Lunar Pathfinder – Looking Forward to Next Year's Launch of the First Commercial Dedicated Lunar Comsat

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ABSTRACT

The Lunar Pathfinder communications relay satellite is currently being developed, leading to a launch towards the end of 2025. The mission is a "public private partnership" between the European Space Agency (ESA), NASA and Surrey Satellite Technology Ltd. Having passed its CDR in 2023 the satellite is currently in manufacture.

Lunar Pathfinder will offer data relay communication services for 8+ years to other lunar missions – orbiters, landers and rovers. Lunar Pathfinder's services will allow other lunar assets to avoid providing their own "Direct to Earth" (DTE) capability with three key benefits for those assets – (1) lower cost of data communications, (2) the ability to communicate when DTE is impossible e.g. when shadowed by craters or when operating on the far-side, (3) lower volume, mass and power requirements for the communications equipment compared to DTE for a given data rate and (4) lower cost launch and/or greater payload capacity due to the lower mass of the communications equipment compared to DTE.

Lunar Pathfinder is also the first node in ESA's Moonlight system which will provide communications and navigation services from a constellation of moon orbiting satellites. Moonlight will be deployed in the second half of this decade and will include Lunar Pathfinder in its initial capability.

The paper provides an overview of the Lunar Pathfinder mission – the satellite, its ground segment and the communications services it offers to its users. The paper also includes status on the satellite build progress.

1 INTRODUCTION

Following its 2025 launch Lunar Pathfinder will offer data relay communication services for 8+ years to other lunar missions – orbiters, landers and rovers. Lunar Pathfinder's services will allow other lunar assets to avoid their own "Direct to Earth" (DTE) capability with three key benefits for those assets – (1) lower cost of data communications, (2) the ability to communicate when DTE is impossible e.g. when shadowed by craters or when operating on the far-side and (3) lower volume, mass and power requirements for the communications equipment compared to DTE for a given data rate and (4) lower cost launch and/or greater payload capacity due to the lower mass of the communications equipment compared to DTE.

In addition to its communication services, Lunar Pathfinder will also act as a technology testbed for other payloads of interest to ESA and NASA. Pathfinder will carry 2 payloads related to future

navigation (PNT) services – (1) A weak signal GNSS receiver to demonstrate possible use of GNSS in future lunar navigation infrastructure and (2) A laser retro-reflector to allow precise ranging and therefore providing ground truth for the assessment of the performance of the GNSS receiver. Finally, Lunar Pathfinder will embark a radiation monitor which will feed data into ESA's Space Weather monitoring network.

Lunar Pathfinder will be launched by Firefly under a contract within NASA's Commercial Lunar Payload Service (CLPS) Programme. The launch is designated CS-3 (CLPS Science Mission 3) and is scheduled to take place late in 2025. The launch vehicle and its transfer stage will inject Lunar Pathfinder into an Inclined & Elliptical Lunar Frozen Orbit (ELFO) chosen to provide excellent coverage of the main areas of interest to future lunar missions, namely the Southern Hemisphere including the South Pole region and the Far Side regions.

Following "hot on the heels" of Lunar Pathfinder, Moonlight's Lunar Communications and Navigation System (LCNS) will be deployed later in the decade in two stages – an initial operational capability targeting a 2027 launch followed by a full operational capability, adding further services, towards the end of the decade. The industrial team developing LCNS commenced the implementation phase in the first quarter of 2024.

2 MISSION RATIONALE

Data Relay is a vital service in support of future lunar missions. The coming decades will see several missions launching into the lunar environment including research space stations, missions from universities and commercial landers carrying rovers and other payloads. Traditionally, such missions would receive telecommands (TC) direct-from Earth (DFE) and send payload data and telemetry (TM) direct-to-Earth (DTE). This obliges these missions to fly dedicated, powerful telecommunications hardware, ultimately resulting in smaller, less performant payloads for spacecraft with given volume, power and mass constraints, thus impacting the primary mission objectives.

In addition, many future missions will be targeted at regions where DTE is not possible such as shadowed craters in the polar regions and missions to the far-side. These missions must make use of data relay services.

Navigation services are also very important for the future of Lunar exploration. For example, having precise navigation PNT services will allow much simpler landing scenarios to be implemented, potentially removing the need to embark altimeters and navigation cameras aiding lower cost, mass and power of landers. Lunar Pathfinder will act as a testbed for navigation technologies to later be embarked on Moonlight and/or other Lunar infrastructure missions e.g. from the USA and Japan.

The figure below shows an estimate of the number of upcoming missions.

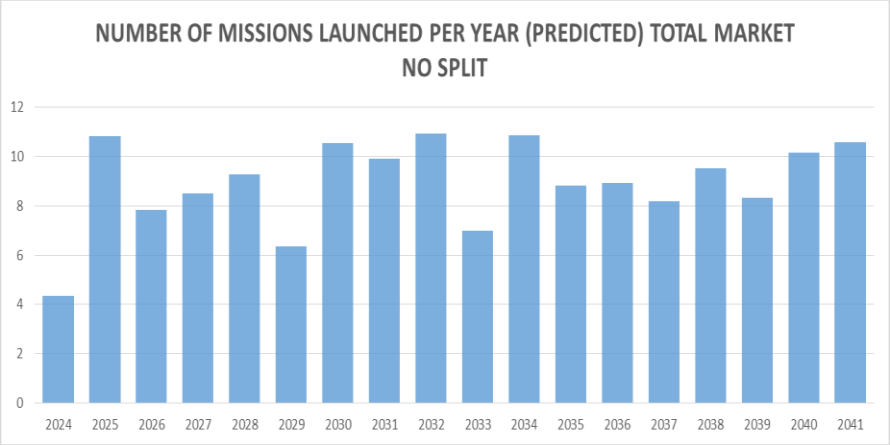

Figure 1. Prediction of Number of Lunar Missions to 2040

3 LUNAR PATHFINDER PROGRAMME

SSTL's Lunar Pathfinder programme is developing the system and services which SSTL commercially offers to potential users. The system consists of a space segment, being a single satellite in lunar orbit, and a ground segment consisting of (a) a mission operations centre (b) a network operations centre (c) a set of ground stations provided by global operator Kongsberg Satellite Services (KSAT) and (d) a service centre (telco) as the primary interface for customers with the system. The system development is well underway having just been through its critical design review.

The mission architecture is shown in the following figure. The mission is divided into three segments:

- Ground Segment (GSEG) consisting of the customer systems, SSTL's systems and the KSAT Ground Stations
- Space Segment (SSEG) consisting of the Lunar Pathfinder satellite
- Launch and Transfer Segment consisting of the CLPS provider launch and transfer vehicles

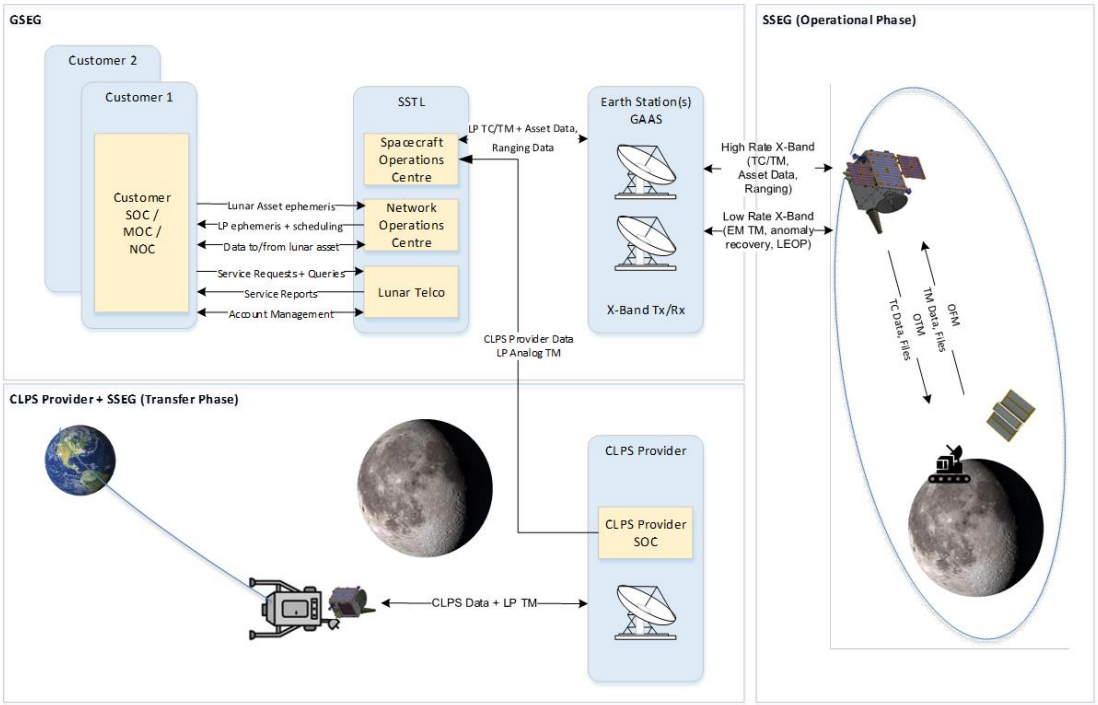

Figure 2. Pathfinder Mission Architecture

The launch of the satellite is scheduled for late 2025 as part of NASA's CLPS programme – the mission is designated CS-3 and the selected launch vehicle will launch Pathfinder alongside other experiments and a far-side radio astronomy mission LuSEE-Night [1]. In 2023, Firefly Aerospace was chosen as the CLPS service provider for CS-3 [2].

4 LUNAR PATHFINDER SATELLITE

The Lunar Pathfinder satellite is a new design but with maximal re-use of subsystems and equipment from SSTL's range of Earth-orbiting satellite platforms. The ~350kg satellite is constructed as a main body and two deployable (hinged) solar panels. The body structure is built around a central thrust-tube assembly. The avionics are dual redundant and interconnected to a pair of CAN busses. The subsystems/payloads making up the design are:

- **Power**: one body-mounted and two deployed solar panels; a single Li-Ion battery with internal graceful degradation; redundant electronics for battery charging and power distribution. Orbit Average Power will be >250W.
- **AOCS**: set of 4 wheels in a tetrahedron configuration; fully redundant sun sensors, gyros and dual-headed star cameras
- **Propulsion**: Single tank of Hydrazine mono-propellant; redundant sets of 4 1N thrusters and propulsion control electronics
- **Environment**: heaters and temperature sensors
- **OBDH**: redundant computers, can busses and payload interface units
- **Moon-link payload**: S-band lunar-link transponder, low noise amplifier (LNA), antenna and its pointing mechanism; redundant high speed data recorders. The moon-link payload uses adaptative data rates (1-4096 kb/s) to maximise the throughput per mission phase and is developed in close coordination with the CCSDS Proximity-1 evolution process to S-band to maximise the interoperability with the upcoming LunaNet network and therefore maximise the benefits to users.
- **Earth-link payload**: redundant Tx and Rx X-band antennas; pointing mechanisms for Tx antennas; Earth-link transponders and high power amplifiers. Tx data rates supported: 12.1 kb/s, 1.2 Mb/s, 2.4 Mb/s and 4.8 Mb/s. Rx data rates supported: 1.8 kb/s, 28.4 kb/s. The Earth-link is developed in compliance with CCSDS TM/TC and ranging standards.
- **Hosted payloads**: GNSS receiver and antenna, radiation monitor and laser retroreflector.

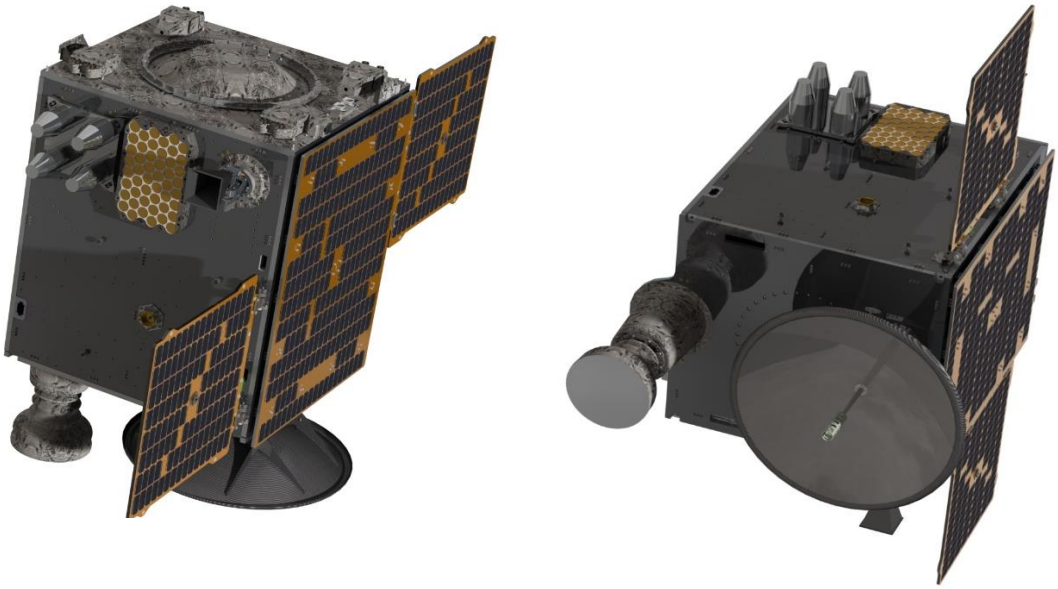

Figure 3. Lunar Pathfinder Satellite

5 SERVICE PROVISION

To service the market SSTL has created “SSTL Lunar”, a new telco dedicated to providing commercial data relay services to customers via Lunar Pathfinder. SSTL Lunar and Lunar Pathfinder are wholly SSTL-owned, and the data relay offering is SSTL-operated. Customers of Lunar Pathfinder will be able to select from three separate store-and-forward services, as shown in Table 1.

Table 1. Lunar Pathfinder service offerings

Service	Description
Autonomous	Includes an agreed data volume to be relayed over an agreed timeframe, typically 24 hours, between the user and the user’s asset via Lunar Pathfinder using automated planning
Scheduled	As per the Autonomous Service, but with the added possibility for the user to specify the schedule of the lunar communication contact window
Emergency	Allows rapid planning and initiation of a Scheduled Service contact as soon as possible and always within 12 hours of SSTL Lunar receiving an Emergency Service request from the user, subject to ground station availability and visibility of assets.

Noting that Lunar Pathfinder implements a store-and-forward communications architecture there will always be a latency in the data transfer ranging from a few minutes, if all links are active, to several hours if there is no visibility to an Earth station when the asset is communicating. The figure below shows the overall architecture from the customer network operation centre (NOC) to the lunar asset.

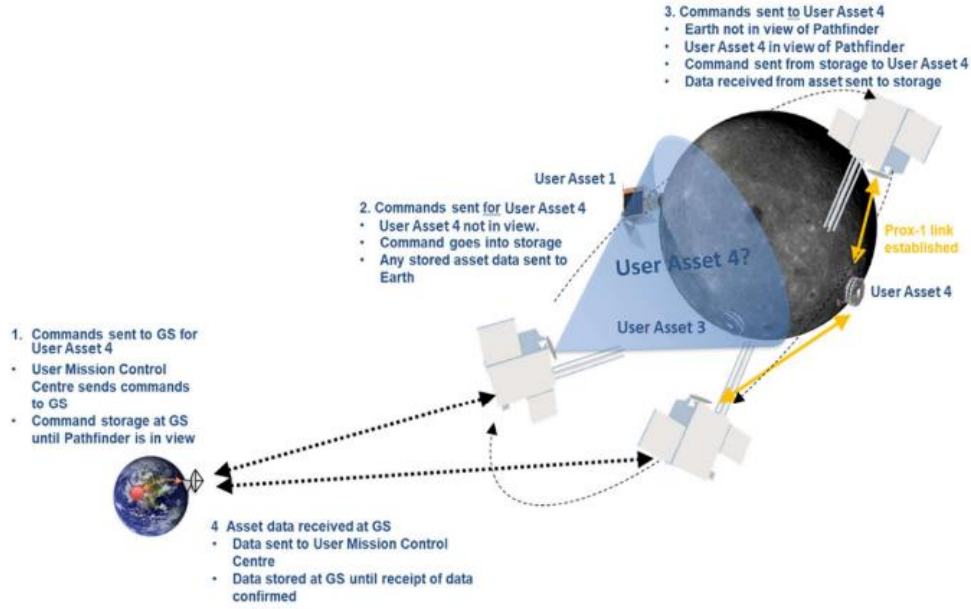

Figure 4. Lunar Pathfinder Data Transfer Process

Further details of the end-to-end service can be found in SSTL's Lunar Pathfinder Service Guide [3], freely available online for prospective users. SSTL also offer a Lunar Pathfinder Mission Builder application online [4], which can be used by prospective users to perform an initial assessment of the services they can receive through Lunar Pathfinder.

The table below summarises the specification for the services offered over the Moon link and the Earth link:

Table 2. Lunar Pathfinder Service Specifications

Link	Band	Fwd Freq. (MHz)	Fwd Data Rate	Ret Freq. (MHz)	Ret Data Rate
Moon	S-band	2025-2110	0.5-2.0 Mbps	2200-2290	0.5-2.0 Mbps
Earth	X-band	7190-7235	<30 kbps	8450-8500	≤ 5 Mbps

The Moon link operates using the CCSDS Proximity-1 protocol [5] for the physical and data link layers with Version-4 transfer frames, in which the lunar assets data will be encapsulated. This protocol is incorporated into the LunaNet interoperability standard [7] endorsed by the major space agencies.

The Earth link is implemented using a Ground network provided by our "Ground Segment As A Service" (GAAS) partner, KSAT of Norway.

A more detailed summary of the system can be found on the ESA website at [6].

6 SCHEDULE & PROGRAMMATICS

Lunar Pathfinder passed through its CDR in the first half of 2023 and is now in Phase D. The launch of the satellite is scheduled for late 2025 by Firefly, the chosen CLPS service provider for CS-3.

The ~26 day Launch and Early Operations (LEOP) Phase will cover all the activities from the launch of the primary vehicle through to transfer and injection into Lunar orbit by Firefly's Blue Ghost transfer vehicle which will place Pathfinder into an Elliptical Lunar Frozen Orbit (ELFO) with orbital apoapsis chosen to give excellent coverage of the south pole region where a lot of the upcoming missions are targeted.

The chosen orbit also gives good coverage of the far-side where data relay is essential to communicate with landed assets.

LEOP will complete with detumbling of the satellite after separation from the transfer vehicle followed by confirmation that the satellite is in a safe state.
Following LEOP there will be a ~14 day service commissioning phase where both the platform and the payload will be commissioned.

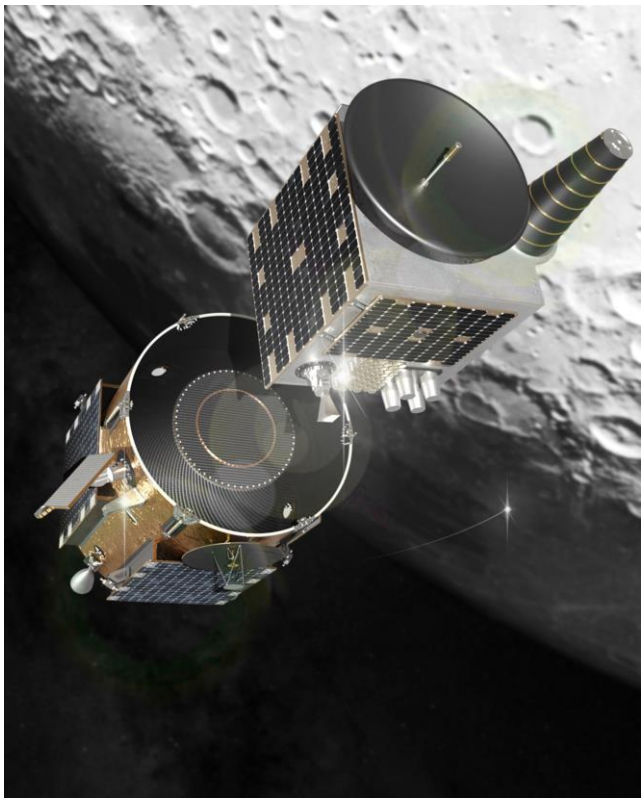

Figure 5. Blue Ghost deploying Lunar Pathfinder

Following the commissioning phase Pathfinder will be in a position to offer communications services early in 2026. Section 5 describes the service provision that will be offered to Pathfinder's users over the planned 8+ years of operation until mid-2034. The routine operational phase could be extended should the system still being functional and with consumables (propellant) remaining.

Table 3. Chosen ELFO Orbital Parameters

Orbital parameter	Value
Semi major axis [km]	5740.0
Periapsis altitude [km]	673.4
Apoapsis [km]	7331.8
Eccentricity	0.58
Inclination [°]	46.8
Right Ascension of the Ascending Node (RAAN) [°]	252
Argument of pericentre	86.2
Period	~ 10.8 hours

The disposal phase of ~3 months will complete the mission. End-of-life disposal is to deorbit with surface impact, with impact site around 40°N to 60°N.

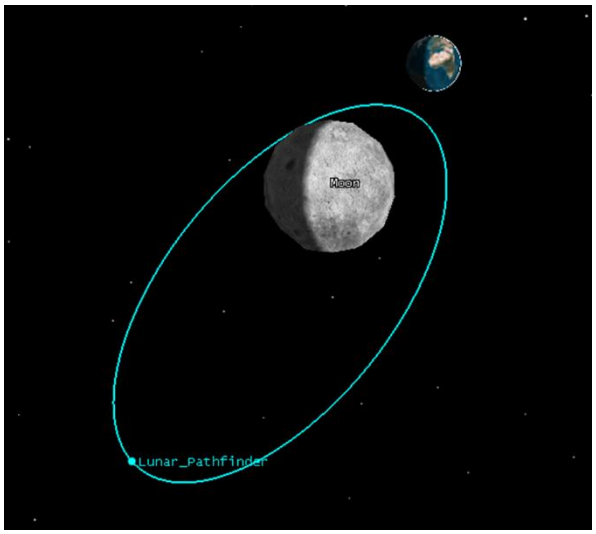

Figure 6. Visualisation of Pathfinder ELFO

7 CONCLUSIONS

Data relay satellites have a key role to play in the coming decades as increasing numbers of lunar missions are launched. SSTL's Lunar Pathfinder spacecraft will launch in 2025 and provide data relay services to ESA, NASA and commercial customers.

Lunar Pathfinder will offer interoperable data relay communication services for 8+ years to these lunar missions – orbiters, landers and rovers. Lunar Pathfinder's services will be a mission enabler for a variety of missions – particularly to those who must use data relay due to their location but also to those who can benefit from the simpler interface to Earth stations and in terms of mass & power requirements.

Lunar Pathfinder will be joined, later in the decade, by the additional communications and navigation satellites from the ESA Moonlight programme heralding the dawn of ubiquitous comms and nav services in the lunar environment.

For more information on SSTL's Lunar Pathfinder, please contact the SSTL lunar team at lunar@sstl.co.uk.

8 REFERENCES

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