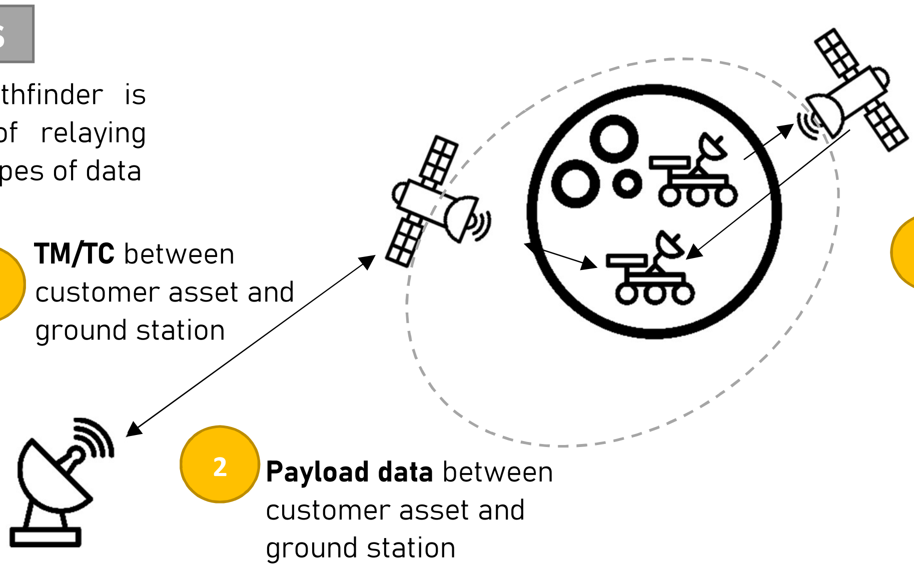
Concept of Operations

2 Concept of Operations

2.1 At a Glance

DATA TYPES

Lunar Pathfinder is capable of relaying various types of data



1 **TM/TC** between customer asset and ground station

2 **Payload data** between customer asset and ground station

3 **Point to point** exchange of data between lunar assets without involving earth station, via Lunar Pathfinder*.

*This service will not be available initially.

PROTOCOL

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

Lunar Pathfinder uses a **CCSDS Proximity-1** protocol for communication with customer assets with Proximity-1 V4 Transfer Frames in which the assets data will be encapsulated.

Benefits

- Works with **multiple assets in the same coverage area**
- Works with **assets of varying performance levels**

ENCRYPTION

The Moon Link Payload will **not** be encrypted. However the user data **can be** encrypted by the customer.

COMMUNICATIONS

Communication links between the customer asset and the data-relay spacecraft are established via **hailing**.

Store and Forward Architecture

- Autonomous or Scheduled data relay.
- Data is **stored** in the payload until links are **available**.

Benefits

- Commands can be sent to Lunar Pathfinder, destined for asset, even when asset **is not in view of Earth**
- Data can be **stored at ground station** until next access to Lunar Pathfinder
- 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** – users can work normal hours rather than having to wait for end-to-end links
- Data is stored within the SSTL Ground Segment not at the ground station

2.2 Lunar Pathfinder Service Operation Process

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 **Network Operations Centre (NOC)**. At each node in the system, data is stored until the next link becomes available. The following procedure describes the various steps of the communication service provision:

1. **Uplink data sent to Lunar Services NOC**
    - To command their spacecraft the user sends command files, or software patches, to the Lunar Services NOC, 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 NOC, with sufficient time for delivery to the asset prior to implementation – 24 hours in nominal operations.
2. **Uplink data sent to Lunar Pathfinder**
    - The commands are sent to the ground station from the Lunar Services NOC and then transmitted over the X-Band link to Lunar Pathfinder.
    - When the next data transfer session commences with Lunar Pathfinder, the commands are transmitted from ground and received by the Pathfinder spacecraft, which are subsequently stored in the data recorder of 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 is 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 service is being used then the link can be planned so that all of the data can be transferred during this access.
    - TM and Payload data can be received by the Moon Link payload while the link is active:
        - 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 Ground Station**
    - At the next opportunity of data transfer, the data stored on-board Lunar Pathfinder is transmitted to the ground station.

5. **Asset data to users**
    - Once the data is at the ground station, it is sent to the Lunar Services NOC over a VPN and is stored until it can be passed to the users.
    - The data is accessed by the users via Kiteworks.

Figure 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 shows the overall architecture, from the customer NOC to the customer lunar asset.

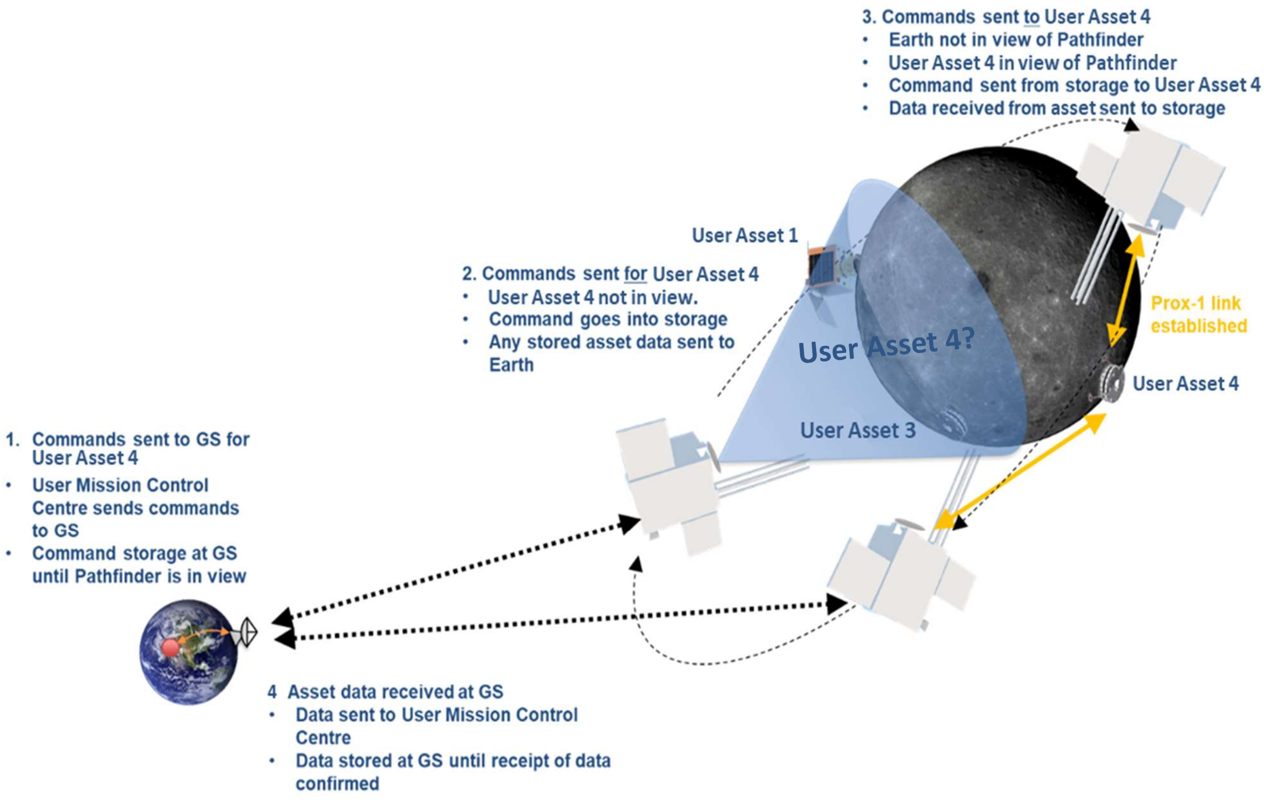


Figure 1: Lunar Pathfinder Data Transfer Process

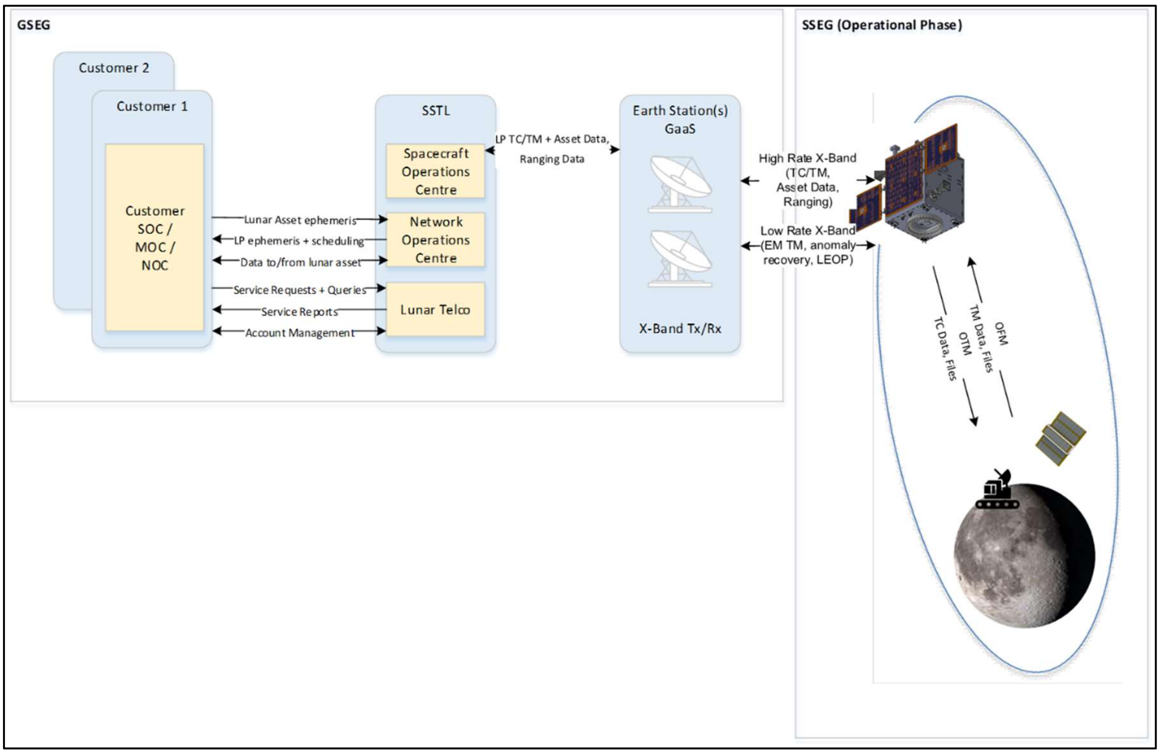


Figure 2: Overall Service Delivery Architecture

2.2.1 Lunar Pathfinder Hailing Operation

Communication links between the customer asset and the data-relay spacecraft are established via **hailing**. Pathfinder can work 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 in Figure 3.
- This process can be automated to optimise operational costs.

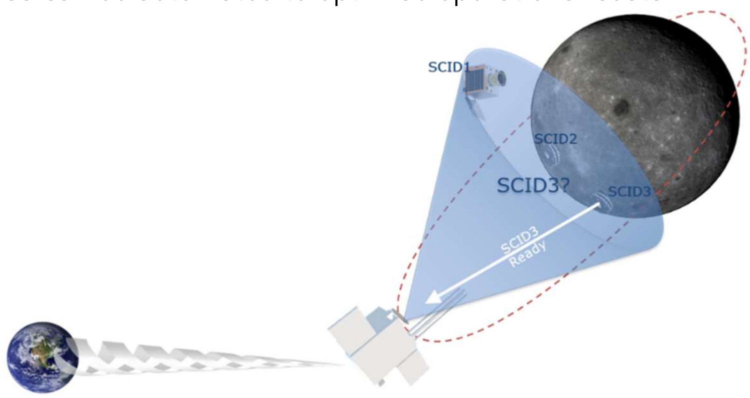


Figure 1: Lunar Pathfinder Hailing Operation

2.2.2 Addressing Varying Asset Performance Levels

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 can be **dynamically adjusted** over a link session as the signal strength changes to maximise data throughput, as shown in Figure 4
- The time when assets receive their allocation can be selected to provide better average data rate.

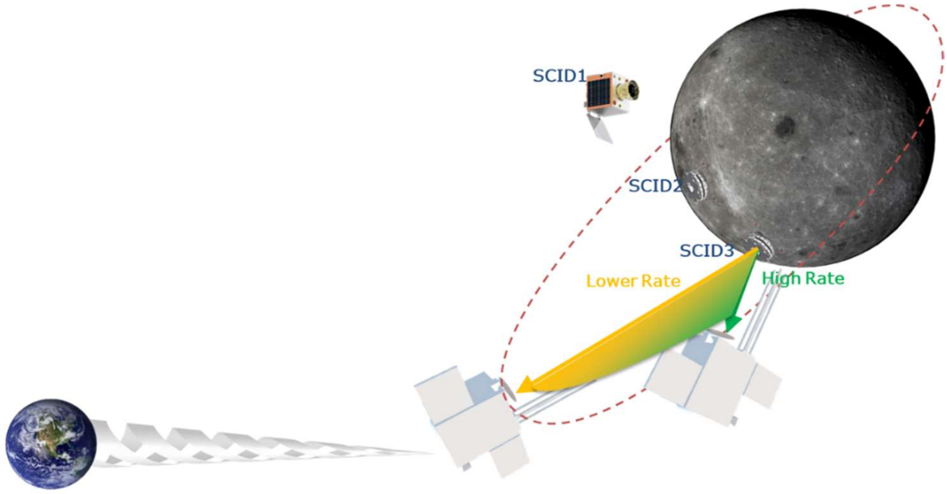
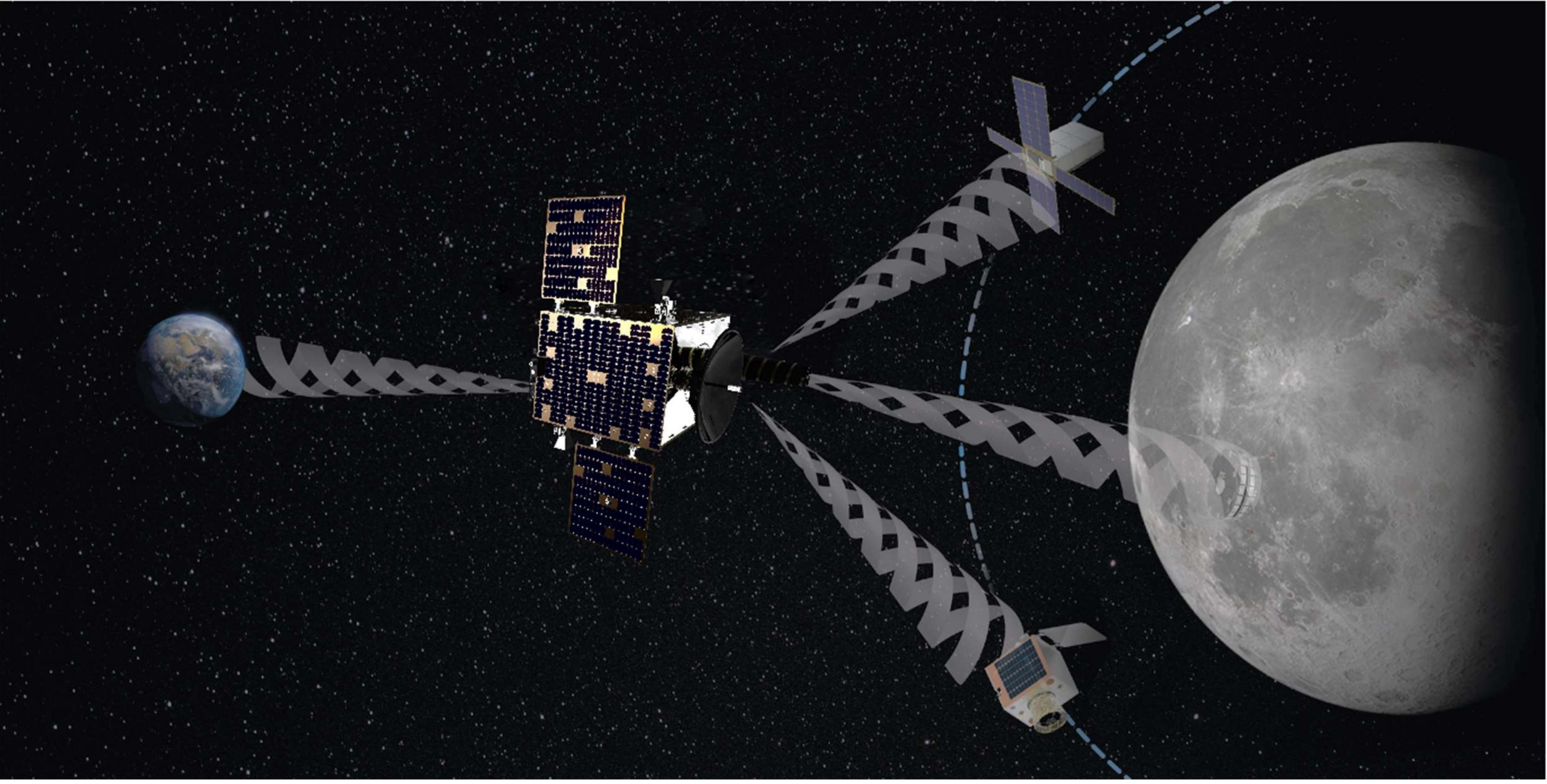


Figure 2: Dynamic data-rate adjustment vs range



Chapter 3

Service Overview

3 Service Overview

Lunar Pathfinder will be the first node of the Moonlight constellation, offering customers early commercial lunar communication services. It is designed with the objective of enabling lunar missions from companies, institutions, or universities to be carried out in a more efficient and cost-effective manner.

3.1 Mission Orbit

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

This orbit provides the long duration coverage of the **lunar southern hemisphere**, which is the initial hotspot of early lunar missions, due to its scientific and commercial potential. The **far side of the Moon** is also serviced by Lunar Pathfinder in this orbit, enabling support for those missions that have zero access to direct to Earth (DTE) communication.

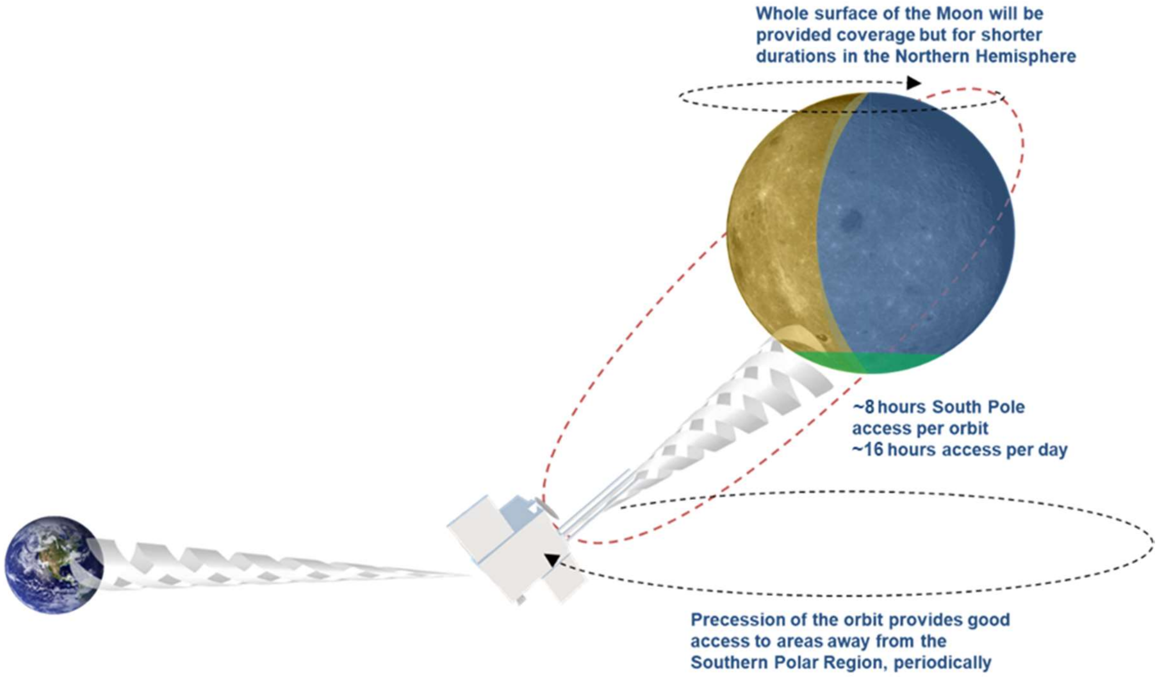


Figure 5: Lunar Pathfinder mission orbit

3.2 Coverage

Depending on the location of the user asset, the **coverage by Lunar Pathfinder will vary** as shown in this section.

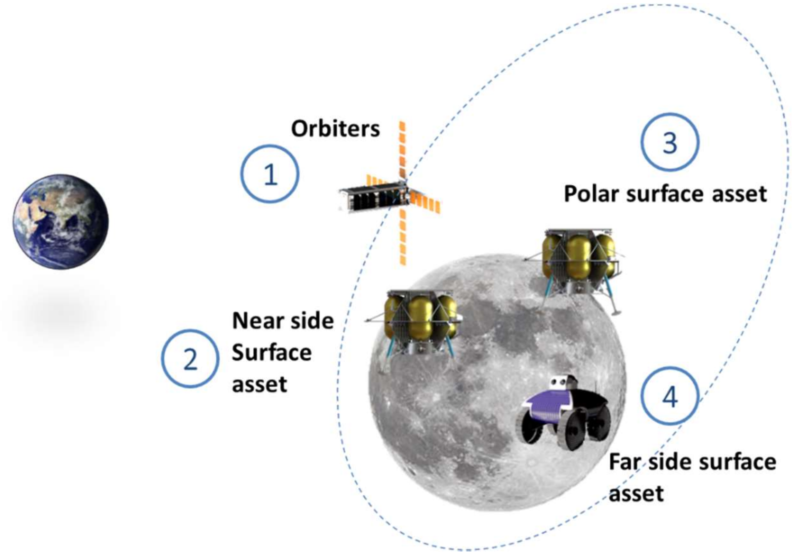


Figure 6: Potential customer asset locations

The following provides an assessment of the coverage of the lunar surface in terms of line of sight to Lunar Pathfinder.

An example of the coverage over a 14 Earth day period can be seen in Figure 7 and Figure 8. Figure 7 looks at the **maximum revisit time** over this period. Revisit refers to gaps in visibility of Lunar Pathfinder from an asset's location.

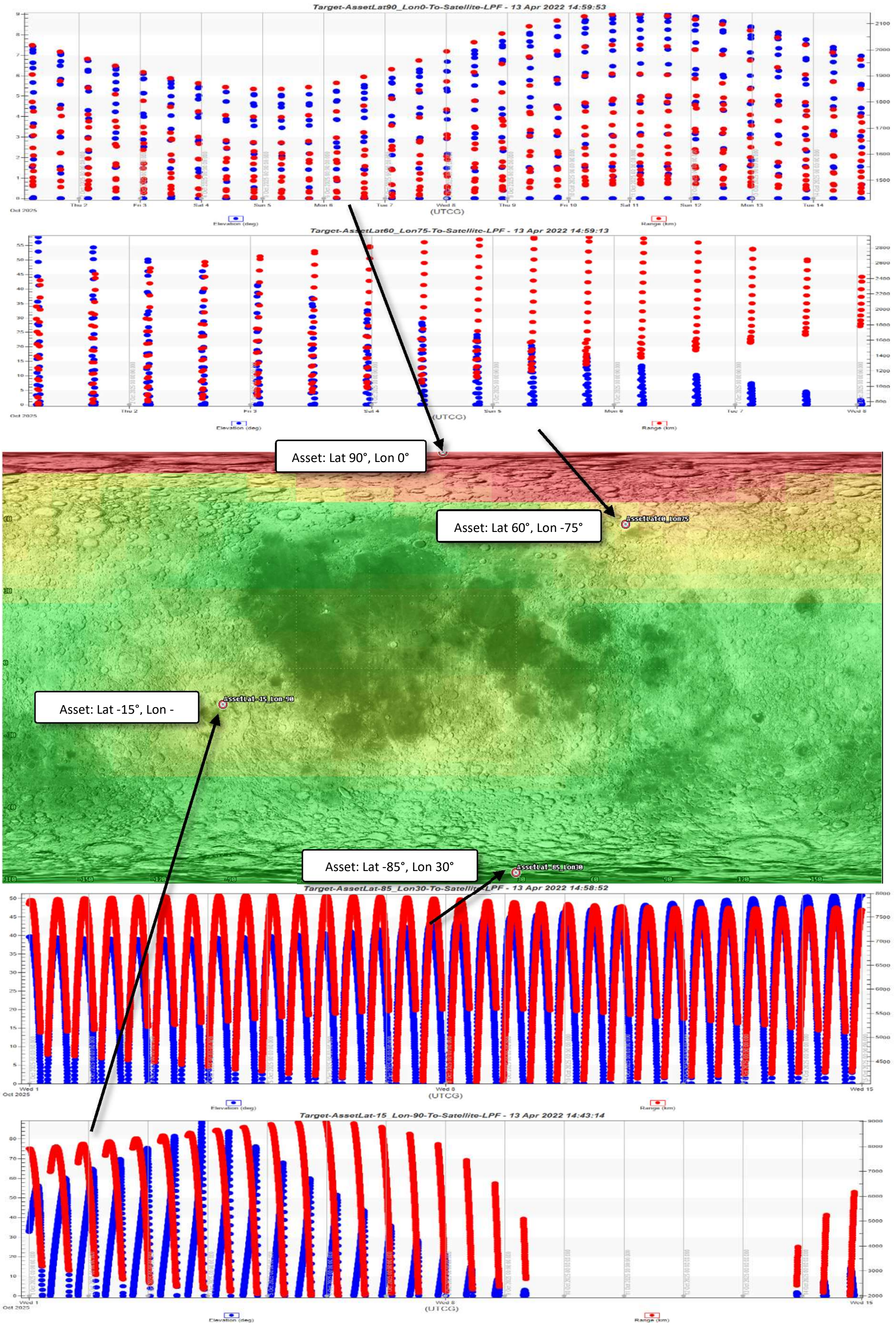


Figure 7: Maximum revisit time over a 14 day Earth period. Elevation and range of Lunar Pathfinder from 4 locations have also been plotted to further explain the nature of the coverage gaps.

Figure 8 shows the total amount of time that Lunar Pathfinder **is accessible during this example 14 day period**. The lower coverage time will be partially compensated, in the northern hemisphere, by the **higher data rates** achievable at **shorter ranges**.

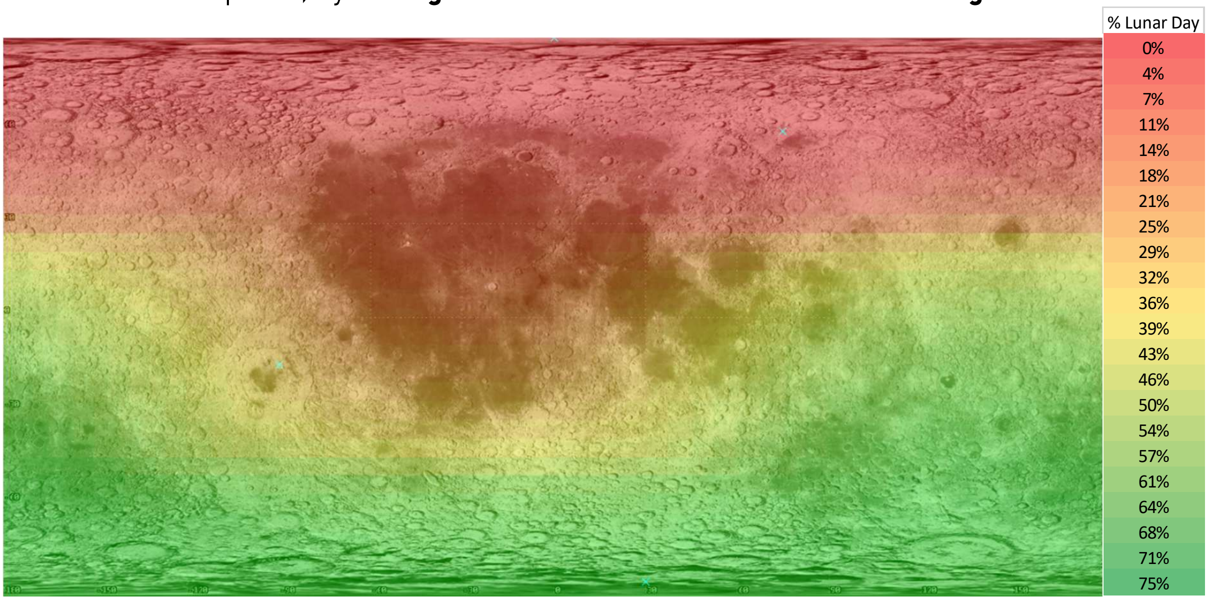


Figure 8: Example of total coverage time over a 14 Earth day period (% of the analysed time period, 14 days)

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 9 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.

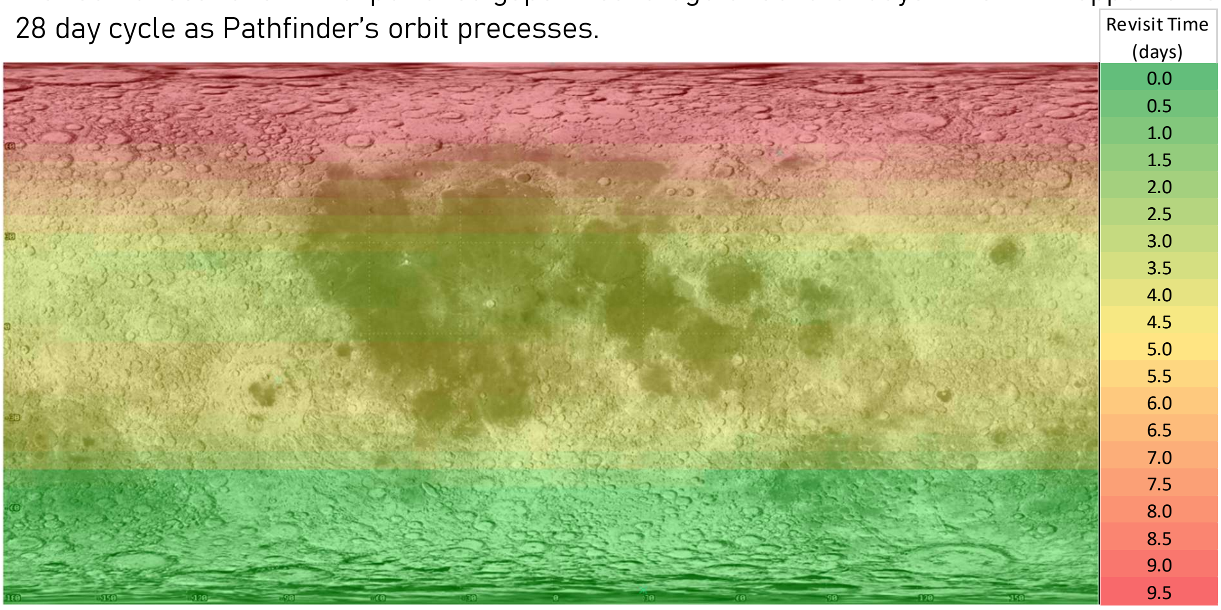


Figure 9: Maximum revisit time over 1 year

Figure 10 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 9 as most all locations will receive frequent accesses when not in the gap periods as can be seen in Figure 7.

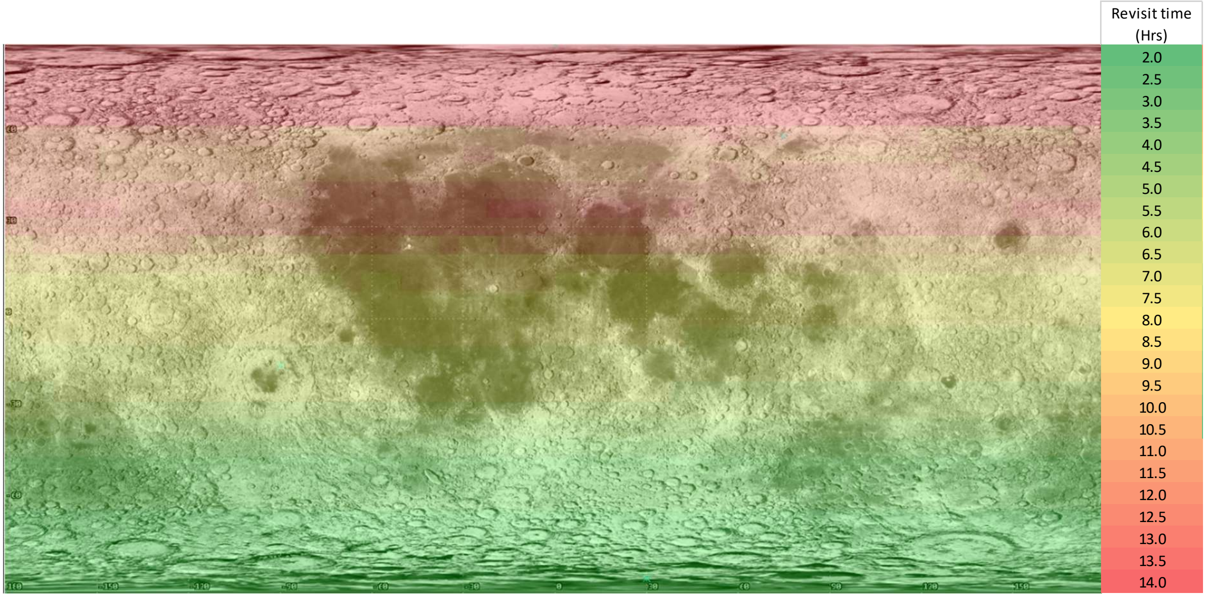


Figure 10: Average revisit time over 1 year.

3.3 Communications Payload

Lunar Pathfinder offers **2 simultaneous channels of communication** to lunar assets:

1. S-band
2. Ultra-High Frequency (UHF).

Data is then relayed back to Earth ground station in **X-band**. Figure 11 shows links and associated bands and frequencies.

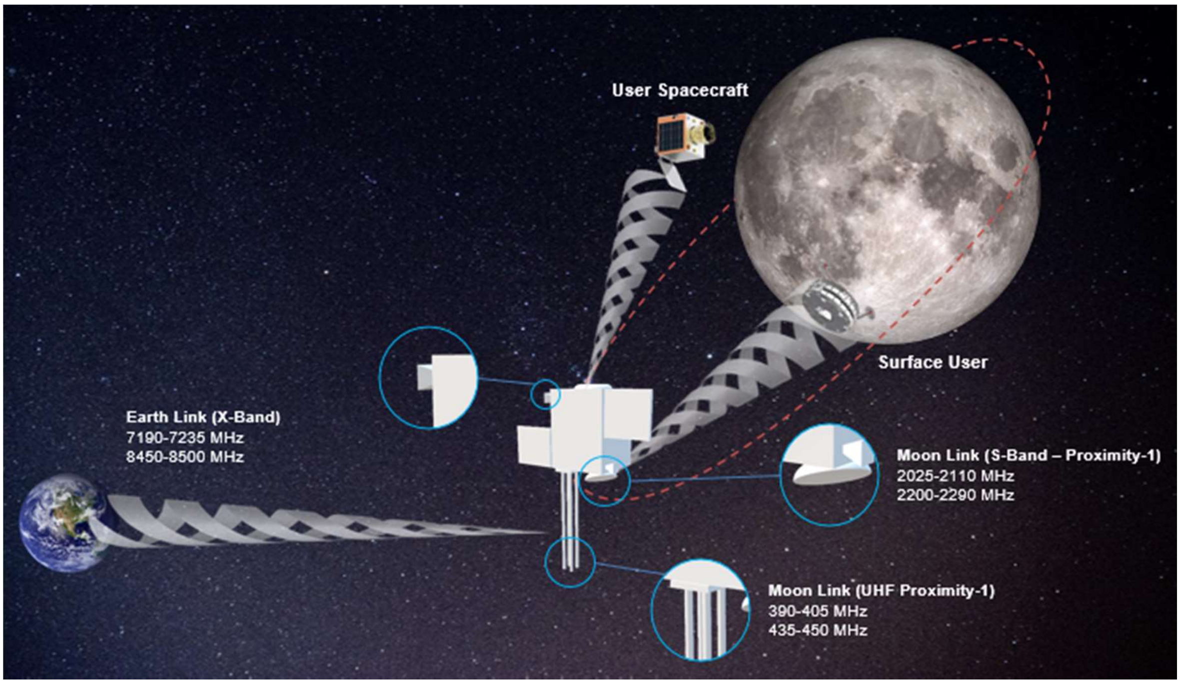


Figure 3: Lunar Pathfinder Earth and Moon links

Table 3-1: Lunar Pathfinder Specifications

Link Type	Channel Band	Forward Frequency	Forward Data Rate	Return Frequency	Return Data Rate
Moon	S-band	2025-2110MHz	0.5kbps-2Mbps* *Dependent on asset performance	2200-2290MHz	0.5kbps-2Mbps
Moon	UHF	390-405MHz	0.5kbps-2Mbps* *Dependent on asset performance	435-450MHz	0.5kbps-2Mbps
Earth	X-band	7190-7235MHz	Up to 30kbps	8450-8500MHz	≤ 5Mbps

3.4 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 service** 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 a 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 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.

3.4.1 Lunar Pathfinder Spacecraft Radio Frequency Interfaces

The Radio Frequency (RF) Interface is shown in the tables below. Please note that the S-Band Physical Layer definitions provided below include additional modulation and coding functionality above that in the Proximity-1 standard. These are provided to allow for efficient use of the S-band spectrum.

Table 3-2: LP Moon Link RF Interface

	UHF Forward Link (OTM-U)	UHF Return Link (OFM-U)
Frequency	390 – 405 MHz	435 – 450 MHz
Polarisation	RHCP	RHCP
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	Variable, as per Table 3-3	Variable, as per Table 3-3
Useful data rate	Variable, as per Table 3-3	Variable, as per Table 3-3
EIRP & G/T at HPBW	> 7.85 dBW @ θ = 38.7°	> -22.47 dB/K @ θ = 36.8°

	S-band Forward Link (OTM-S)	S-band Return Link (OFM-S)
Frequency	2025-2110 MHz	2200-2290 MHz
Polarisation	RHCP	RHCP
Modulation	PCM(SP-L)/PM or GMSK	PCM(SP-L)/PM or GMSK
SP-L Modulation index	1.047 rad	1.047 rad
SP-L Modulation index variation	± 5%	± 5%
GMSK BT Product	0.25	0.25
Coding	Uncoded OR Convolutional (r=1/2, k=7) OR LDPC (r=1/2, k=1024) OR LDPC (r=2/3, k=4096)	Uncoded OR Convolutional (r=1/2, k=7) OR LDPC (r=1/2, k=1024) OR LDPC (r=2/3, k=4096)
Symbol rate	Variable, as per Table 3-3	Variable, as per Table 3-3
Useful data rate	Variable, as per Table 3-3	Variable, as per Table 3-3
EIRP & G/T at HPBW	>20.14 dBW @ θ = 7.1°	>-10.13 dB/K @ θ = 6.1°

3.4.2 Data Rates

The data rates in Table 3-3 are presented for uncoded links and links coded convolutional or with LPDC

Table 3-3: Moon link symbol/data rates

Prox-1 Coded Symbol Rates (R_{cs}) [b/s]	Prox-1 Uncoded Data Rates (R_d) [b/s]	Prox-1 Convolutionally Coded Data Rates (R_d) [b/s]	Prox-1 LDPC r=1/2 computed data rates (R_d) [b/s]	Prox-1 LDPC r=2/3 computed data rates (R_d) [b/s]
1000	1000	N/A	N/A	N/A
2000	2000	1000	969.6969697	1319.587629
4000	4000	2000	1939.393939	2639.175258
8000	8000	4000	3878.787879	5278.350515
16000	16000	8000	7757.575758	10556.70103
32000	32000	16000	15515.15152	21113.40206
64000	64000	32000	31030.30303	42226.804124
128000	128000	64000	62060.60606	84453.608247
256000	256000	128000	124121.2121	168907.21649
512000	512000	256000	248242.4242	337814.43299
1024000	1024000	512000	496484.8485	675628.86598
2048000	2048000	1024000	992969.697	1351257.7320
4096000	4096000	2048000	1985939.394	2702515.4639

Note:

- The achievable symbol rate will depend on link margin and available spectrum.
- The coded symbol rate may change to a different value during a communications session via a COMM_CHANGE directive sent from LP to an Asset or vice-versa but will always be one of the data rates specified in Table 3-3.

3.4.3 Lunar Pathfinder Orbital Parameters

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. The orbit ephemeris will be **updated daily** and made available to the user via the Kiteworks interface.

Item	Value
Semi major axis (km)	5740
Periselene altitude (km)	673
Aposelene altitude (km)	7331
Eccentricity	0.58
Inclination (deg)	54.856
RAAN (deg)	0
Argument of Pericenter (deg)	86.322

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

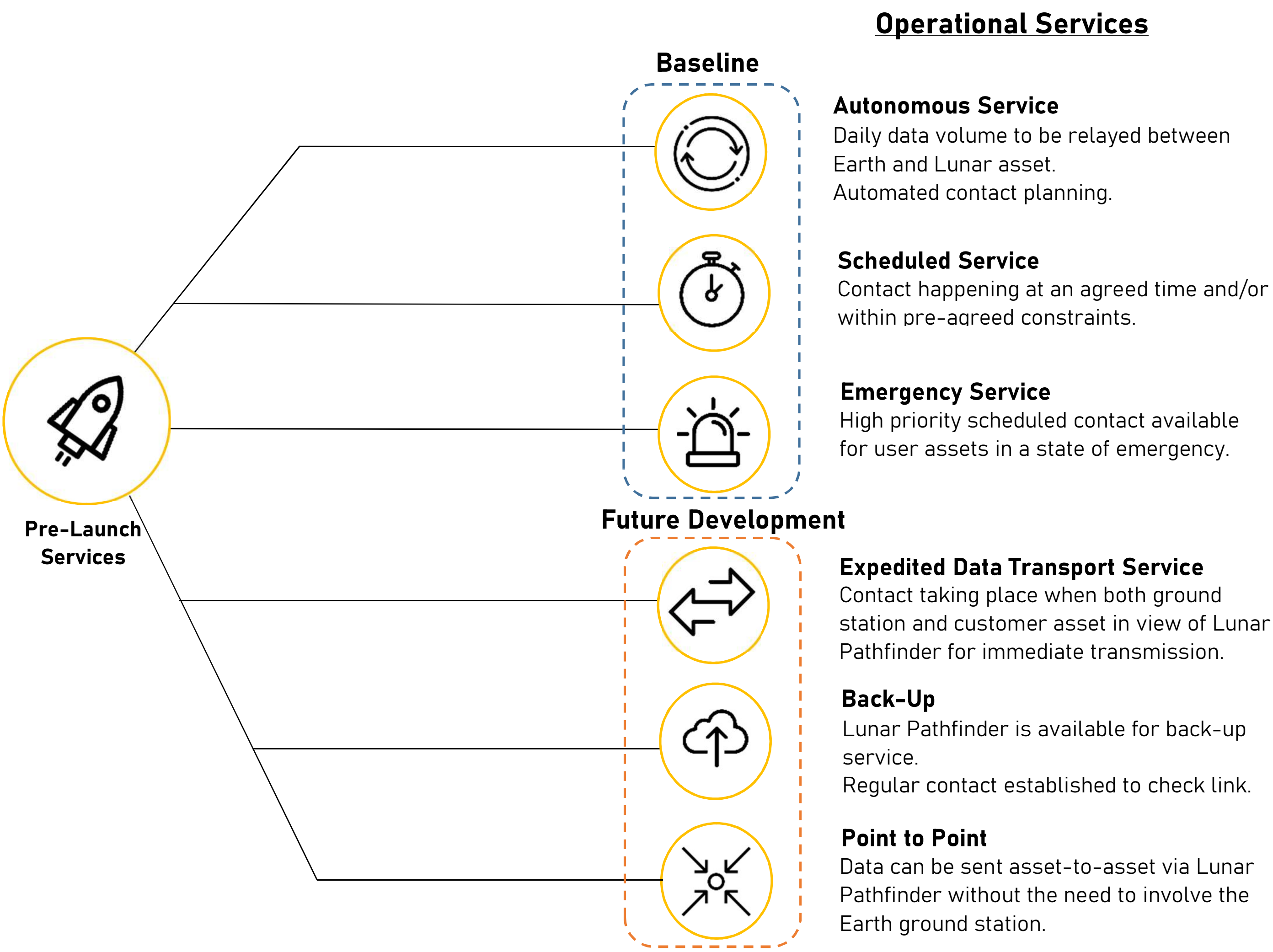
The orbit has been designed to primarily favour servicing missions at the Lunar South Polar Region as this location is of key interest due to the geological properties in the region and the presence of large permanently shadowed crates containing volatiles.

This being said, missions 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**.

3.5 Lunar Pathfinder Service Options

Lunar Pathfinder offers a range of communication service options, allowing customers to choose the solution best suited to their mission.

All service packages include a **pre-launch service** (defined in Section 5.1), 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**.



3.5.1 Baseline Services

3.5.1.1 Autonomous Service

What is it?

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.

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

What is included?

- Pre-Launch Services
- 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.

3.5.1.2 Scheduled Service

What is it?

Some missions may require a more dedicated service from Lunar Pathfinder, which is provided 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.

The mission plan will give priority to the customers of the Scheduled Service package over the Autonomous Service package ones over the agreed period.

What is included?

- Pre-Launch Services
- 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.

3.5.1.3 Emergency Service

What is it?

The Emergency Service provides a faster re-tasking of ground and space segment to prioritise communications to a user asset experiencing an emergency. As soon as the user determines that their asset is in an emergency state, the user will be able to request emergency support. This service is effectively the Scheduled Service with a top priority contact.

What is included?

- Pre-Launch Services
- Operational Services:
  - A high priority re-tasking of ground and space segment enabling rapid contact scheduling to communicate with an asset in an emergency state.

3.5.2 Services in Development

3.5.2.1 Expedited Data Transport Service

What is it?

The Expedited Data Transport service represents the highest level of performance within the Scheduled Service package. When allowable, it guarantees that at the time the customer asset is contacted by the Lunar Pathfinder, the latter has already established a link with an Earth Ground Station. This enables Pathfinder to forward data to and from the asset as soon as it has been received by Pathfinder enabling the lowest latency service for the link.

At the start of Lunar Pathfinder operations, Expedited Data Transport service availability will be constrained by Earth Ground Station coverage. Starting with 1 ground station, this service will be limited in availability until Earth Ground Station coverage is ramped up.

What is included?

- Pre-Launch Services
- Operational Services:
    - 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.

3.5.2.2 Back-Up Service

What is it?

This is the minimum service 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.

What is included?

- Pre-Launch Services
- Operational Services:
    - Regular hailing of 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.

3.5.2.3 Point to Point Service

What is it?

The Point2Point service will allow users to send data to other assets in the lunar environment without first sending the data to Earth. The service will allow a user to send data addressed to a particular asset. This data will be stored on-board Pathfinder. During the next available access the data will be transferred to the receiving asset.

What is included?

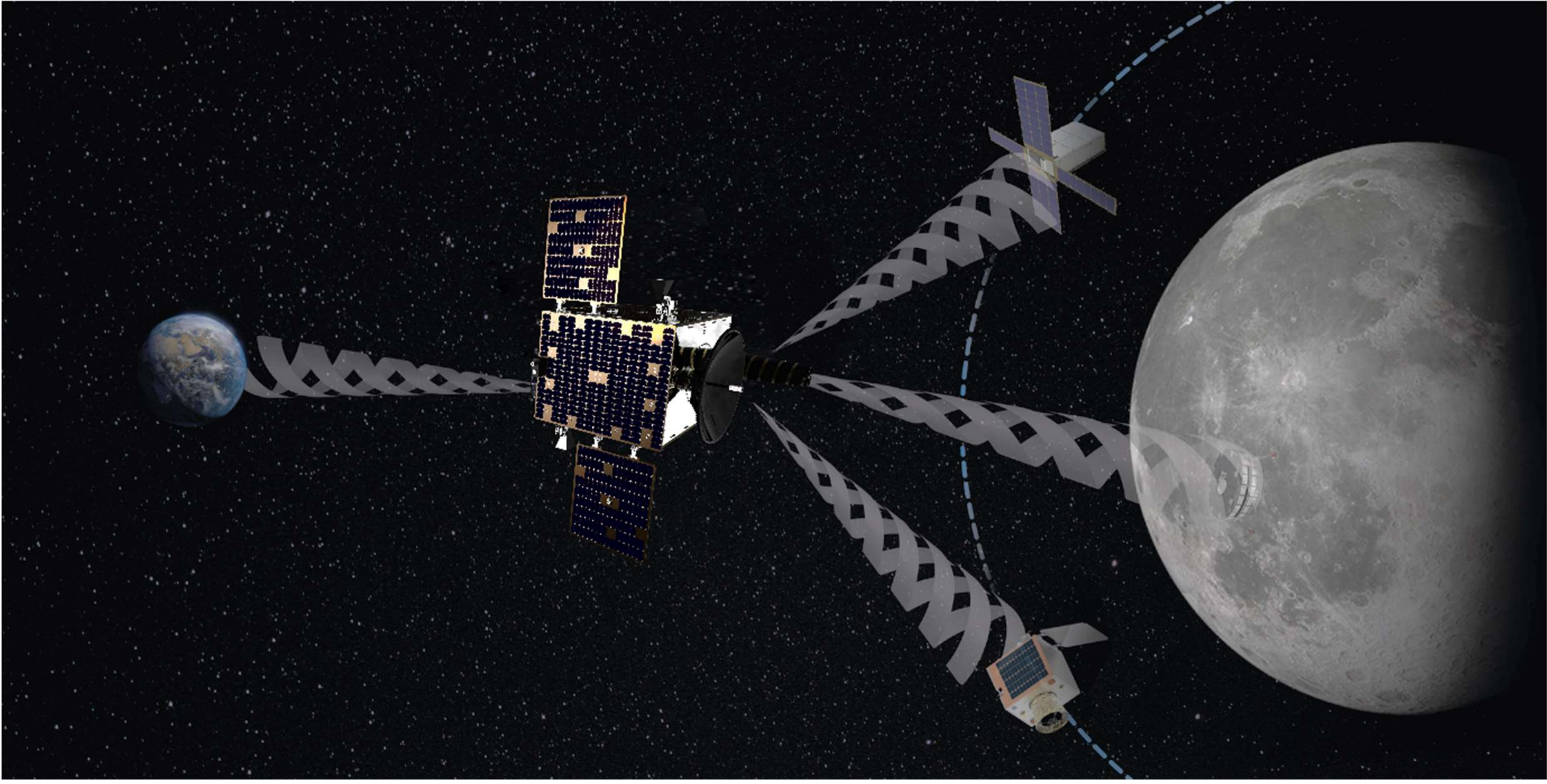
- Pre-Launch Services
- Operational Services:
    - Involves passing data between assets via the Moon Link only.

- This service product would be suited to missions involving the coordination of two or more assets beyond their line of sight.

3.6 Ground Segment

Depending on the service need, Lunar Pathfinder will use several ground stations, appropriately distributed around the Earth. The ground station network employs antenna from all over the world, run by Kongsberg Satellite Services (KSAT), Goonhilly Earth Station (GES) and the Indian Space Research Organisation (ISRO).

Figure 12: (From left to right) Goonhilly Earth Station, India DSN Antenna, and Kongsberg Satellite Services



Chapter 4

User Case Scenarios

4 User Case Scenarios

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.

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.

4.1 User Case #1 – Surface Landers

This user case is geared towards customers wishing to use lunar communication 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 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. For this analysis the RF performance was assumed to be within the following range: EIRP between 21.5 and 26.5 dBW, and G/T between -19.2 and -11.5dB/k.

<u>User case assumptions:</u>

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 enters 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**
  - 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

4.2 User Case #2 - Autonomous Rover

This user case is geared towards customers wishing to use lunar communications services for autonomous rovers. A good example in 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. For this analysis the RF performance was assumed 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 4.1.

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

4.3 User Case #3 - Tele-Operated Rover

This user case is geared towards customers wishing to use Lunar communications 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 communications 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		-6	dB/K

User case performance:

Note: Explanation of the terms in the user cases are provided in User Case #1 in Section 4.1

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

4.4 User Case #4 – CubeSat

This case looks at a CubeSat mission in a LLO with a 100km polar orbit. This type of orbit is likely to be popular for missions 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		-23.4	dB/K

User case performance:

Note: Explanation of the terms in the user cases are provided in User Case #1 in Section 4.1.

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.

4.5 User Case #5 – Lander on the North Pole

In the case of a lander at the North Pole the same assumptions as 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

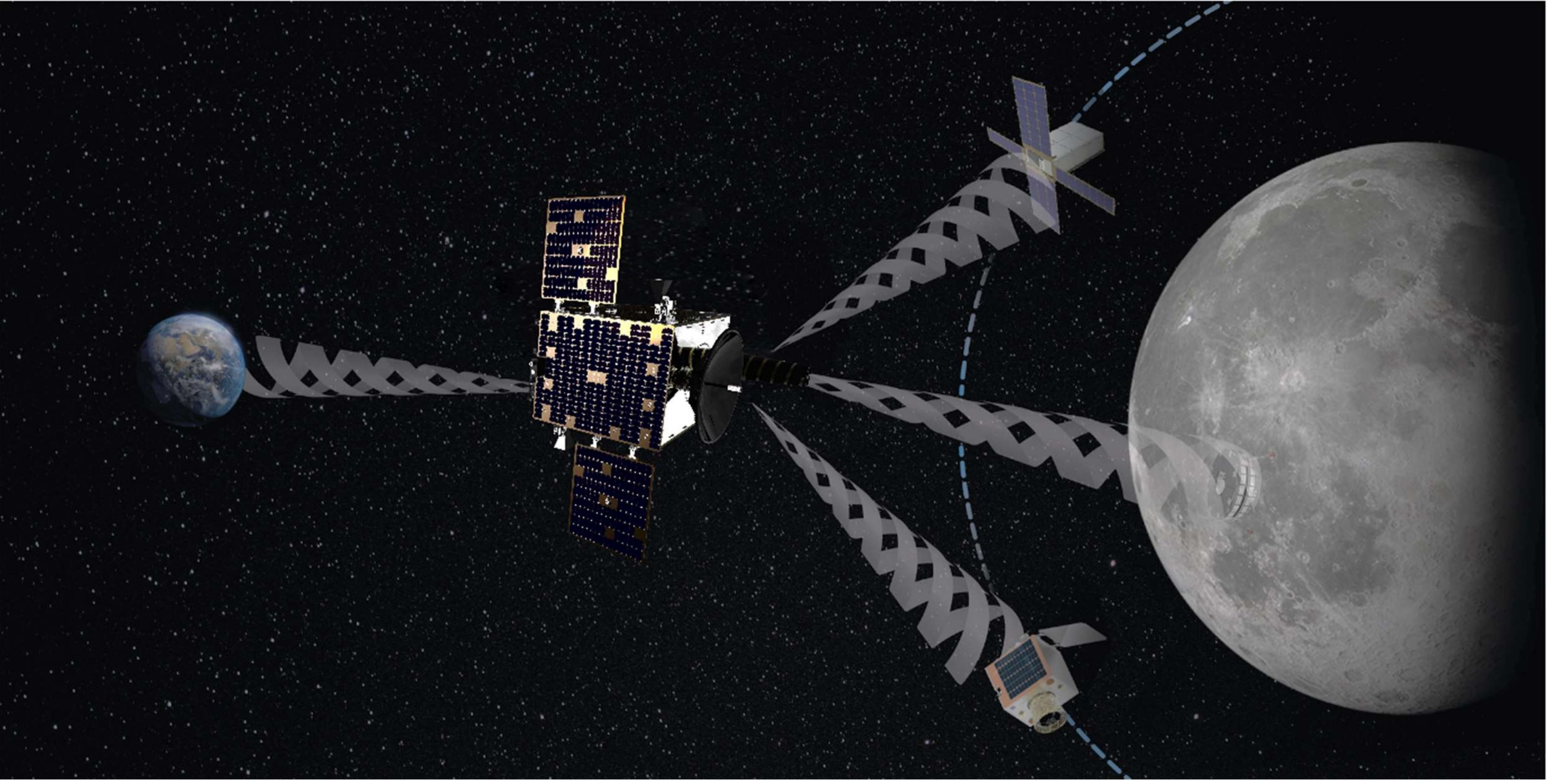
This scenario assumes that the mission is receiving dedicated "scheduled" service. Indeed this specific location requires the operations of Lunar Pathfinder in order to be serviced.

<u>User case performance:</u>

Note: Explanation of the terms in the user cases are provided in User Case #1 in Section 4.1.

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 compared to 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.



Chapter 5

Support Services

5 Support Services

5.1 Pre-Launch Support and Link Commissioning for Customer Asset

Prior to contract signature for Lunar Pathfinder 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 Interface Compatibility Design review will be held, in which SSTL engineers review documentation to assess the design of the user's mission and spacecraft regarding compatibility with 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. An SSTL team will be sent to the user's facility to conduct the testing.
- Test Readiness Review with SSTL engineers will mark the start of a 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 Review Board the user's asset will be clear to use the system pending successful link commissioning in orbit, or on the surface, of the Moon.

After successful launch of the asset, and once it has reached the phase of its mission in which the User's service Package is intended to start, 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 mission before commencing the service package delivery. Commissioning activities will test the precise functionalities of the chosen service package. The specific tests will be dependent on the exact nature of the service package and will be pre-agreed through discussions with SSTL engineers during the design and testing phases.

5.1.1 Enhanced Mission Planning Services

In the process of acquiring their service package, SSTL Lunar can work with the user to assess 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.

5.2 Engineering Support and Customer Services

In order to provide each customer with the support they need throughout the duration of the mission, a Service Management Solution has been designed in line with the ITIL v3 Service Lifecycle best practice. This will standardise the planning, delivery, maintenance and lifecycle management of the service with the objective of maintaining and improving its reliability, predictability and efficiency.

The Service solution incorporates the required mechanisms to measure, monitor and report on CLMSS service and capability performance, using agreed and consistent service performance reporting parameters, thus ensuring the quality of the delivered CLMSS services.

Figure 13 illustrates the Service Operating Model. The operational processes and functions that will assure the service product throughout its lifecycle will be as follows:

- **Service Desk**
  The Service Desk provides a Single Point of Contact (SPOC) for all customer service related incidents and queries. This will provide rapid troubleshooting, delivering enhanced efficiency and a seamless operating experience.
- **Service Request Management**
  Fulfilment of all pre-defined, user-initiated service requests in an effective and user-friendly manner, allowing transparency and assurances to the customer that their request is under action.
- **Incident Management**
  Restoration of normal service operation as quickly as possible minimising the impact on Mission operations, thus ensuring that the best possible levels of service quality and availability are maintained.
- **Problem Management & Trend Analysis**
  Reducing the likelihood and impact of incidents by identifying actual and potential root causes of incidents, and managing workarounds and known errors. Defining these patterns will aid in predicting future incidents and resolving them before they arise for the customer.
- **Configuration Management**
  Defines and controls the components of the service and infrastructure while maintaining an accurate view of the historical, current and future planned state of the service assets. This supports all the other service management processes and functions.
- **Change, Release and Deployment Management**
  Minimises the risk associated with Changes, where there is addition, modification of removal of anything that could have an effect on CLMSS service. This ensures an uninterrupted delivery of service to customers during any system changes.
- **Capacity Management**
  Ensures that all relevant resources, technical, organisational and procedural, are sufficient to meet upcoming business requirements cost-effectively. This holistic approach allows the optimisation of operations, providing the highest possible levels of service to the customer.

- **Availability Management**
  Ensures that services deliver agreed levels of availability to meet the needs of the customers and users so that they will match the present and future requirements of the customer mission.
- **Security Management**
  Ensures the services are secure and accessible only by authorised personnel, identifies any security vulnerabilities, and monitors for intrusion. This will safeguard the integrity and availability of customer data, allowing them to procure the service with the utmost confidence.
- **Service Reporting**
  Provides the mechanism to measure, monitor and report on the CLMSS IT service performance capability performance, using agreed and consistent service performance reporting parameters.
- **Continual Service Improvement**
  Ensures that customer pain points are addressed, while services are optimised and continually aligned to the changing business and customer needs.

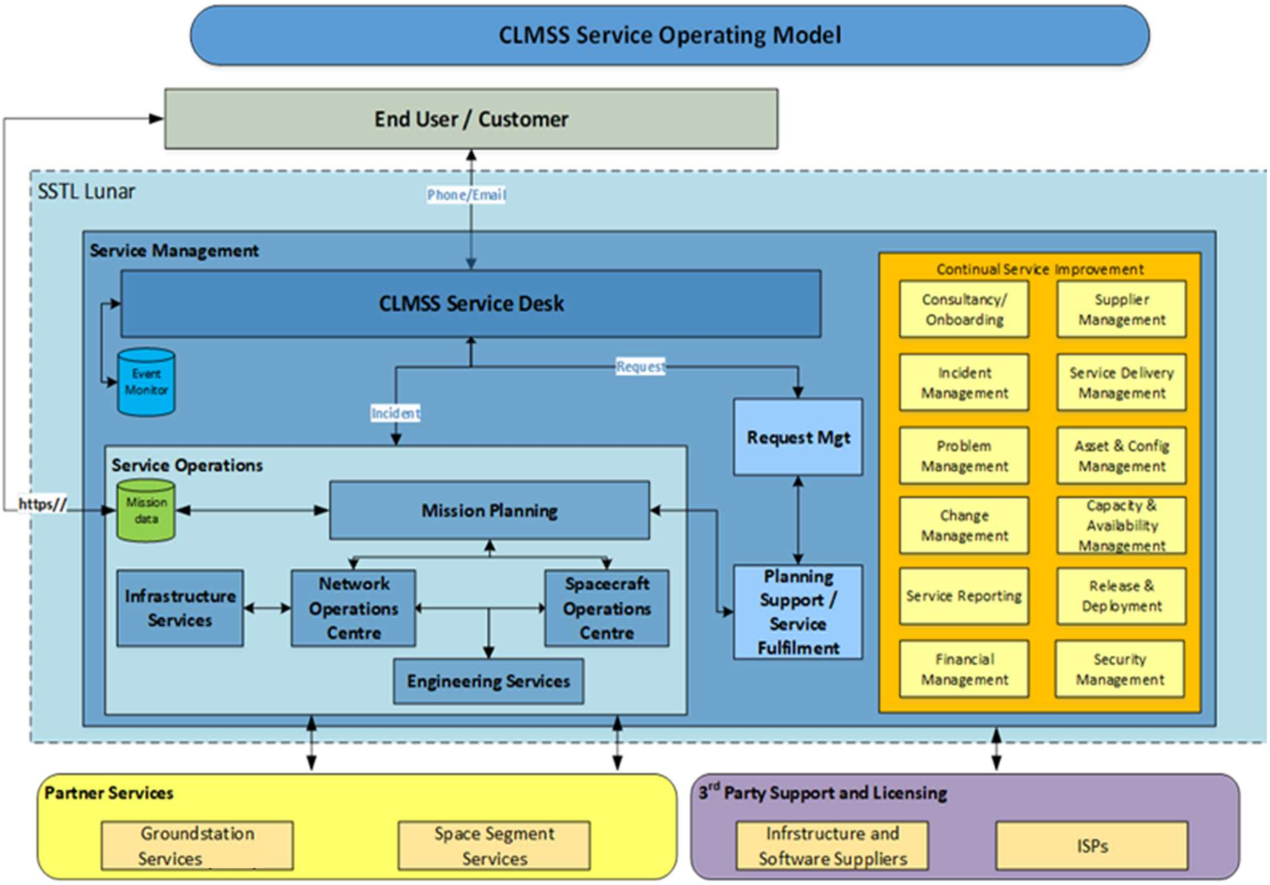
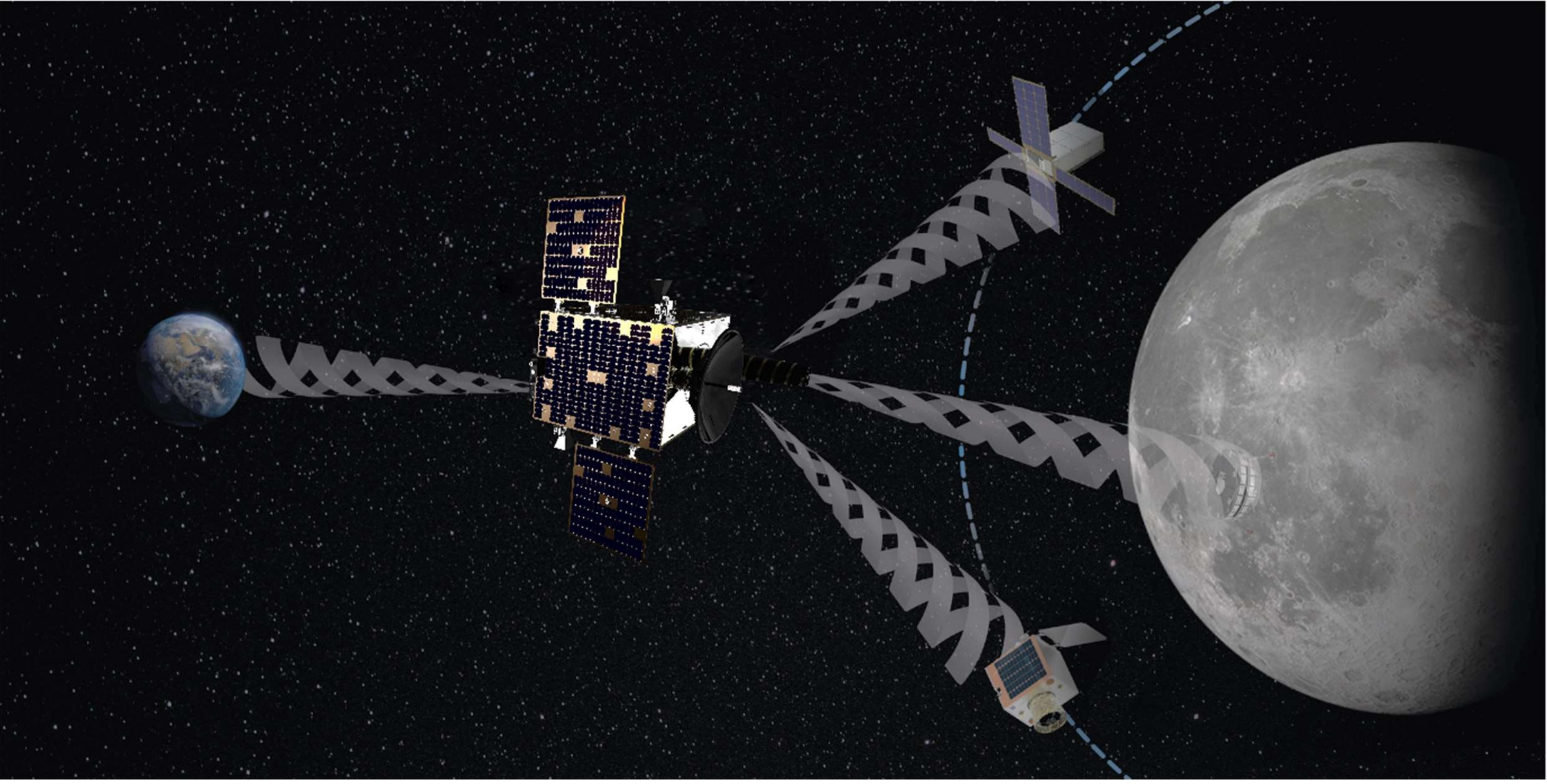


Figure 13: Lunar Pathfinder Operating Model



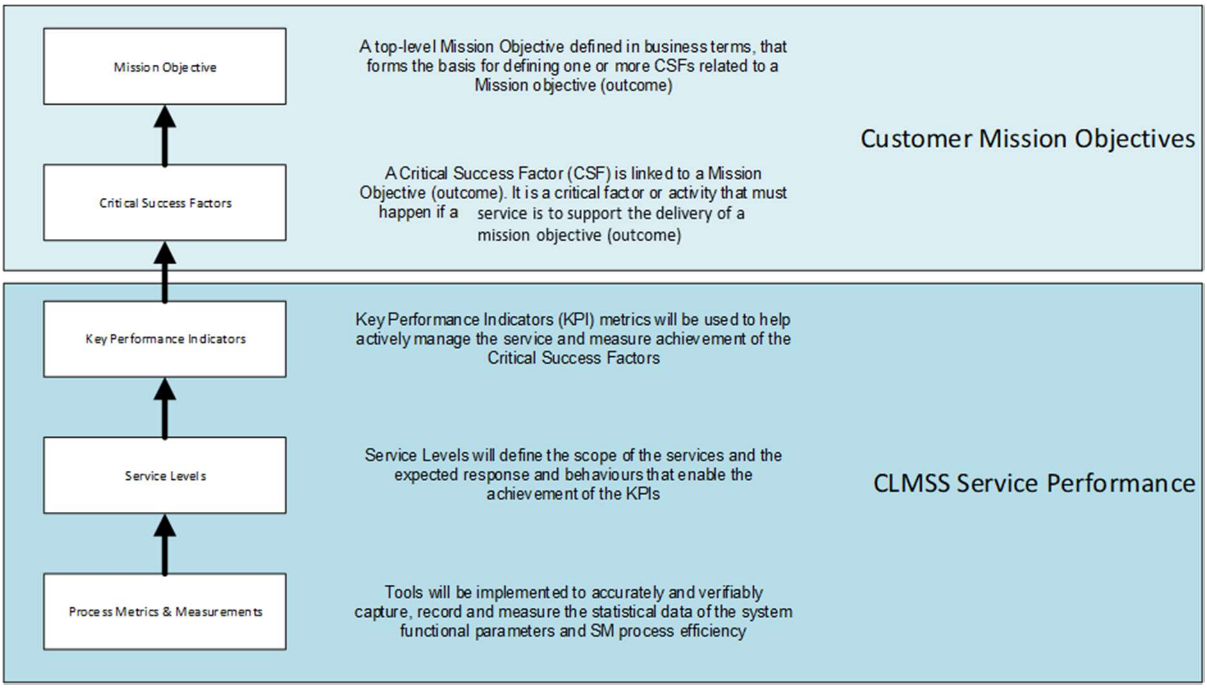
Chapter 6

Service Level Agreements

6 Service Level Agreements

A set of service level agreements (SLA) will be in place for each of the service products offered by Lunar Pathfinder. These Service Levels and Key Performance Indicators (KPI) will be tailored, and agreed with each customer, in order to meet the specific requirements and critical success factors of each Mission.

Each SLA and KPI will be measured and reported throughout the Service duration to ensure that the delivered product is meeting or exceeding its quality expectations.



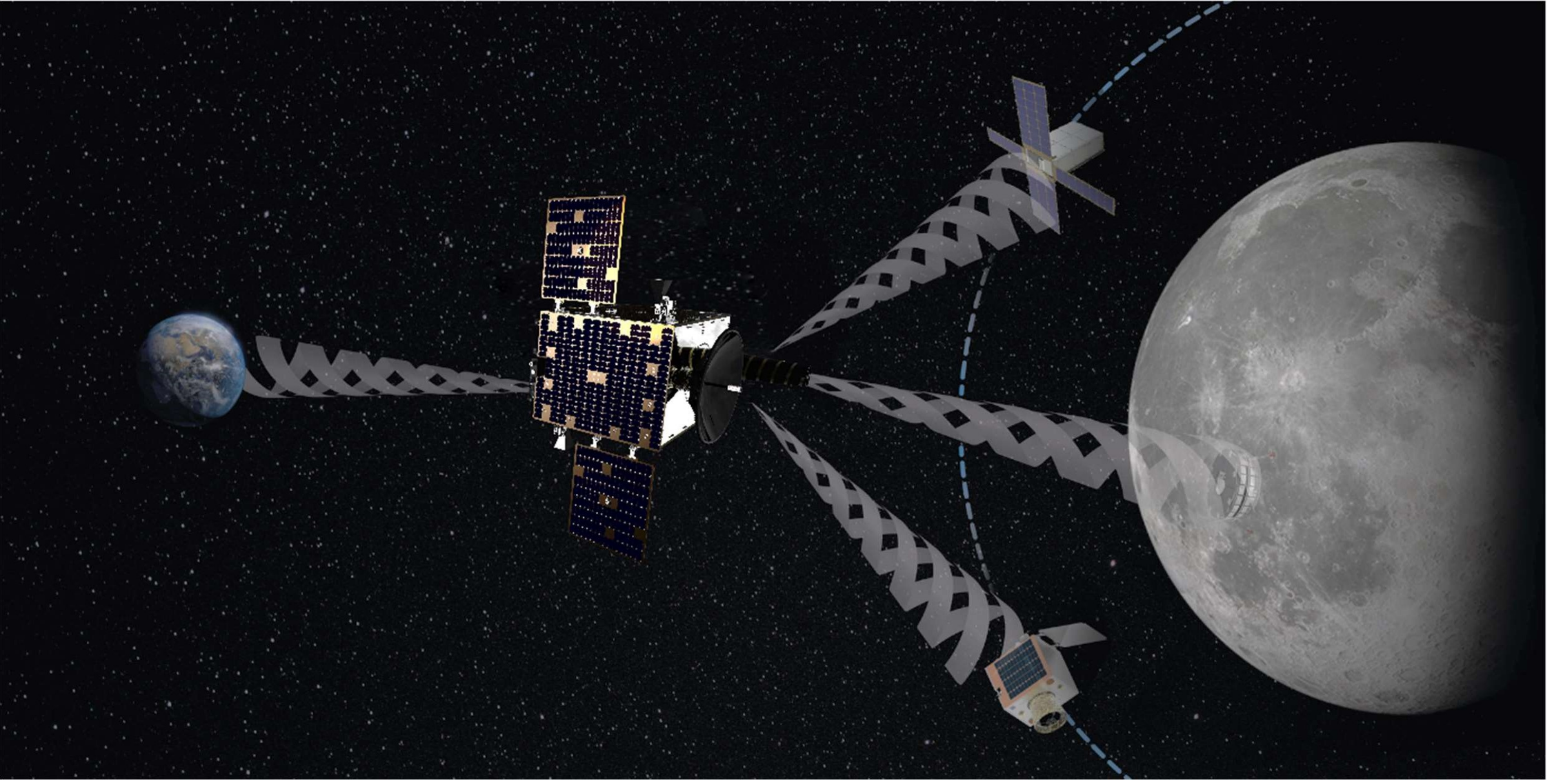
Examples of the identified key functional KPIs that will be common across most services will be:

KPI/PI Ref	KPI/PI title	KPI/PI description
KPI (Critical)	Availability	Achieved Service Availability (calculated as a percentage) over the accumulated planned contact durations, within a KPI reporting period.
KPI (Critical)	Forward End-to-End Latency	The point at which initiation of the uplink transmission from the Ground Station begins, to the point at which the signal transmission from the Lunar Pathfinder spacecraft ends
KPI (Critical)	Return End-to-End Latency	The point at which the user asset data file is closed (received) on-board Lunar Pathfinder, to the point at which the closed data files(s) are transferred to the user data exchange facility (data exchange shall be timestamped, and end-time shall be calculated from this)
KPI (Critical)	Forward Data Volume	Successfully achieved data transfers (i.e. agreed data volumes) completed in the forward direction.
KPI (Critical)	Return Data Volume	Successfully achieved data transfers (i.e. agreed data volumes) completed in the return direction.

The above KPIs are not exhaustive and additional measures can be agreed, to support specific Mission objectives, subject to negotiations and agreements between parties.

In addition to the above functional measures, non-functional KPIs and SLAs will be implemented to ensure that the Customer Support Services provide the responsiveness and support the customer needs for the duration of the service. Examples are provided below:

KPI/PI Ref	KPI/PI title	KPI/PI description
PI	Contact Response	Percentage of responses to initial customer contact achieved within SLA
PI	P0 & P1 Incident Service Restoration	Percentage of P0 & P1 Incidents resolved within agreed SLA
PI	P2 Incident Service Restoration	Percentage of P2 Incidents resolved within agreed SLA
PI	P3&4 Incident Service Restoration	Percentage of P3&4 Incidents resolved within agreed SLA
PI	Emergency Service Request Fulfilment	Percentage of Emergency Service Requests fulfilled within agreed SLA
PI	Problem Workaround	Time to implement Workaround
PI	Problem Fix	Time to implement Fix
PI	Change Success	Number of unsuccessful Changes within Change reporting period
PI	Reporting	Production of Service report within 10 days of end of Reporting Period measured Annually



Chapter 7

Contact Us

7 Contact Us

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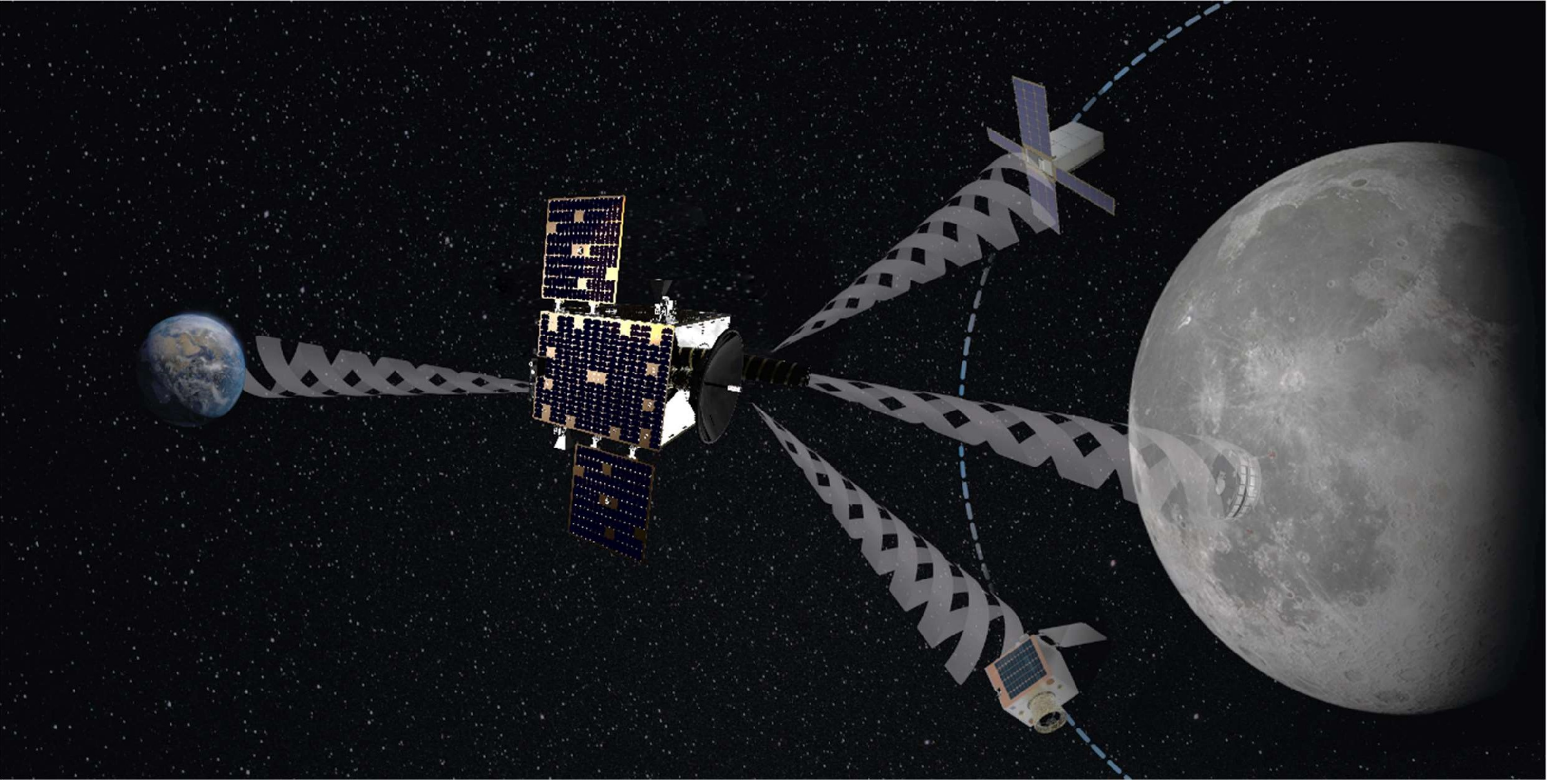

Chapter 8

Appendix

8 Appendix

8.1 Relevant Documents

Document ID	Title	Document Version	Revision Date
RD-1	CLMSS Moon Link ICD	V12	June 2022
RD-2	CLMSS User-To-Ground ICD	V1	April 2022
RD-3	CLMSS User Manual	V3	August 2022

8.2 List of Acronyms

CLMSS	Commercial Lunar Mission Support Services
EIRP	Effective Isotropic Radiated Power
ELFO	Elliptical Lunar Frozen Orbit
ESA	European Space Agency
GES	Goonhilly Earth Station
ITIL	Information Technology Infrastructure Library
KPI	Key Performance Indicator
LDPC	Low-density Parity-check
LLO	Low Lunar Orbit
MCC	Mission Control Centre
NOC	Network Operations Centre
OFM	Orbiter From the Moon
OTM	Orbiter To the Moon
PCM	Pulse-code Modulation
SCID	Spacecraft Identification
SLA	Service Level Agreements
SPOC	Single Point of Contact
SSTL	Surrey Satellite Technology
TM	Telemetry and Telecommand
TRB	Test Review Board
UHF	Ultra-High Frequency
VPN	Virtual Private Network