Lunar Surface Relay – Mobile: Concept to Provide Relay Links to Surface Assets

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At the request of NASA's Space Communication and Navigation (SCaN) program, the Glenn Research Center's (GRC) Compass concurrent engineering team developed a conceptual design of a Lunar Surface Relay- Mobile (LSR-M) system to provide a variety of surface and relay communication links in support of future Artemis sorties. The team determined that a mobile asset, with its ability to relocate to support a variety of surface sites and leverage more hospitable winter locations on the lunar south pole, would be of particular use in the architecture. Following the design of a solar array and battery powered baseline case, a quick look design further investigated adding a multi-mission radioisotope thermoelectric generator (MMRTG) to the system to reduce battery requirements to survive the lunar night and remove the need to relocate to favorable night locations during the lunar winter.

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I. Introduction

A. Study Background and Assumptions

Communication links will be key for surface users throughout the ambitious Artemis campaigns. Given the proposed distances, varied sortie site options, and the feature rich lunar terrain, a surface-deployed communications terminal would benefit from a mobility option. At the request of the Space Communication and Navigation (SCaN) program, the Compass Team explored a Lunar Surface Relay- Mobile (LSR-M) solution to provide 5G/Wi-Fi/ultra-high frequency (UHF) links for a variety of surface assets at Artemis sortie sites while providing trunk links via Ka, X, and S-band to orbiting communications relays and direct to Earth (DTE).

B. Requirements, Assumptions and Trades

The LSR-M is required to provide 5G and UHF surface communications for Artemis assets at distances up to 5 km and relay them back to Earth, the Lunar Gateway, or up to two Lunar Communications Relay and Navigation Systems (LCRNS). Additionally, a shorter distance Wi-Fi system was required, reaching approximately 300 m. The mobile option, rather than a static option, is considered enabling for re-use and re-positioning to support a variety of Artemis sortie sites on a roughly annual cadence. The LSR-M is assumed to operate between 84° and 90° South on the lunar surface and is only responsible for providing communication relay services while sunlit (although the design described herein does allocate a 30-minute period per 24 hours for broadcasting position, navigation, and timing (PNT) information to orbiting relays while in prolonged shadow).

The system is required to survive a 354-hour lunar night using solar arrays and batteries. The Compass Team did not include isotopes in the baseline case; however, additional trades included an investigation of a radioisotope thermoelectric generator (RTG) to further support the design. Thermal trades included approaches for to keeping the electronics and batteries warm to survive the lunar night. Mechanical trades focused on options for a retractable 10 m tower. Finally, the system assumed a lifetime requirement of 10 years.

C. Concept of Operations (CONOPS)

There are several advantages to making a mobile version of a lunar surface relay (LSR) communication system. The LSR-M can be placed in optimal locations for relay between surface elements and maximum sunshine availability for power. The LSR-M can also be landed in a 'safe' area for the lander and later be re-located to these optimal sites. It additionally allows the option of supporting multiple different sortie sites with a single element, given the ability to re-locate. Finally, the 10 m boom allows for greater coverage for the surface links, where the boom is likely taller than what other mobile elements currently envisioned in the architecture might support, such as the Lunar Terrain Vehicle (LTV).

Launch and delivery of the LSR-M is assumed to be accomplished by a human class cargo lander [1] or a to-be-determined-large class commercial lunar payload services (CLPS) lander around the timeframe of Artemis IV or V. No final lander design(s) was chosen; however, the selected lander needs to accommodate both the payload mass and deployment of LSR-M to the lunar surface. It is assumed that the delivering lander will provide the LSR-M an allocation of power while in transit to the lunar surface and for a checkout period after landing. Additionally, limited power will be available to the system from its own stowed arrays.

Once deployed to the lunar surface, the LSR-M will finalize commissioning and checkout operations and then begin its first transit operations. While in transit mode, the LSR-M retracts its 10 m boom to lower the center of gravity of the vehicle. During transit, the rover relies primarily on battery power and then periodically stops to recharge the batteries. This pattern continues until it arrives at its first (and subsequent) deployment locations. Once in its deployment location, the boom is extended, and the battery system is charged once more to survive the first lunar night.

During the lunar night, most electronics are turned off, with only a watchdog computer, heaters, and the atomic clocks running most of the time. There is sufficient energy from the batteries to allow the system to send and receive a PNT signal for approximately 30 minutes of every 24-hour period while in shadow. This also serves as a health check on the system. The system is kept warm in the environment by using the waste heat of the electronics that are running (mainly the atomic clocks) and heaters to complement a robust insulation system. The deployment locations are selected to experience no more than a 354-hour darkness period during the lunar night. The use of a 10 m boom for the solar arrays expands the set of possible deployment/nighttime locations. This will be of the most importance when the lunar south pole experiences winter, extending the nighttime durations past 354 hours for much of the surface.

If the nighttime location is different than the location required to support an Artemis sortie, the LSR-M stows its 10 m boom and transit to the sortie support site at lunar dawn and re-deploys the boom. This series of CONOPS repeats to ensure the LSR-M can survive the lunar night and support the required sites given careful planning.

During the lunar day, the LSR-M is available to provide full relay capabilities (including live video) for six users providing DTE or relay through the orbital services when the surface is not in direct view of Earth. Onboard rubidium clocks provide PNT information, which are envisioned to be disciplined by a higher accuracy system, such as the orbital relay services system. During that time, the solar arrays generate sufficient power for operations and to recharge the battery for the next shadow period.

At the conclusion of the Artemis sortie site support, the LSR-M relocates to the next sortie site to support preparation operations and the eventual next sortie. At the conclusion if its 10-year life, operators can drive the mobile system to a disposal site.

Fig. 1 shows a sample full crewed traverse (with LTV) use case. The coverage of the traverse from the Human Landing System (HLS) alone is limited to close proximity to HLS and a bit of the surface on the adjacent slope. Fig. 2 shows the same use case with the addition of the LSR-M, providing full coverage of the traverse. While the LTV could provide coverage throughout the traverse once away from HLS, these coverage diagrams show that when the HLS is out of sight of the crew, the LSR-M can provide walk back coverage for astronauts in the event of an LTV breakdown. [2]

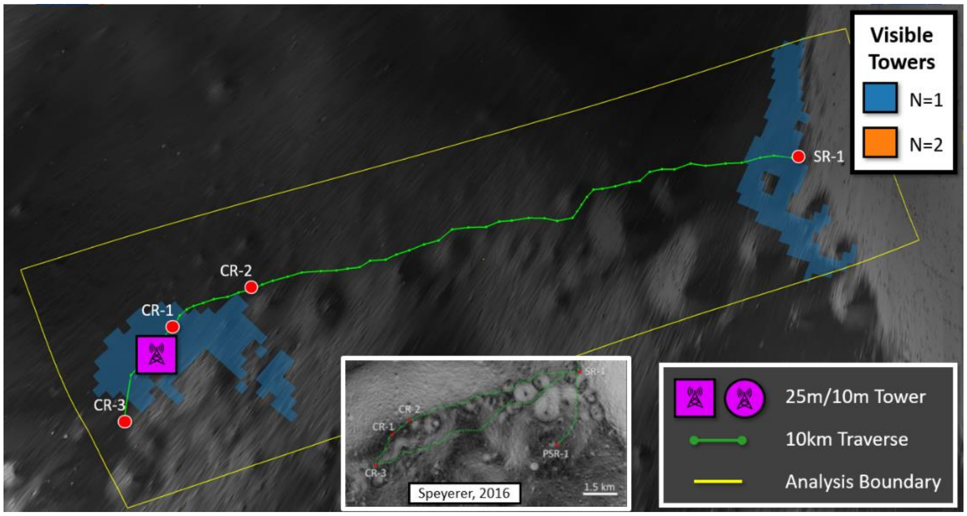

Fig. 1 Sample Use Case: Long Range Traverse, HLS Coverage

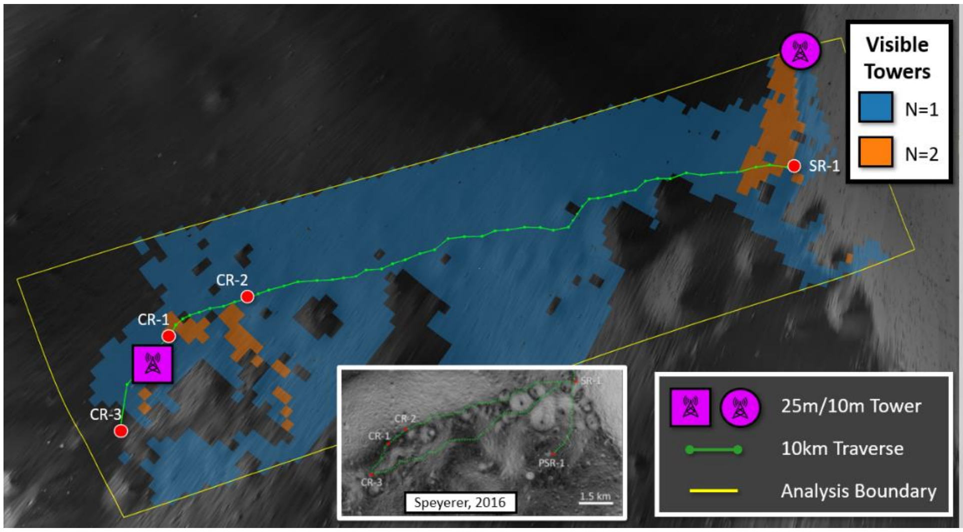

Fig. 2 Sample Use Case: Long Range Traverse, HLS and LSR-M Coverage

II. Basic Design and Concept Description

A. Concept Description

Fig. 3 shows the LSR-M in its fully deployed relay configuration and the stowed roving configuration.

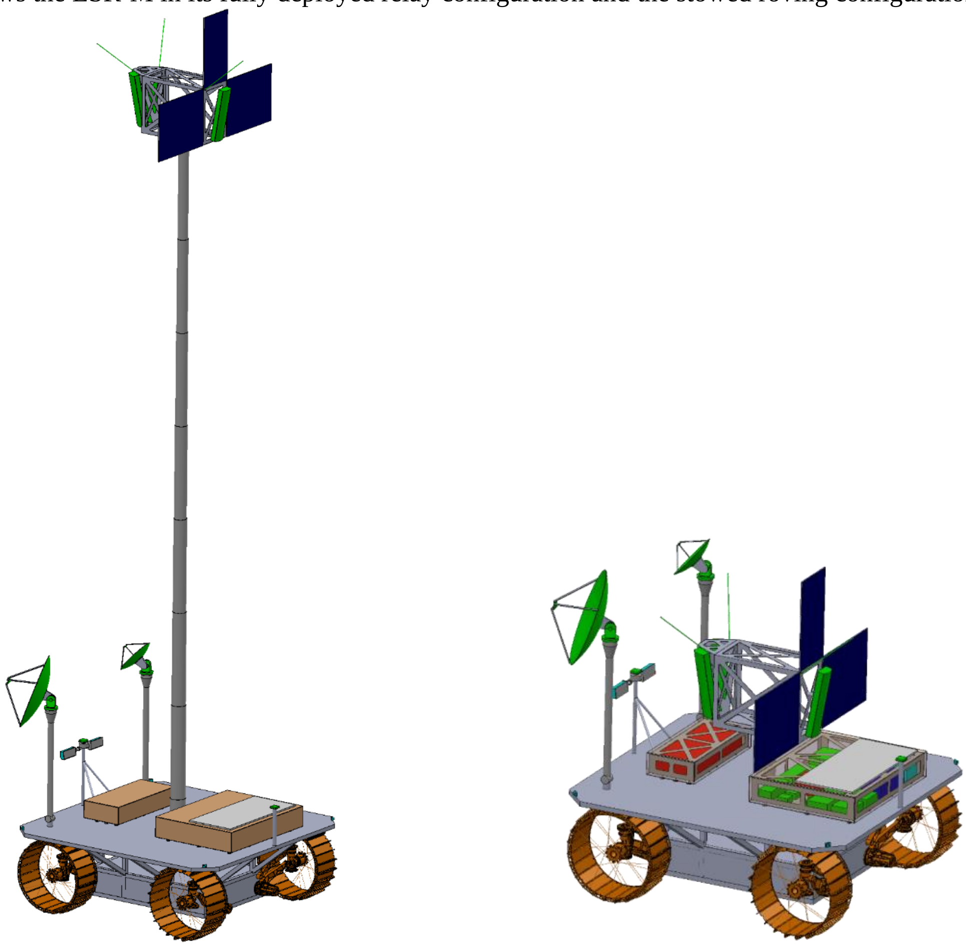

Fig. 3 Deployed Configuration of LSR-M (left) and Roving Configuration (right)

To reduce the heat leak from the system as much as possible during the lunar night, all the electronics are stored in two thermally isolated and insulated boxes: the electronics box and the battery box. The battery box holds the approximately 160 kgs (basic mass) of batteries along with two rubidium atomic clocks. The clocks' temperature is further controlled within an additional box inside the battery box, as their operation is contingent on maintaining a stable temperature. The electronics box carries the balance of the electronic components, including all the radios for the communications system, the power management and distribution system, the inertial measurement units, the camera electronics (not the optics), and the command and data handling system (computers and mass memory storage). These boxes are shown in Fig. 4.

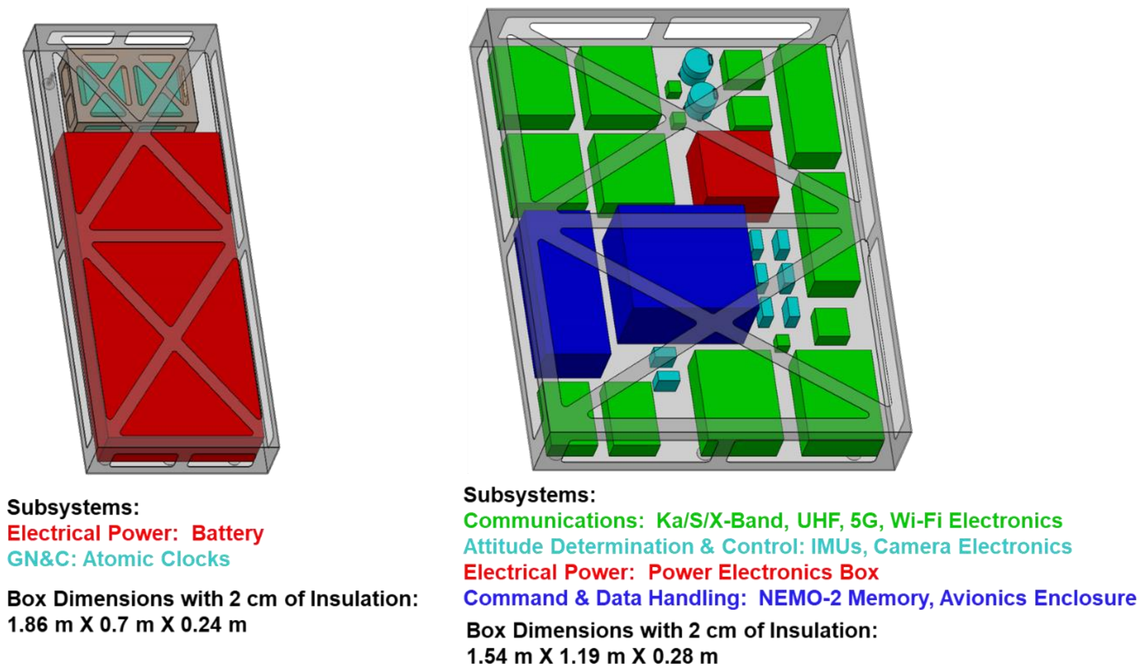

Fig. 4 Battery Box (left) and Electronics Box (right) Components and Details

The solar panels, 5G panels, and UHF antennas are all mounted on a box at the top of the boom, which allows them to be raised 10 m when deployed. The Wi-Fi antennas, retroreflectors, and hazard avoidance cameras are located on the deck of the rover, along with the parabolic antennas, which are mounted on 2 m booms. The design also includes a mast which carries the navigation cameras, lighting system for use during roving, and an S-band omni antenna for transit modes and PNT signals. External components can be seen in Fig. 5.

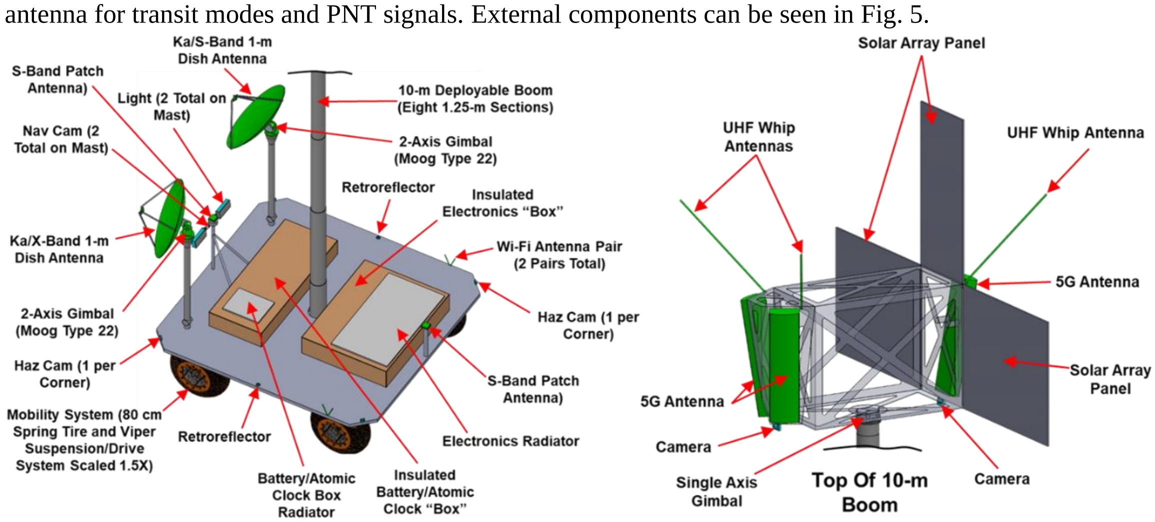

Fig. 5 External Components of the LSR-M

The overall dimensions of the LSR-M are shown in Fig. 6 and Fig. 7, in both the stowed and fully deployed configurations.

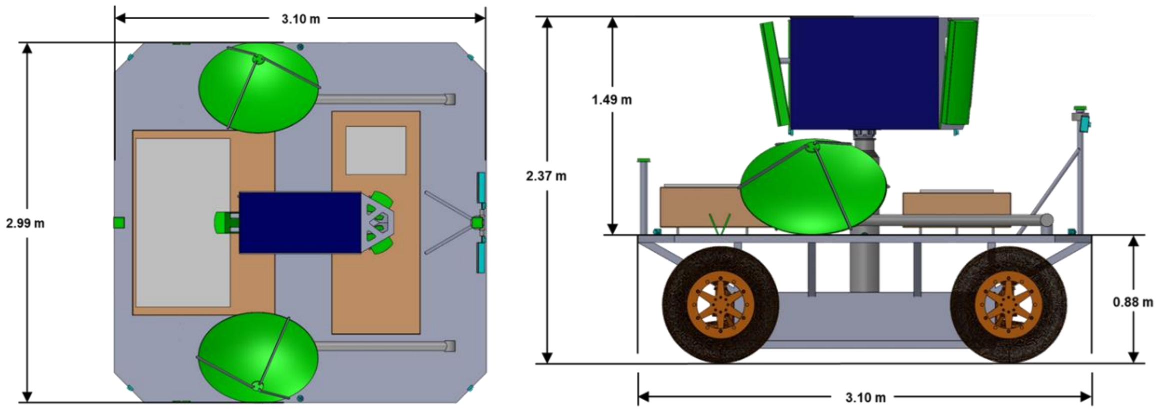

Fig. 6 Overall dimensions of the LSR-M

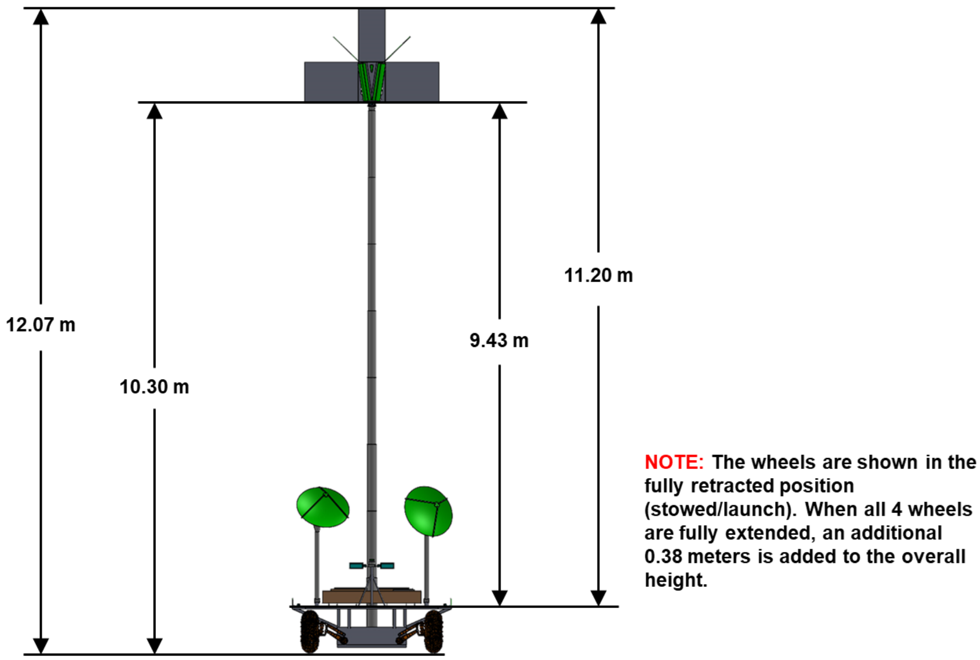

Fig. 7 Deployed Dimensions of the LSR-M

Table 1 shows the basic subsystem masses for the LSR-M, along with the mass growth allowance (MGA) and margin totals. MGA and margin totals are shown in green to indicate they meet the qualification for a 'green' rating according to the AIAA mass risk assessment criteria. [3]

Table 1 Mass Summary for the LSR-M

MEL Summary: Case 3_Lunar Surface Relay CD-2023-197	Lunar Surface Relay (LSR)
Main Subsystems	Basic Mass (kg)
Attitude Determination and Control	17.7
Command & Data Handling	60.7
Communications and Tracking	84.3
Electrical Power Subsystem	221.5
Thermal Control (Non-Propellant)	37.0
Mobility	187.6
Structures and Mechanisms	256.4
Element Total	***865.1***
Element Dry Mass (no prop,consum)	865.1
Element Mass Growth Allowance (Aggregate)	223.7
MGA Percentage	26%
Predicted Mass (Basic + MGA)	1088.8
System Level Mass Margin	129.8
System Level Growth Percentage	15%
Element Dry Mass (Basic+MGA+Margin)	***1218.6***

III. Subsystem Design Highlights

B. Communications

The communication systems for the LSR-M are the crux of the design. The terminal must provide priority-based demand communication link service to users with a variety of data needs and connection types, including:

- Communications among LSR users
- Communication to Earth via LSR-M to relay satellites/Gateway
- Communications to Earth via DTE
- LSR-M terminal platform command and control links

The terminal includes S/X/Ka-band systems in accordance with Lunar standards and spectrum planning and uses two high-gain antennas (HGA) with gimbals to communicate with LCRNS, Gateway, and/or NASA's Near Space Network's Lunar Earth Ground Stations (LEGS), as applicable. Additionally, the terminal includes UHF and Wi-Fi/5G-band systems for lunar surface user data and an S-band system for rover command and control. The design concept incorporated single fault tolerant systems and maintained 3 dB of link margin in the communications link budget analysis. Table 2 shows the link requirements for each of the systems and users.

Table 2 Link Requirements and Users by System

Lunar Surface Links:		
5G/Wi-Fi links	~6 Users, 139 Mbps	Up to 5 km range
UHF	1 Mbps	
Return Links:		
Link to LCRNS	Ka-band, 120 Mbps	60 Mbps user, 60 Mbps coding (1/2 FEC)
	S-band, 72 kbps	36 kbps user, 36 kbps coding (1/2 FEC)
Link to Gateway	Ka-band, 50 Mbps	25 Mbps user, 25 Mbps coding (1/2 FEC)
	S-band, 200 kbps	100 kbps user, 100 kbps coding (1/2 FEC)
DTE Link	Ka-band, 252 Mbps	126 Mbps user, 126 Mbps coding (1/2 FEC)
	X-band, 24.92 Mbps	12.46 Mbps user, 12.46 Mbps coding (1/2 FEC)

A visual representation of these links and potential users is shown in Fig. 8.

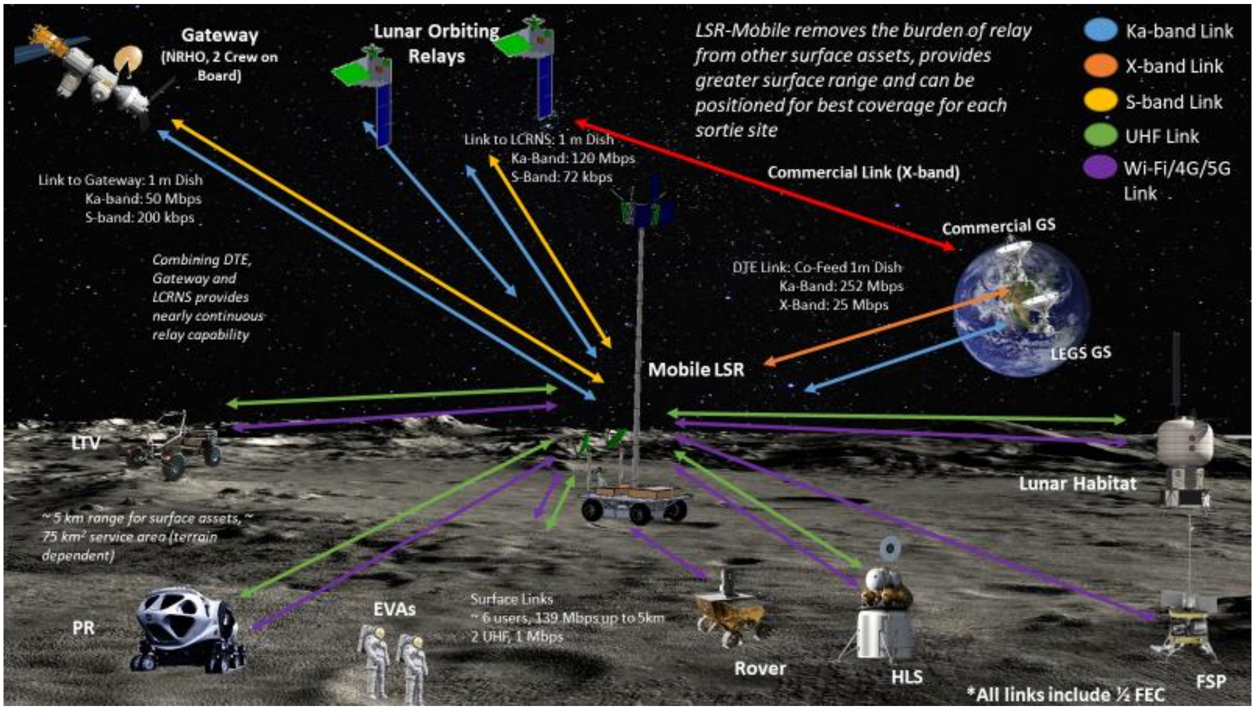

Fig. 8 Visual Representation of Surface and Relay Links Accomplished by the LSR-M

The rover concept implemented the following design to accomplish the required data rates and links. The X/Ka-band DTE communication system consists of a single 1 m diameter steerable antenna with 0.8 deg half-power-beamwidth for high data rate communications given an available line of sight link. The S/Ka-band relay via either Gateway in the near-rectilinear halo orbit (NRHO) or LCRNS system in a low frozen orbit around the moon, consists of a single 1 m diameter steerable 0.8 deg half-power-beamwidth antenna for high data rate communications. Fig. 9 shows a functional block diagram of these two systems.

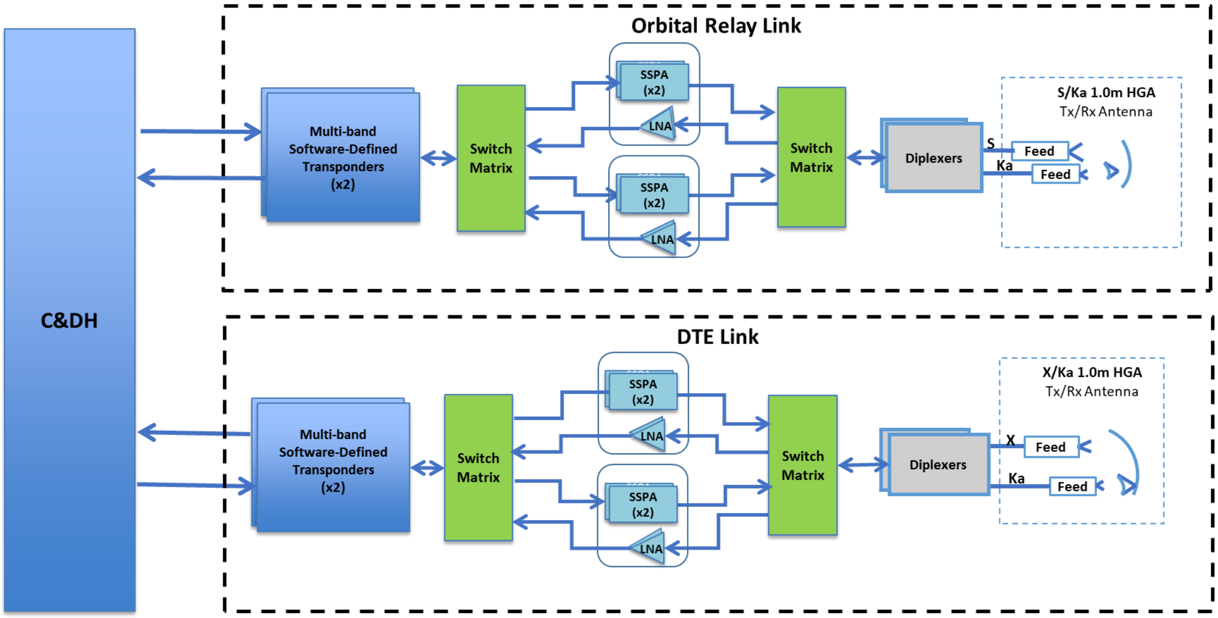

Fig. 9 Functional Block diagram of the DTE and Orbital Relay links

A separate S-band system is carried for rover and PNT communications and telemetry data. This consists of an omni antenna for wide range coverage to an orbiter to support rover communications. Alternatively, rover control could be accomplished via a feedhorn anchored to the same X/Ka-band gimbal platform in the DTE parabolic reflector. Finally, the LSR-M's lunar surface network consists of UHF and 5G service for the nearby users. Fig. 10 shows a functional block diagram of the 5G system.

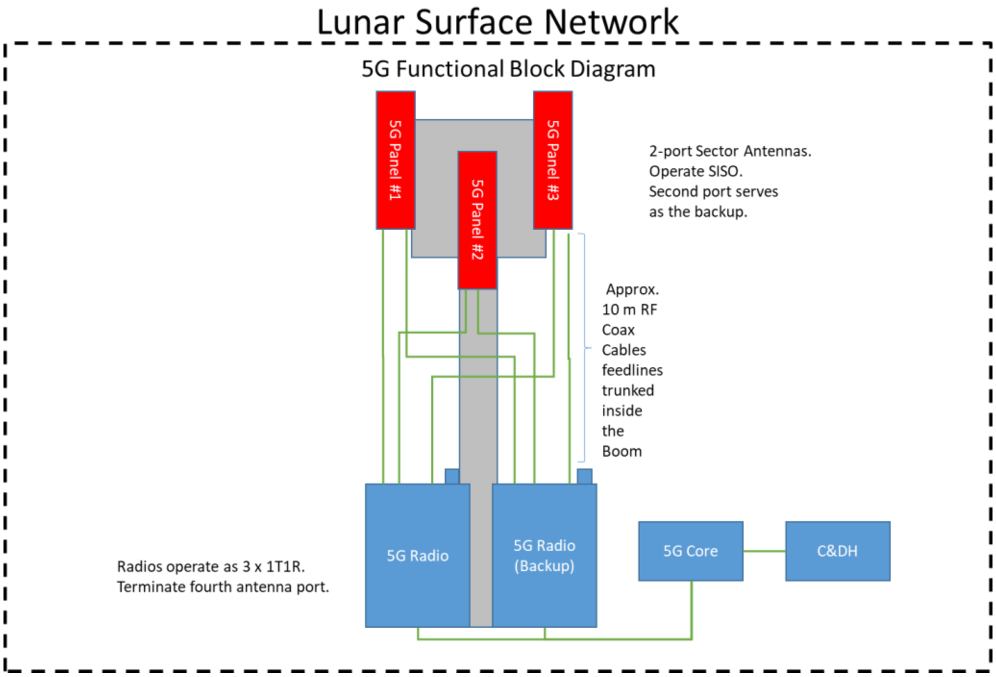

Fig. 10 Functional Block Diagram of Lunar Surface 5G System

Note that, although most of the components of the communication system are well understood, with Technology Readiness Levels (TRL) of 6 and higher, the Wi-Fi and 5G systems have low TRLs in the range of 3 to 4. While common terrestrially, further development of these systems for space is required prior to their use.

Tables 3, 4, and 5 show the link budgets for the high data rate links to Earth, Gateway and LCRNS.

Table 3 LSR-M DTE Link Budgets

Ka-band System, 1 m antenna			
Parameter #	Parameter	Value	Notes
1	Frequency, MHz	25500-27000	LSR specified Freq. Reference (ICSIS)
2	Data Rate, Mbps	126	DTE, (maximum) ½ FEC
3	Range, Km	408,000	Average Distance
4	Power, W	10.0	Available SSPA
5	System loss, dB	-3	Assumed
6	Atmospheric loss, dB	1.5	
7	Antenna Pointing loss, dB	0	Based on antenna type
8	Antenna gain, dB	46.1	Assume 55% efficient antenna
9	Link Margin, dB	3.0	Required
X-band System, 1 m antenna			
Parameter #	Parameter	Value	Notes
1	Frequency, MHz	8450-8500	LSR specified Freq. Reference (ICSIS)
2	Data Rate, Mbps	12.4	DTE, (maximum) ½ FEC
3	Range, Km	408,000	Average Distance
4	Power, W	5.0	Available SSPA
5	System loss, dB	-3.0	Assumed
6	Atmospheric loss, dB	0.3	

7	Antenna Pointing loss, dB	0	Based on antenna type
8	Antenna gain, dB	36.3	Assume 55% efficient antenna
9	Link Margin, dB	3.0	Required

Table 4 LSR-M to Gateway Link Budgets

Ka-band System, 1 m antenna			
Parameter #	Parameter	Value	Notes
1	Frequency, MHz	25500-27000	LSR specified Freq. Reference (ICSIS)
2	Data Rate, Mbps	25	Relay, (maximum) ½ FEC
3	Range, Km	70,000	Average Distance (Gateway)
4	Power, W	10.0	Available SSPA
5	System loss, dB	-3	Assumed
6	Antenna Pointing loss, dB	0	Based on antenna type
7	Antenna gain, dB	46.1	Assume 55% efficient antenna
8	Link Margin, dB	3.0	Required
S-band System, 1 m antenna			
Parameter #	Parameter	Value	Notes
1	Frequency, MHz	2200-2290	LSR specified Freq. Reference (ICSIS)
2	Data Rate, Mbps	100	DTE, (maximum) ½ FEC
3	Range, Km	70,000	Average Distance (Gateway)
4	Power, W	5.0	Available SSPA
5	System loss, dB	-3.0	Assumed
6	Antenna Pointing loss, dB	0	Based on antenna type
7	Antenna gain, dB	24.6	Assume 55% efficient antenna
8	Link Margin	3.0	Required

Table 5 LSR-M to LCRNS Link Budget

Ka-band System, 1 m antenna			
Parameter #	Parameter	Value	Notes
1	Frequency, MHz	25500-27000	LSR specified Freq. Reference (ICSIS)
2	Data Rate, Mbps	60	Relay, (maximum) ½ FEC
3	Range, Km	20,000	Average Distance (LCRNS)
4	Power, W	5.0	Available SSPA
5	System loss, dB	-3	Assumed
6	Antenna Pointing loss, dB	0	Based on antenna type
7	Antenna gain, dB	36.2	Assume 55% efficient antenna
8	Link Margin, dB	3.0	Required
S-band System, 1 m antenna			
Parameter #	Parameter	Value	Notes
1	Frequency, MHz	2200-2290	LSR specified Freq. Reference (ICSIS)
2	Data Rate, Mbps	36	DTE, (maximum) ½ FEC
3	Range, Km	20,000	Average Distance (LCRNS)
4	Power, W	1.5	Available SSPA
5	System loss, dB	-3.0	Assumed
6	Antenna Pointing loss, dB	0	Based on antenna type
7	Antenna gain, dB	18.6	Assume 55% efficient antenna
8	Link Margin	3.0	Required

In addition to the communications links, the Command and Data Handling System carries 40 Tb of non-volatile storage, which provides the ability to store 8 hours of data per day at 100 Mbps for up to 14 days (or 24 hours/day for 5 days).

C. Position, Navigation, and Timing

The LSR-M carries two distinct systems within the PNT subsystem. The first is dedicated to navigating the mobility system between deployment locations, while the second provides stable PNT signals to other assets. The rover navigation system is based largely on the work done by the Volatiles Investigating Polar Exploration Rover (VIPER) team and will not be discussed in-depth here. For more information, VIPER references are provided [4], [5]. The second PNT system fulfills two assumptions: a) an LSR terminal reference site will include a suite of extremely stable clocks to maintain lunar time and b) An LSR as a reference site will include sensors which provide a measure of relative position or relative orientation.

To meet these goals, the design includes rubidium clocks with an integrated heater plate to maintain temperature and thus low clock drift. These clocks are assumed to be disciplined by another asset, such as the LCRNS, as part of LunaNet [6]. Additionally, two hemispherical retroreflectors are included on the deck of the rover to provide range measurements for orbiting assets or a relative attitude.

D. Thermal Control

The thermal control system maintains the operating temperature of the electronics and other components of the LSR-M within their desired temperature range. This is accomplished by insulating the electronics and battery boxes to minimize heat loss to the surroundings and provide a means of controlled heat rejection for when the internal heat production is greater than what is needed. To accomplish these functions, the main components of the thermal system include:

- Radiator panels for removing the waste heat from electronics
- Heat pipes and cold plates for moving the heat from the electronics package to the radiator
- Multi-layer insulation (MLI) to insulate the electronics
- Heaters
- Temperature sensors, controllers, switches, and data acquisition

Table 6 provides the specifications used to size the thermal control system components.

Table 6 Specification for the Thermal System Operation

Specifications	Value/ Description
Dimensions: Thermal Vaults	Electronics Enclosure: Length 1.5 m, Width 1.15 m, Height 0.24 m, Surface Area: 4.7 m^2 Battery Enclosure: Length 1.815 m, Width 0.7 m, Height 0.196 m, Surface Area: 3.53 m^2
Waste Heat:	Electronics Enclosure: 216 W (daytime), 34 W (nighttime) Battery Enclosure: 34 W (daytime), 34 W (nighttime)
Operating Temperature:	Thermal Vault: Daytime 300 K Max, Nighttime 285 K, Min
Insulation (MLI)	25 layers of MLI are used to cover all external surfaces for the communications enclosures
Environment	for Electronics and Battery, 267 K to 64 K sink temperature range on the surface
Radiators	Horizontal surface mount radiator for rejecting heat from the electronics and battery enclosures.
Cooling	Variable conductance water heat pipes with cold plates are used to move the heat from the electronics to the radiator.
Heating	Electric heaters are used to provide heating to the internal components as needed.

E. Electrical Power System (EPS)

The baseline design of the LSR-M relied on a Solar Array alone for power generation. In discussion of the later cases, the incorporation of an MMRTG will be discussed. To assess the power requirements, Table 7 provides a power equipment list (PEL).

Table 7 Power Requirements by Power Mode

Description	Power Mode 1	Power Mode 2	Power Mode 3	Power Mode 4	Power Mode 5	Power Mode 6	Power Mode 7	Power Mode 8	Power Mode 9	Power Mode 10
Case 3_Lunar Surface Relay CD-2023-197	Sunlit Recharge	Commissioning and Checkout (sunlit)	Deploy from Lander (sunlit)	LSR Transit (sunlit)	LSR Peak Transit (sunlit)	LSR DTE Operations (sunlit)	LSR LCRNS Operations (sunlit)	LSR Gateway Operations (sunlit)	LSR Hibernation (shadow)	LSR Health Check Operations (shadow)
	x hours	72 hours	72 hours	100 hours	30 mins	up to 354 hours	up to 354 hours	up to 354 hours	346.5 hours	~7.5 hours per 354 hours of shadow
	(W)	(W)	(W)	(W)	(W)	(W)	(W)	(W)	(W)	(W)
Lunar Surface Relay (LSR)	**80.6**	**234.5**	**207.6**	**334.6**	**667.8**	**217.5**	**282.8**	**230.0**	**53.7**	**149.6**
Lunar Surface Relay (LSR)	80.6	234.5	207.6	334.6	667.8	217.5	282.8	230.0	53.7	149.6
Attitude Determination and Control	38.0	52.0	60.0	56.0	56.0	40.0	39.0	39.0	34.0	34.0
Command & Data Handling	8.5	45.5	40.5	25.5	25.5	35.5	53.5	53.5	1.5	9.0
Communications and Tracking	0.0	117.0	10.1	10.1	10.1	117.1	162.1	112.1	0.0	75.1
Electrical Power Subsystem	34.1	20.0	17.0	43.0	76.2	24.9	28.2	25.4	15.2	31.5
Thermal Control (Non-Propellant)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0
Mobility	0.0	0.0	80.0	200.0	500.0	0.0	0.0	0.0	0.0	0.0
Bus Power, System Total	81	234	208	335	668	218	283	230	54	150
30% growth	24	70	62	100	200	65	85	69	16	45
Total System power with growth	105	305	270	435	868	283	368	299	70	195

Solar Array Driver Battery Driver

The EPS is responsible for generation, storage, and distribution of electrical power to the various loads on the LSR-M. The energy storage consists of a lithium-ion battery, which is discharged during shadowed operations as well as roving. The nighttime duration is the sizing mode for the battery, to support 346.5 hours of nighttime hibernation (Power Mode 9), as well as 7.5 hours of nighttime health check operations (Power Mode 10). The solar array is sized to accommodate the peak sunlit mode (Power Mode 7) as well as recharging the battery to prepare for another shadow period. It is worth noting that, although these CONOPS assumed a maximum night period of 354 hours, location choice on the south pole can make this number higher or lower, depending on terrain.

F. Mobility System

The mobility system of the LSR-M is based on a scaled-up version of the VIPER chassis with one notable difference: This design uses shape memory alloy (SMA) wheels. These wheels accommodate the increased mass of the rover and can deflect without permanently deforming. SMA tires like these are currently TRL 4 for lunar applications. Each wheel (of approximately 80 cm outer diameter) has an independent suspension system that allows the rover to level on a 10 degree slope. The system can traverse slopes of up to 15 degrees and travels at a nominal speed of 0.8 km/hr. As the system is based heavily on the VIPER design, details are not included in this paper, but the concept can be found in the VIPER references [4], [5].

IV. Design Variation- RTG-Enabled LSR-M

Given the promising outcomes of the baseline design, the Compass Team investigated a number of design variations. Unlike the baseline design, these were not ‘full’ design variations (typical Compass process), but rather excursions from the baseline to investigate likely changes implemented in the system. The most promising variation is discussed: adding an MMRTG.

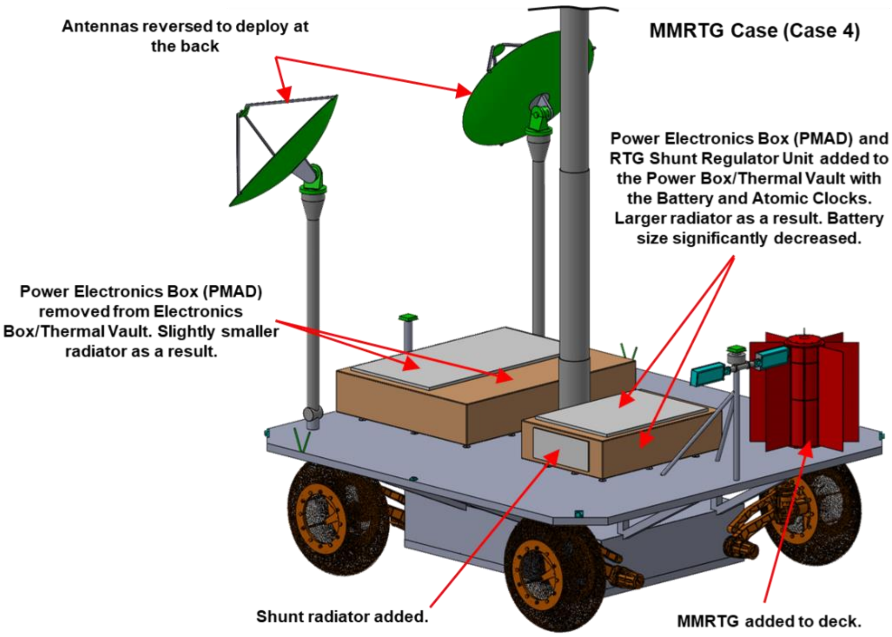

Fig. 11 Changes in Design to Integrate MMRTG

The addition of an MMRTG, producing an estimated 100 We at the start of the mission and an estimated 79 We at the end of mission, promised to provide additional flexibility by removing the LSR-M's reliance on solar power. This allows for winter storage anywhere on the South Pole.

Fig. 11 calls out the main changes made to the system for the RTG case, as compared to the baseline system described above. These include moving the power management and distribution (PMAD) to the battery box and adding a RTG shunt regulator unit. As a result, the radiator size on that box is increased. The addition of the RTG results in the need for less energy storage and thus a much-reduced battery size, freeing up space to include and move these items. Additionally, the antennas are switched to deploy at the other end of the rover to accommodate the RTG on the deck.

Along with the power provided by the RTG, waste heat is also available for use to maintain system operating temperatures. The battery box has enough waste heat that this option was not implemented there, but the electronics box was kept warm by using waste heat from the RTG, transferred via variable conductance heat pipes.

As mentioned above, the battery capacity was reduced as it was no longer required to provide 'keep alive' power during the lunar night. Instead, it was sized to provide roving load leveling to allow for 8 hours of roving prior to recharge, to align with a typical workday. The largest change to the CONOPS was the added ability to provide limited nighttime relay for 4 out of every 24 hours. This is a large improvement over the minimal timing signal and health check capability of the baseline design.

The total mass of the system is approximately 1000 kgs, including 21 percent mass growth allowance (MGA) and 15 percent system level margin, for a cumulative 36 percent. Table 8 shows these masses. The MGA is applied by the subsystem subject matter experts according the AIAA guidelines [3]. This mass is ~200kg less than the corollary solar array/battery system. This may provide benefit by accommodating the rover on a lander more easily, due to the mass reduction.

The MMRTG Case is not without complications, however. Launching an RTG brings additional safety requirements along with the need for a plan for loading the RTG on the pad. These are not insurmountable, however, and large efforts have been made by the Radioisotope Power Systems (RPS) Program to reduce the burden of launching RTGs.

Table 8 Mass Summary for LSR-M Case with MMRTG

MEL Summary: Case 4_RTG_Lunar Surface Relay CD-2023-197	Lunar Surface Relay (LSR)
Main Subsystems	Basic Mass (kg)
RPS	46.0
Attitude Determination and Control	17.7
Command & Data Handling	60.7
Communications and Tracking	84.3
Electrical Power Subsystem	50.3
Thermal Control (Non-Propellant)	40.3
Mobility	187.6
Structures and Mechanisms	249.7
Element Total	***736.5***
Element Dry Mass (no prop,consum)	736.5
Element Mass Growth Allowance (Aggregate)	156.6
MGA Percentage	21%
Predicted Mass (Basic + MGA)	893.1
System Level Mass Margin	110.5
System Level Growth Percentage	15%
Element Dry Mass (Basic+MGA+Margin)	1003.6

V. Conclusions

A. Conclusions and Lessons Learned

Throughout the design of the LSR-M, one key advantage became quite clear: location flexibility. The lunar terrain at the south pole makes line of sight to surface users difficult to maintain and the optimal site for one set of CONOPS may be entirely useless for another sortie site. The ability to relocate the LSR asset provides the ability to select both the optimal relay site for each sortie and the optimal sun site for weathering the prolonged nights during lunar winter. The addition of location choice to the extended line-of-sight-reach of a 10 m boom, as compared with the 2 m height expected on other assets, such as LTV, provides an extended reach for the surface communication systems. Additionally, this lends flexibility to landing options for the LSR-M. It can be delivered to safe, scientifically unimportant regions and can re-locate itself to where it is most needed.

A few challenges were also identified throughout the design process. The paths to reach good visibility hilltops can require traversing challenging terrain and extensive planning. Erecting and collapsing a tall boom is also an unproven technology, although other NASA-funded efforts, such as the Vertical Solar Array Technologies (VSAT) project, are investigating similar efforts. Finally, the 5G and Wi-Fi systems for lunar applications are low TRL and require additional investment to create space rated systems.

Surviving extended periods of shadow on the lunar surface is a large contributor to the mass of the system, requiring ~160 kg of batteries just to provide ‘keep alive’ conditions. For a mobile system, however, nighttime survival batteries can be re-used to provide extended mobility times. Accounting for the ripple effect through the design, the mass of overnight systems (batteries, more array area, insulation, standoff structures) totals more than 300 kg including the appropriate MGA and margin percentages. This is a significant amount of mass to deliver to the moon.

Adding an MMRTG system, providing ~79 We at end of mission provided several advantages over the baseline design. Rather than simply ‘keep alive’ and minimal health checks, the system can provide 4 hours of science relay every 24 hours (~36 kbps). Additionally, the mass of the battery can be reduced by a factor of 10, leading to a total rover mass reduction of ~215 kg! This still maintains enough battery to be able to drive with the mobility system for 8 hours a day. In rough metrics, adding survive the night capability to the solar array/battery only case required ~4.4 kg per 1W needed for 354 hours overnight. However, if an RTG was used instead, this value dropped to ~1.4 kg per 1W of overnight power.

B. Next Steps

The LSR-M studies produced promising results at the conceptual design level and pointed to future analysis to further mature the concept. Along the design path, the Compass team investigated other variations to the LSR-M, beyond the RTG implementation. These included adding an optical communications technology demonstrator and attempting to reduce cost and mass by offloading the backhaul capability and focusing on surface assets only. Future investigations can also include implementing and deploying the LSR-M in an equatorial environment. As currently designed, it can operate in the equatorial environment and could help extend the reach of 5G systems, but is not relocatable between regions, say polar operation to equatorial, due to the travel distances involved.

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VI. Supporting Materials

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