5G System for Lunar Surface Communications Evaluation
And Radio Propagation Measurements

Statement of Work (SOW)

1. BACKGROUND

This Statement of Work (SOW) outlines the initial phase of NASA's lunar 5G communications deployment, a foundational element of the Ignition Moon Base initiative. The project leverages a decision from the Moon-to-Mars Analysis of Alternatives, which identified a hybrid architecture combining 3GPP cellular and Wi-Fi wireless technologies as optimal for lunar surface operations. This effort aims to advance the technology readiness level of lunar 5G base stations and user equipment from TRL 3 to 6/7. This work ensures that robust communication capabilities mature in parallel with mobility systems, payload operations, and human-systems planning, accelerating NASA's vision for early lunar surface operations and supporting the rapid development of the Moon Base.

Crewed and uncrewed missions to the Moon require robust, low-latency and high-throughput surface wireless communications capabilities to carry out scientific experiments, enable payload activities and support future industrial development on the lunar surface. Currently envisioned solutions are based on 3GPP cellular technologies and provide a network-centric approach to the lunar surface communication challenge in which a Network-in-a-Box (NIB), integrated onto a lander or a large rover, provides wireless connectivity to all end-user devices, called user equipment (UE), carried by payloads, small rovers and/or astronauts. This type of network architecture is well suited for providing very high data rates and large coverage areas around the NIB and can be expanded easily by deploying more NIBs as the use cases and deployment requirements evolve.

This network architecture is complemented and expanded with direct device-to-device connectivity and a mesh network between end devices for the devices outside of the NIB coverage area. Such direct connectivity and a mesh network are critical to ensure communication between end devices outside of a NIB, extend the coverage area locally around the devices, and optimize efficient sharing of information and data between end devices for local coordination, mission operations and planning. The end devices (i.e. the UEs) are directly interconnected in a full mesh network using device-to-device connectivity via 5G New Radio (NR) SideLink. Some or all of the end devices may act as aggregators and connect to one or more of the NIBs using direct 5G connections (using the Uu Interface), if such a network node is present and accessible. The NIBs could, for example, be mounted on a lander, Lunar Terrain Vehicle (LTV), Pressurized Rover (PR) or Multi-Purpose Habitat (MPH) or be standalone nodes on the lunar surface. The mesh network extension needs to be fully compatible and coexist with the network centric

approach, leveraging 3GPP 5G NR capabilities to guarantee interoperability of the overall end-to-end network.

The lunar surface communications network is centered around a highly compact, SWaP (size, weight and power) optimized, resilient architecture that comprises:

1. 3GPP standard compliant Network-in-a-Box (NIB) that consolidates all the 5G Radio Access Network and 5G Core Network functionalities.
2. The 5G NIB is comprised of a Digital Processing Unit (DPU) and one or more Radio Units (RU) along the Split 7.2 option.
3. The Digital Processing Unit (DPU) includes the 5G Centralized Unit (CU), the 5G Decentralized Unit (DU) of the 5G radio access, and the 5G Core Network.
4. The Radio Unit (RU) includes the lower physical layer, the digital front end, the power amplifiers and filters.
5. The Digital Processing Unit and the Radio Unit also include all the Operations and Management (O&M) software.
6. Each Digital Processing Unit can support up to 4 RUs in a modular fashion (for example for a sectorized solution).

The lunar surface communications network will also have integrated Wi-Fi 6 networking capabilities with a Wi-Fi mesh network between end devices. The Wi-Fi 6 solution is integrated into the same hardware form factor with the 5G solution in a modular fashion and can be removed as an option if Wi-Fi 6 is not needed for certain deployments or missions.

An end-to-end communication solution also includes 3GPP standard compliant User Equipment (UE) that can be connected to the 5G NIB over the Uu interface. In addition, the 5G NIB and 5G UE also support Mode 1 SideLink with a mesh network between the UEs.

2. SCOPE OF WORK (CLIN STRUCTURE)

2.1 CLIN001 OVERVIEW

5G NIB Development and Lab Demonstration: The Contractor shall develop a next generation Network-in-a-Box (NIB) prototype system that includes 5G and Wi-Fi 6 along with a wideband antenna for 5G and Wi-Fi 6 and operation in multiple frequency bands. The prototype system will use industrial-grade components and demonstrate the key functionalities and capabilities in a lab environment.

2.1.1 WORK SCOPE

The Contractor shall develop a 5G Network-in-a-Box (NIB) operating in band N78 to provide extended 5G coverage and connectivity that support 5G New Radio (NR) User Equipment (UE) on both the direct link over the standard Uu interface and over the 5G SideLink. The mesh networking capabilities between the 5G NR UEs are under the control of the 5G NIB and provide the network-assisted SideLink configuration and scheduling (called SideLink Mode 1 in the 3GPP standards). The 5G NIB shall support the following configurations:

- 3GPP 5G NIB connecting 5G NR UEs in Mode 1 with a NIB assisted UE autonomous SideLink mesh network,
- 3GPP 5G NIB connecting 5G NR UEs in Mode 0 over the standard Uu interface.

In addition to the above 5G NIB capabilities, the Contractor shall develop, build, integrate and demonstrate Wi-Fi 6 access point capabilities with a Layer 3 mesh networking developed on top of 802.11s ad-hoc capabilities. CLIN 0001 will develop all the needed mesh network and software functionalities.

Further, the Contractor shall also develop and demonstrate wideband antennas for the NIB that support:

- Operation in band N41 and N78 for 5G NIB,
- Simultaneous operation in 2.4GHz and 5GHz bands for Wi-Fi 6.

Finally, the Contractor shall demonstrate the hybrid network architecture of 5G NIB with 5G NR UE with SideLink Mode 1 and Wi-Fi 6 mesh networking as an advanced lab system. The lab prototype system will also demonstrate the connectivity of the 5G NR UE to a 5G NIB using Mode 0. This lab prototype demonstration will accelerate the technology readiness level in preparation for future lunar missions.

2.1.2 OBJECTIVES

Objective 1: Build the 5G NIB (for integrated gNodeB and core network software) and Wi-Fi 6 hardware proof of concept unit (as bread boards initially and targeted flight hardware subsequently) supporting 5G Sidelink Mode 1 and Wi-Fi 6. The bread board unit serves to advance and test the NIB capabilities and the connectivity and interoperability with UEs. The system includes a single-sector 5G NIB prototype unit comprised of a Digital Processing Unit (DPU) (with the 5G DU, CU and 5G Core) and a 2 x 4 MIMO RU unit (with 2 transmit and 4 received antennas and operating in band N78) based on the targeted flight hardware and software architecture using industrial-grade components. The 5G components are pin-compatible with radiation tolerant / space hardened variants of the same components; while the Wi-Fi 6 solution will utilize firmware modifications, hardware protectors and component redundancy to improve the radiation tolerance as much as possible.

Objective 2: Develop software for the 5G NIB SideLink Mode 1 and Wi-Fi 6 access point and mesh networking functionalities.

Objective 3: Integrate the 5G NIB and Wi-Fi 6 software with the NIB targeted flight hardware and create a 5G and Wi-Fi 6 NIB prototype unit using industrial grade components and all needed software for 5G SideLink Mode 1 and Wi-Fi 6.

Objective 4: Development of a wideband antenna for the NIB supporting both 5G in band N78 and Wi-Fi 6 in the 2.4GHz and 5GHz bands, respectively.

Objective 5: Demonstrate the 5G and Wi-Fi 6 prototype unit in a lab environment and validate the key functionalities and performance objectives of the NIB to meet the target use cases and mission requirements. This may include a demonstration of an end-to-end network connecting the 5G NIB to 5G NR UE prototype units with SideLink Mode 1 as well as a demonstration of Wi-Fi 6 with a mesh network between UEs.

2.1.3 CONTRACTOR TASKS

The Contractor shall perform the following activities accompanied by the deliverables listed in Section 2.1.5.

1. **Project Kickoff Meeting**

   The Contractor shall present, and review project plans, schedules, and activities required to meet the program delivery, including the recommended list of main key performance parameters (KPP). The project kickoff meeting shall be conducted at the Contractor facility.

2. **Preliminary System Requirements Review**

   The Contractor shall submit an initial list of target requirements for the:

a. 5G NIB with SideLink Mode 1 to support anticipated use cases

b. Wi-Fi 6 to be integrated in a modular fashion with the 5G NIB to support anticipated use cases

c. Wideband antenna for multi-band operations for 5G and Wi-Fi 6

NASA will review and provide comments via offline interactions. NASA will also provide updates to use cases and requirements for lunar missions that may impact the 5G NIB, the integrated Wi-Fi 6, and the wideband antenna system.

3. Final System Requirements Review

The Contractor shall present the final list of the 5G NIB, the integrated Wi-Fi 6 and the wideband antenna system requirements and use cases.

The Contractor shall provide the final system requirements document and receive the signoff from NASA on use cases, system requirements and performance parameters. This agreed-upon version will be considered the baselined document.

Any proposed change to the baselined requirements will require NASA approval.

4. Preliminary Design Review (PDR) of 5G and Wi-Fi 6 NIB (including SideLink Mode 1) and the Wideband Antenna

The Contractor shall create a Preliminary Design Review (PDR) package, in supplier format, for the 5G NIB with integrated Wi-Fi 6 and a wideband antenna based on the baselined requirements.

The Contractor shall present the PDR material to NASA and gather feedback for incorporation in the next development phase.

5. Critical Design Review (CDR) of 5G and Wi-Fi 6 NIB (including SideLink Mode 1) and the Wideband Antenna

The Contractor shall create a Critical Design Review (CDR) package, in supplier format, for the 5G NIB with integrated Wi-Fi 6 and a wideband antenna including feedback from NASA on the PDR material. In addition to the technical design, the Contractor shall present path-to-flight hardware options for the next phase of the design.

A CDR meeting will be conducted at the Contractor's location.

NASA will review and sign off the CDR material prior to manufacturing the 5G and Wi-Fi 6 NIB units.

6. Development of 5G NIB software (in particular supporting network assisted SideLink Mode 1) and the Wi-Fi 6 mesh networking software

The Contractor shall develop the 5G NIB software including SideLink Mode 1 and the Wi-Fi 6 software. The 5G and Wi-Fi 6 NIB shall be capable of connecting to 5G NR UE prototype units using 5G SideLink Mode 1 and Wi-Fi 6.

7. Development of Wideband Antennas

The Contractor shall develop a wideband antenna that supports both N78 for 5G and 2.4 GHz and 5 GHz for Wi-Fi 6, respectively.

8. Build Integrated 5G and Wi-Fi 6 NIB Prototype Engineering Units

The Contractor shall build two (2) functioning prototype engineering units of a 5G and Wi-Fi 6 NIB along with industrial prototype wideband antennas. In addition, the Contractor shall develop and integrate the associated software components for the 5G and the Wi-Fi 6 NIB including the basic operations and management (O&M) related software components to ensure its proper operation.

9. Lab Demonstration of Integrated 5G NR and Wi-Fi 6 Prototype

The contractor shall demonstrate:

a. A 5G and Wi-Fi 6 NIB to validate its capabilities, key features, functional characteristics and quantify its performance in a lab environment with relevant use case testing and mission-realistic traffic profiles.

b. The NIB shall be connected to a mesh network of at least three (3) 5G NR UE prototype engineering units connected via SideLink Mode 1 and via Wi-Fi 6 to validate the end-to-end network capabilities, key features, functional characteristics and quantify its performance in a lab environment.

Results from the demonstration shall be summarized in a test report delivered to NASA.

10. Final Report

The Contractor shall submit a final report with the project outcomes and deliverables for NASA review and acceptance.

2.1.4 REPORTING REQUIREMENTS

1. Technical Interchange Meetings (TIMs)

The Contractor shall meet with NASA regularly at a cadence agreed upon by the Contractor and NASA but at a minimum every two weeks. During the TIMs, the Contractor shall present technical and programmatic accomplishments as well as challenges

and risks. The TIMs shall allow for collaboration and provide NASA with detailed insight into progress.

2. Monthly Progress Reports

The contractor shall report status in person or via teleconference to the TM or designated alternates monthly. Reports shall include development status, risk characterization, schedule overview, monthly accomplishments and upcoming milestones. The contractor shall provide all reports at least one day in advance of the monthly meeting via email and maintain an email distribution list with the concurrence of the TM. The contractor shall comply with all additional requests for status meetings and reports.

2.1.5 DELIVERABLE SCHEDULE

The required deliverables are listed in Table 1. Deliverables shall be in supplier format unless indicated otherwise and should be delivered to the TM and COR.

Table 1. CLIN 0001 Deliverables and Due Dates

#	**Deliverables**	**Date / Frequency**
1	Kick-off Meeting Presentation	ATP + 2 weeks
2	Monthly Progress Reports	End of each month
3	Preliminary System Requirements Document	ATP + 4 weeks
4	Final System Requirements Document	ATP + 8 weeks
5	Preliminary Design Review Presentation	ATP + 4.5 months
6	Critical Design Review Presentation	ATP + 8.5 months
7	Final Lab Demonstration	ATP + 15 months
8	Final Report	ATP + 17 months

2.1.6 MILESTONE PAYMENT SCHEDULE

Table 2 defines the milestones and associated milestone payments for CLIN 0001.

Table 2. CLIN 0001 Milestone Payment Schedule

#	Milestone	Success Criteria	Milestone Payment
1	Kick-off Meeting	Summary level project plans, schedules, and activities required to meet delivery documented in the presentation and covered during the meeting.	TBD
2	System Requirements Review	Final list of system requirements documented, covered during the meeting and approved by NASA.	
3	Preliminary Design Review	Preliminary Design Review package submitted and reviewed during the meeting and approved by NASA.	
4	Critical Design Review	Critical Design Review package submitted and reviewed during the meeting and approved by NASA.	
5	Final Lab Demonstration	Lab Demonstration of 5G and Wi-Fi 6 NIB and end-to-end network connectivity to 5G NR UE Prototype Units.	
6	Final Report	Final Report including project outcomes.	

2.2 CLIN002 OVERVIEW

3GPP/5G and Wi-Fi 6 Integrated Surface Network and Flight Demonstration on Lunar Surface: The Contractor shall develop, manufacture, and demonstrate on lunar surface an integrated 5G NR and WiFi 6 communications system by connecting a lander-mounted NIB with rover/hopper-mounted user equipment over a 1–2 km range. The demonstration will characterize lunar RF propagation, evaluate key radio parameters, and calibrate models to support future mission network deployment and operations planning. This CLIN will begin upon completion of the System Requirements Document delivery from CLIN 0001.

2.2.1 WORK SCOPE

The scope of this project is to develop a minimum viable solution of a 5G NR UE and 5G NIB with integrated Wi-Fi 6 with the key features needed to successfully demonstrate the network solution on the lunar surface and accelerate the technology readiness level in anticipation of operational readiness for subsequent lunar missions. The envisioned technology demonstration would include a 5G and Wi-Fi 6 NIB integrated into a lunar lander and connecting one or more 5G NR and Wi-Fi 6 UE integrated into lunar rovers / hoppers with a targeted maximum range of 1-2km. The demonstration will quantify the RF propagation environment on the lunar surface, investigate the impact of different RF parameters in terms of radio frequency, channel bandwidth, RF transmit power, etc. The demonstration will allow calibration of the propagation models being developed and potentially used for future network deployment and mission operations planning.

2.2.2 OBJECTIVES

Objective 1: Development, system testing, and proto-qual testing of a 5G NR and Wi-Fi 6 UE and NIB solution on target flight HW/SW architecture using industrial-grade components.

Objective 2: Integration with lander and rover/hopper mission partners (to be identified and selected).

Objective 3: Milestone-based program with System Requirements Review (SRR), Preliminary Design Review (PDR) and Critical Design Review (CDR) gates.

Objective 4: Functional testing of 5G NR and Wi-Fi 6 UE and NIB capabilities, validation of key features and performance objectives in terrestrial mission emulation.

Objective 5: Demonstration on lunar surface.

2.2.3 CONTRACTOR TASKS

The Contractor shall perform the following activities accompanied by the deliverables listed in 2.2.5.

Specific tasks of the project include:

1. **Project Kickoff**

   The Contractor shall host a Kickoff Meeting within 2 weeks of CLIN award.

2. **Systems Requirements Document (SRD)**

   The Contractor shall create a system requirements document (SRD) that defines the hardware, software, and firmware requirements and traces to NASA requirements in EHP-10068_RevA_Change_1. The SRD shall be reviewed by NASA for concurrence.

3. **UE 5G Mode 1 and Wi-Fi 6 Benchtop Test**

   The Contractor shall develop software, integrate software with system, and complete benchtop test of 5G Mode 1 and Wi-Fi 6 for the UE.

4. **5G and Wi-Fi 6 Proto-flight Development**

   The Contractor shall develop, test (system and qualification), and manufacture proto-flight units of wideband omni-directional antenna for the UE and NIB for operation in multiple 5G and Wi-Fi 6 frequency bands.

5. **Obtain Range Safety and RF Transmission Licenses**

   The Contractor shall coordinate with the appropriate entities in NASA, National Science Foundation (NSF), Federal Communications Commission (FCC), ITU-R and/or National Telecommunications and Information Administration (NTIA) to ensure 5G-NR equipment (3GPP Band N41 and N78) can be operated on the Moon and the appropriate waiver licenses are obtained and include status in the Project Monthly Status report.

   The Contractor shall coordinate with the Range Safety Office to provide all documentation as per AFSPCMAN 91-710, Vol 1, Chapter 3 and include status in the Project Monthly Status report.

6. **Operations and Management (O&M) Development**

   The Contractor shall develop and test Operations and Management (O&M) platform, software agents, and mission control software.

7. **5G and Wi-Fi 6 UE and NIB Reliability Design and Test**

The Contractor shall meet hardware and software reliability assurance requirements; test (system and qualification) the integrated 5G NR and Wi-Fi 6 UE and NIB.

8. Manufacture Engineering and Redundant Proto-Flight UE and NIB

The Contractor shall manufacture engineering and redundant proto-flight units of the integrated 5G NR and Wi-Fi 6 UE and NIB. NASA will be permitted to conduct inspections at key points during the manufacturing process on a non-interference basis. Inspections shall be coordinated between the Contractor and NASA early to ensure inspections cause no schedule impact.

The Contractor shall also provide all flight paperwork equivalent to a CLPS mission. This includes CONOPS, procedures, drawings, bill of materials, mass properties, structural analysis, thermal analysis, and test results as available. Updates will be provided as available.

9. Terrestrial Demonstration

The Contractor shall conduct end-to-end system testing and validation in terrestrial demonstration / mission emulation.

10. UE and NIB Lunar Vehicle Integration

The Contractor shall integrate UE into deployed rovers / hoppers and integrate NIB into lander (the exact effort required depends on the selected lander and rover / hopper mission partners).

11. RF Propagation Measurement Software Development

The Contractor shall develop and test software (for the UE, NIB and O&M) for the RF propagation measurements on lunar surface.

12. Lunar Surface Demonstration

The Contractor shall support lunar surface demonstration and collect RF propagation measurement data and deliver to NASA.

Some of the system specifications need to be confirmed / defined once the lander and the rover / hopper partners are identified.

13. Final Report

The Contractor shall submit a final report with the project outcomes and deliverables for NASA review and acceptance.

2.2.4 REPORTING REQUIREMENTS

1. Technical Interchange Meetings (TIMs)

The Contractor shall meet with NASA regularly at a cadence agreed upon by the Contractor and NASA but at a minimum every two weeks. During the TIMs, the Contractor shall present technical and programmatic accomplishments as well as challenges and risks. The TIMs shall allow for collaboration and provide NASA with detailed insight into progress. During execution overlap with CLIN 0001, one TIM for both CLINs is acceptable.

2. Monthly Progress Reports

The contractor shall report status in person or via teleconference to the TM or designated alternates monthly. Reports shall include development status, risk characterization, schedule overview, monthly accomplishments, and upcoming milestones. The contractor shall provide all reports at least one day in advance of the monthly meeting via email and maintain an email distribution list with the concurrence of the TM. The contractor shall comply with all additional requests for status meetings and reports.

2.2.5 DELIVERABLE SCHEDULE

Table 3 defines the deliverables for CLIN 0002.

Table 3. CLIN 0002 Deliverable Schedule

#	**Deliverables**	**Due Date**
1	Kickoff meeting Presentation	Start date + 2 weeks
2	Monthly Progress Reports	End of each month
3	System Requirements Document	Start date + 4 months
4	Preliminary Design Review Presentation	Start date + 6 months
5	Critical Design Review Presentation	Start date + 9 months
6	Test Readiness Review Presentation	Start date + 15 months
7	Bench Demonstration and Test Report	Start date + 18 months
8	Lunar Demonstration	Start date + TBD
9	Final Report	Start date + 23 months

2.2.6 MILESTONE PAYMENT SCHEDULE

Table 4 defines the milestones and associated milestone payments for CLIN 0002.

Table 4. CLIN 0002 Milestone Payment Schedule

#	Milestone	Success Criteria	Milestone Payment
1	Kick-off Meeting	Summary level project plans, schedules, and activities required to meet delivery documented in the presentation and covered during the meeting.	TBD
2	System Requirements Review	Final list of system requirements documented, covered during the meeting and approved by NASA.	
3	Preliminary Design Review	Preliminary Design Review package submitted and reviewed during the meeting and approved by NASA.	
4	Critical Design Review	Critical Design Review package submitted and reviewed during the meeting and approved by NASA.	
5	End-to-End System Testing and Validation in Terrestrial Demonstration / Mission Emulation	Lab Demonstration of Mode 0 and Mode 1.	
6	Lunar Demonstration	Lunar Surface Demonstration of end-to-end network connectivity between NIB to 5G NR UE.	
7	Final Report	Final Report, in supplier format, of the project outcomes.	

3. TECHNOLOGY READINESS LEVEL (TRL) ADVANCEMENT

5G Communications System (NIB, UE)

Before contract: TRL 3

After execution: TRL 6/7

This effort advances a lunar surface 5G communications payload (NIB and UE) from a laboratory and prototype system demonstration to an operational environment demonstration. The payload consists of an integrated 5G-NR system implementing both the NIB and UE functionality within a common avionics architecture. The hardware utilizes a combination of commercial, automotive-grade and industrial-grade components selected to provide a development path toward future radiation-tolerant and radiation-hardened implementations.

Prior to flight, the integrated system will be demonstrated in representative lunar mission environments through subsystem integration, environmental testing, and end-to-end communications validation, achieving a TRL of 6. The proposed lunar surface demonstration will operate the integrated communications system in the actual mission environment and validate key operational capabilities, including network establishment, device registration, timing and synchronization, uplink and downlink communications, command and telemetry transport, fault recovery, and sustained system operation.

Successful completion of the lunar surface demonstration will advance the integrated 5G communications payload to TRL 7 by demonstrating a prototype system in an operational lunar surface environment. The demonstration will also reduce technical risk associated with future lunar surface communications architectures and provide a direct path toward flight-qualified, radiation-tolerant implementations for sustained Artemis and Moon Base exploration missions

4. APPLICABLE DOCUMENT LIST

Document ID	**Document Name**
EHP-10068-RevA_Change_1	Extravehicular activity and human surface mobility program (EHP) communications specification

[End of SOW]