Work Plan 2024 for Moonlight Advanced Technologies Activities

Work Plan Rationale

The focus of the Moonlight programme endorsed with the current funds from CM22 is the Partnership Project to be put in place to foster the emergence of a European Cislunar communication (COM) and navigation (NAV) services provider. However, in a context of international cooperation and future perspective, it is equally important to prepare the future with relevant activities not directly addressed by the Partnership Project. This also provides opportunities for a wider European/Canadian industrial involvement in the development of cislunar COM and NAV solutions for the return of humans to the Moon. More specifically, the Advanced Technologies activities are expected to address in the medium- to long-term:

- The second generation of the Moonlight system, including the consolidation of domains not addressed by Gen 1 (e.g. SAR services, Lunar surface nodes)
- Any technologies required for other future cislunar communication and/or navigation systems
- Any other systems exploiting the communication and navigation services for broader purposes (e.g. local surface augmentations enhancing further Moonlight services; exploiting the combination of Moonlight signals with other sensors; and supporting scientific applications).

In that spirit, the 2024 Work Plan is articulated around three main axes:

- Preparing for future Lunar market evolution
- Enhancing Moonlight services acceptance and user engagement
- Supporting international cooperation.

Other complementary axes (e.g. support to scientific applications) may be considered in future Work Plans, in consistence with the Work Plan rationale.

Preparing for Future Lunar Market Evolution

With more than 400 Lunar missions planned in the next 10 years alone, and with the gradual adoption of COM and NAV services for Lunar missions, the COM capacity demand is expected to grow, potentially well above the capacity supported by currently allocated frequency spectrum. This naturally calls for using optical communications in the future. It is therefore important to prepare solutions suited to the cislunar communication scenario. This is in particular the topic of **ML-COM-01 (**Lunar Laser Communication Terminal).

The Agency has been very proactive with NASA in promoting an international interoperability framework under the LUNANET initiative. Ultimately there will be several systems operating around the Moon. To ensure the best possible services to users, such as higher reliability or continuity of services, and ensure an efficient and sustainable use of system resources and spectrum, this multiple system environment will call for service orchestration and interoperable network management functions, the topic of the **ML-COM-02** activity. On the user side, this will also imply the ability to operate seamlessly with several systems with, in particular, the capability to connect to multiple systems simultaneously, the topic of the activity “Multi-beam reconfigurable user terminal antenna for continuous connectivity on the Moon” **(ML-COM-04)**. This activity will also enable hot redundancy communications, a fundamental aspect to support human spaceflight operations.

In the medium to long term, the number and needs of surface assets will naturally increase in certain areas with corresponding demands for Moon surface specific COM and NAV augmentation solutions. It is therefore important to prepare the ground for “Architecture for local proximity communications on the Moon surface” (**ML-COM-03)** as well as navigation “Lunar local Moonlight/LunaNet augmentation system” (**ML-PNT-03).**

Enhancing Moonlight Services’ Acceptance and User Engagement

One of the most important factors for the successful take-up of the Moonlight services by the Lunar mission community is to ensure readiness of the technologies needed to be installed on board their own Lunar mission’s assets, namely the user terminal. For this reason, three activities have been defined to address building blocks of such user terminal functions with a combined Communication and Navigation user S-band antenna (**ML-PNT-05)**, a miniaturised LunaNet PNT user terminal receiver (**ML-PNT-02)** and a LunaNet S-Band communication user terminal transceiver (**ML-COM-05)**.

Another path to facilitate user adoption is through validation of the performances and supporting user testing in representative conditions, the topic of one of the Work Plan activities aiming for an Earth-based field-testing facility of Moonlight PNT signals using drones (**ML-PNT-01)**.

Supporting International Cooperation

The endeavour for the return to the Moon will be primarily kick-started and fuelled financially by institutions setting the scene and key standards for the growth of commercial initiatives and applications. In this cooperative environment, ESA is proposing the activity “Enhancing the selenodetic reference frames and Lunar reference time” (**ML-PNT-04)** aimed at ensuring that Europe plays a major role in the establishment of internationally-recognised Lunar selenodetic reference frames and Lunar reference time, including its permanent formal monitoring and enhancement.

1. <u>Lunar COM Activities</u>

Five complementary Lunar COM activities are proposed in the 2024 Work Plan:

1. ML-COM-01: Lunar Laser Communication Terminal
2. ML-COM-02: Service orchestration and interoperable Network Management;
3. ML-COM-03: Architecture for local proximity communications on the Moon surface;
4. ML-COM-04: Multibeam reconfigurable user terminal antenna for continuous connectivity on the Moon;
5. ML-COM-05: LunaNet S-band communication user terminal transceiver.

The five activities are described hereafter.

- **ML-COM-01: Lunar Laser Communication Terminal:**

The objective of the activity is to design first a Laser Communication Terminal (LCT) concept suitable for communication over Lunar distances. In a second step, the activity will develop an engineering model of a CCSDS compatible transceiver with critical functions including coding, synchronisation, and modulation.

This activity will enable a European or Canadian laser optical terminal source of future Lunar LCTs, requiring high data rate links. LCT links are currently available for near-Earth (LEO, GEO) and for deep-space (beyond the Moon) applications. The latter is not suited for this type of link as it is based on the "high-photon efficiency" standard and limited to data rate inferior to that required for Lunar communications. Lunar links require the development of both a modified LCT concept and a new transceiver, capable of delivering at least 5 Gbps, for which the standard is currently under definition at CCSDS. Currently several LCTs (transceiver included) for Earth orbit applications are available and several others are under development in Europe. The Lunar LCT concept and transceiver engineering model that will be developed in this activity, will have to be adapted for Lunar distances and the specific operating environment. The design shall support coding, synchronisation, and modulation for at least 5 Gbps rate over Lunar distance.

- **ML-COM-02: Service Orchestration and Interoperable Network Management**

The objective of this activity is to analyse, develop and evaluate concepts for the coordination of the provisioning of communication services to multiple users and across different communication providers. This includes planning and scheduling of communication resources, network management and the provision of user-initiated services.

While the provisioning of communication service can initially rely on manual processes and coordination between users, serving larger user bases should be supported by increasing automation in planning and scheduling the required resources taking agreed Service Level Agreements into account. Furthermore, as multiple communication service providers are expected to be operational for Lunar communication based on the LunaNet Interoperability specification, coordination between these providers for interoperable use of communication resources is required. Dedicated network monitoring and management functions are expected to evolve. To guarantee secure exchange of data, concepts for security management including exchange of credentials across terrestrial and space networks need to be developed.

The activity will analyse and develop concepts for the planning and scheduling of communication sessions based on inputs from multiple users, in accordance with the LunaNet Interoperability Specification. Such planning and scheduling will eventually include communication resources of other providers and related coordination (the user of one communication infrastructure transparently using another infrastructure, like roaming' in terrestrial cellular networks). In addition, the integration of ad-hoc, user-initiated services (i.e. a Lunar asset autonomously requesting a communication session) shall be investigated. Network Management based on proposed standards should be considered to monitor and control service provisioning. Security and the management of security shall be considered as a cross-cutting concern, as it is required for all steps, including service negotiation, service provisioning and management. In particular, the secure exchange of credentials with service users and across network providers shall be studied. The developed concepts shall be demonstrated in a simulated environment and recommendations towards implementation shall be provided.

- **ML-COM-03: Architecture for Local Proximity Communications on the Moon Surface**

The objective of this activity is to define a system-level network architecture for local proximity communications on the Moon surface, considering user connection management, authentication, data traffic routing, as well as interoperability with users from other agencies.

A previous activity (e.g. TDE High Data Rate, Adaptive, Internetworked Proximity Communications for Space) has recommended the usage of terrestrial protocols (3GPP and 802.11) in different use cases/scenarios on the Moon surface. In the framework of this activity, a breadboard based on COTS hardware has been developed with the aim to demonstrate data rates achievable with these protocols under different channel conditions.

Starting from reference network architectures for 3GPP and 802.11, this activity will investigate where to allocate the network functions/network elements required to deploy a surface network (authentication server, user data repository, etc.) either on the Moon surface, in Moon orbit or on Earth.
An additional objective will be to investigate the usage of surface communication signals to augment surface PNT functions.

Finally, the aim will be to design a breadboard of the full surface network solution up to TRL 5, increasing the maturity of the technology for the identified scenarios and proposing an architecture that will be portable to a future flight hardware. The scaled EM will demonstrate authentication on the network, surface-to-surface or surface-to-Earth routing of the user data, handover between different base stations, roaming between different networks.

The resulting hardware could be flown opportunistically as payload on a future mission to the Moon to raise the TRL of this technology**.**

- **ML-COM-04: Multibeam Reconfigurable User Terminal Antenna for Continuous Connectivity on the Moon**

The objective of this activity is to develop and test a multi-beam reconfigurable user terminal antenna for assets on the Lunar surface with multi-orbit connectivity.

In the future, several constellations in Lunar orbit might be available and users could be able to reach several relays simultaneously. The satellites orbiting the Moon will not be in a stationary orbit, thus imposing reconfigurability requirements on Ka-band terminals for assets on the Lunar surface. Multi-beam operation will enable make-before-break capabilities, which allows to maintain connectivity while the terminal switches from a satellite to the other. These characteristics will enable the terminal to connect to satellites in any orbit since the beam can be flexibly reconfigured to point to any desired direction and to connect simultaneously to two (or more) different satellites.

In this activity, a multi-beam phased array antenna able to provide a broadband connectivity with satellites in Lunar orbit shall be developed. A Ka band operational frequency will be considered as defined by the relevant Lunar frequency recommendations (SFCG) and the LunaNet interoperability specification. The terminal antenna will support transmit and receive operations either with a single or a dual-aperture solution. In the first part, a phased array antenna will be developed. In the second part, a scaled representative demonstrator of the antenna will be manufactured and tested.

- **ML-COM-05: LUNANET S-Band Communications User Terminal Transceiver**

The LunaNet framework aims to define the specifications required to achieve interoperability among different LunaNet Service Providers (LNSP). As part of the LunaNet Interoperability Specification (LNIS), ESA and NASA have defined the list of services that might be provided by LNSP including data relay services in S-band. The S-band data relay capabilities provided by LNSP compatible with LunaNet will ease the operations of Lunar missions, covering a variety of user scenarios:

- Fixed Lunar surface users (facilities, assets)
- Mobile Lunar surface users (rovers, vehicles, extra-vehicular activities)
- Lunar landers.

Advancing the user technology is considered key to secure the adoption of Moonlight and LunaNet services. In particular, it is critical to have user terminals at engineering model level, reducing the non-recurrent costs of future user missions.

The unit developed within this activity will consider the LunaNet specifications and ensure sufficient level of re-configurability to accommodate specific implementations from different LNSP. The solution shall be based on a scalable and upgradable (flexible) platform focusing primarily on Moonlight communications and upgradable to other relay missions (Lunar Pathfinder, LunaNet, etc) without hardware modification of the core radio. The core radio should be based on flexible architecture, that can be adapted to different use cases (e.g. small/large rover, crewed lander, small/large orbiters) and with different classes of size, weight and power.

Leveraging emerging digital processing technologies, and considering high levels of hardware, firmware/software integration within state-of-the-art FPGAs, System in Package (SiP) and System on Chip (SoC), will enable a collective improvement in digital back-end processing capabilities and efficiency of design.

The activity will cover the design, development, and validation of a full S-Band communications user terminal transceiver Engineering Model (including RF, digital elements and any required software). Further to that, a roadmap for the development of the subsequent qualification and flight models will be presented.

2. Lunar PNT Activities

Five complementary Lunar PNT activities are proposed in the 2024 Work Plan:

1. ML-PNT-01: Earth-based field-testing facility of Moonlight PNT Signals Using Drones;
2. ML-PNT-02: Miniaturised LunaNet PNT User Terminal Receiver;
3. ML-PNT-03: Lunar Local Moonlight/LunaNet Augmentation System;
4. ML-PNT 04: Enhancing the Selenodetic reference frames and Lunar reference time;
5. ML-PNT 05: Combined communications and navigation user S-band antenna.

The activities are described hereafter.

- **ML-PNT-01: Earth-based field-testing facility of Moonlight PNT signals using drones**

The objective of this activity is to define, develop and validate a test facility that generates Lunar PNT-like signals as planned to be broadcast by the Moonlight service on Earth through the use of real RF broadcast signal from moving drones. This facility shall emulate faithfully the actual movement, position and geometry (dilution of precision) of the Moonlight LCNS satellites with respect to the users and replicate the associated RF signals format, power levels and associated characteristics (e.g. RF modulation, frequencies, Doppler ranges, attenuation effects). It shall provide the Moonlight Signal messages in line with the defined Lunanet Signal in space standards protocols and be representative of the designed Moonlight expected performances by providing a good characterisation of the actual orbit and clock on-board accuracies, etc.

This unique facility may allow multiple benefits of the Moonlight Programme, such as:

- the characterisation of realistic Moonlight achievable ML-PNT performances to potential interested users;
- support the testing, qualification and performance assessment of Moonlight LCNS receivers (alone or when integrated with other sensors on Lunarsurface conditions);
- the assessment (prior to launch) with all hardware sensors in the loop of Lunar rover models PNT performances using Moonlight;
- the preparation and support of Lunar PNT interoperability tests among different space agencies;
- to assess and trade off potential Moonlight PNT system evolutions;
- to assess, test and validate potential Lunar surface specific mission scenarios;
- the evaluation of Moonlight PNT local augmentation solutions;

- to support astronaut training and operations using Moonlight PNT services.

- **ML-PNT-02: Miniaturised LunaNet PNT user terminal receiver**

The objective of this activity is to define, develop and validate an Engineering Model of a LunaNet PNT user terminal covering the Lunar Augmented Navigation Service (LANS).

On Earth, the GNSS spaceborne receiver market has increased significantly in the last 20 years, being now the de facto sole equipment for satellite Guidance Navigation and Control and orbit determination in LEO, GTO and GEO. It is expected that the same will happen in cislunar space once Moonlight PNT services are operational. To support this, it is essential to develop engineering models within ESA Member States to secure that the necessary user technology is available in Europe. This, in turn, is key to secure market share and to ensure spaceborne receiver autonomy for future ESA and ESA Member State Lunar exploration missions.

Effort will need to be devoted to reducing the Size Weight and Power (SWaP) of the unit, essential considering the high cost of launch (euro/kg) in cislunar space and the expected limited size and power for some Lunar missions. The target is to have a single hardware unit that can be used in multiple user missions covering orbital, landers and surface users. Part of the software is considered generic and applicable to all users, however the specific navigation engine within the software will be adaptable to the user (e.g. an orbital user will have a very different navigation software with respect to a surface user). For this activity, in addition to the standard navigation algorithm applicable to every user scenario, the navigation software will be focused on Lunar orbiters, targeting the implementation of real time reduced dynamic solution. The development of specific sensor and/or data fusion algorithms expected to be adopted for landers and surface operation will be covered in other activities.

- **ML-PNT-03: Lunar Local Moonlight/LunaNet Augmentation System**

The objective of this activity is to define, develop and verify an EM of a Lunar surface element that augments Moonlight LCNS to facilitate robust metre-level user positioning in the local Lunar area.

There is widespread use of various differential and augmentation techniques on Earth to supplement, monitor and correct satellite-based navigation signals to great effect and as such it is considered a mature technology that has great potential to be leveraged on the moon. This potential is even further enhanced for Moonlight due to the lack of an atmosphere on the Moon, which is one of the main drivers for the augmentation performance in terms of baseline range and latency on Earth. In addition, since service volume is focused on the South pole and because of the smaller radius of the Moon with respect to Earth (about one third), it is estimated that a single well-placed Lunar-based local differential station may provide a service to the majority of the service volume. The ability of the augmentation system to support safety-of-life type applications is also a critical asset when considering crewed operations on and around the Moon.

The aim of this proposed activity is the definition, development and verification of an Engineering Model of the augmentation system and associated user terminal in terms of hardware and software algorithms and then the demonstration of the system operations concept and user performance in different scenarios, up to TRL 6.

- **ML-PNT-04: Enhancement of Selenodetic Reference Fames and Lunar Reference Time**

The objective of this activity is to support the Agency in the international endeavour to define the interoperability standards in terms of selenodetic reference frames and Lunar reference time and in the definition of a mid- and long-term strategy for enhancement of the selenodetic reference frames and Lunar reference time, including potential experimentation and the set-up of dedicated cislunar infrastructures.

This activity is conceived as a framework activity to support ESA in those fields, including as specific tasks:

- Provision of expert support to ESA's participation in relevant international discussions;
- Support to the drafting and/or review of related conventions and standardisation documents;
- Understanding of the necessary links/synergies between the Lunar reference frames (selenodetic and timing) and the Earth-based equivalents;
- Support to ESA in discussions concerning future international governance of these Lunar references and in the identification of a potential and significant European contribution;
- Definition of a mid- and long-term strategy for the enhancement of the realisations of selenocentric reference frames and Lunar reference time;
- Provision of concepts and associated requirements for a reference international selenocentric reference station that could be installed systematically and progressively on the Lunar surface to support the Lunar selenocentric reference frame realisations improvement. This could include, potentially, Moonlight PNT surveyed receivers, laser retroreflectors and Lunar surface VLBI transmitters;
- Assessment of how the Moonlight PNT services (and its planned evolution) may support the actual realisation of the Lunar reference frames and Lunar reference times;
- Definition of how specific atomic clocks on Lunar orbit or Lunar surface could contribute towards the generation of a reference physical Lunar clock providing a physical realisation aligned to the defined international Lunar reference time.
- Elaboration of possible experiments exploiting Earth and Lunar clocks for scientific research, such as general relativity;
- Assessment of how laser ranging emitted from Lunar orbiters, exploiting Moonlight PNT precise orbiting positioning, may be used against surface LRRs in support to Lunar geodesy and reference frames improvement. Conception of a possible experimental set-up and associated mission requirements;
- Assessment of all lessons learned from this exercise and its possible extrapolation to Martian conditions.

This activity is considered highly strategic for Europe to allow it to play an important role in the future definition, enhancement and governance of the reference frames.

- **ML-PNT-05: Combined Communication and Navigation User S-band Antenna**

The objective of this activity is to develop a dual band self-diplexing antenna for cislunar space users to support both the communication and navigation services simultaneously.

For Moonlight users aiming at exploiting both communication and navigation services, it is of interest to seek solutions that implement miniaturisation and synergies in order to reduce as much as possible the Size, Weight and Power (SWaP) of this joint equipment. In this context, a specific antenna supporting both comms and navigation services will be a significant easiness in the utilisation of the Moonlight (and more generally LunaNet standard compatible users) services and will facilitate applications such as differential augmentation systems using Moonlight, requiring reception of navigation signals as well as the capability to perform bi-directional communication.

The antenna will require high stability in terms of RF performance vs temperature and shall be designed and developed in order to receive the signal without severe deformation. Multipath effect mitigation solutions should be analysed in order to minimise the impact of the surrounding environment on the overall antenna performance. At the same time, the antenna can also be used for Lunar missions such as landers or surface rovers, allowing to cover both communication and navigation needs.

This activity will cover the design, development, and validation of a full Engineering Model for the combined communications and navigation user terminal S-Band antenna (including RF, digital elements, and any required software). Further to that, a roadmap for the development of the subsequent qualification and flight models will be presented.

The complete Work Plan 2024 is presented in Annex 1 in tabular form and in detailed form in Annex 2.

An ITT for activities designated Implementation Category R will only be initiated either:

- On the explicit request of at least one delegation; or
- On the initiative of the Executive following consultation of the JCB.

All the work plan activities are currently Category R. Interested industry are encouraged to contact their ESA relevant delegation.

Their contact details are published on https://connectivity.esa.int/national-delegations).

ANNEX 1: SUMMARY TABLE FOR MOONLIGHT ADVANCED TECHNOLOGY ACTIVITIES IN THE WORK PLAN 2024

Ref	Title of Activity	Cost (k€)	Classification	Proc. Policy
Communications activities				
ML-COM-01 *(*)*	Lunar Laser Communication Terminal	2000	R	C
ML-COM-02	Service Orchestration and Interoperable Network Management	750	R	C
ML-COM-03	Architecture for Local Proximity Communications on the Moon Surface	1000	R	C
ML-COM-04	Multi-Beam Reconfigurable User Terminal Antenna for Continuous Connectivity on the Moon	1500	R	C
ML-COM-05	LunaNet S-band Communication User Terminal Transceiver	1500	R	C
Navigation activities				
ML-PNT-01	Earth-Based Field-Testing Facility for Moonlight PNT Signals Using Drones	1000	R	C
ML-PNT-02	Miniaturised LunaNet PNT User Terminal Receiver	1000	R	C
ML-PNT-03	Lunar Local Moonlight/LunaNet Augmentation System	2000	R	C
ML-PNT-04	Enhancing the Selenodetic Reference Frames and Lunar Reference Time	500	R	C
ML-PNT-05	Combined Communication and Navigation User S-band Antenna	750	R	C
TOTAL (k€)		12,000		

ANNEX 1

Moonlight Work Plan 2024

DESCRIPTIONS OF ACTIVITIES

Activity Ref.	Activity Title	Budget (kEuro)	Classification
ML-COM-01*	Lunar Laser Communication Terminal	2000	R
Objective:	The objective of the activity is to first design a Laser Communication Terminal (LCT) concept suitable for communication over Lunar distances. In a second step, the activity will develop an engineering model of a CCSDS compatible transceiver with critical functions including coding, synchronisation, and modulation.		
Targeted Improvements:	Enabling a European or Canadian Lunar communication terminal operating with a data rate one order of magnitude higher than current designs, with Earth (from 100s Mbps to 10Gbps), and compatible with the Lunar orbit environment.		
Description:	This activity will enable a European or Canadian laser optical terminal source of future Lunar LCTs, requiring high data rate links. LCT links are currently available for near-Earth (LEO, GEO) and for deep-space (beyond the Moon) applications. The latter is not suited for this type of link as it is based on the "high-photon efficiency" standard and limited to data rate inferior to that required for Lunar communications. Lunar links require the development of both a modified LCT concept and a new transceiver, capable of delivering at least 5 Gbps, for which the standard is currently under definition at CCSDS. Currently several LCTs (transceiver included) for Earth orbit applications are available and several others are under development in Europe. The Lunar LCT concept and transceiver that will be developed in this activity, will have to be adapted for Lunar distances and the specific operating environment. The design shall support coding, synchronisation, and modulation for at least 5 Gbps rate over Lunar distance.		
Deliverables:	Documentation, Lunar laser communication terminal concept and transceiver engineering model with critical functions		
Estimated current TRL:	3		
Target TRL:	5		
Technology harmonised:	Yes - 2022 - Optical Communication for Space		
Dependency:	None		
S/W Clause:	No		
Service Domain:	5		
Technology Domain:	17 - Opto-Electronics		

** See also activity 5G.045 in the Work Plan for the ARTES 4.0 SPL "Optical and Quantum Communication - ScyLight" for 2024 (ESA/JCB(2024)7,REV.1).*

Activity Ref.	Activity Title	Budget (kEuro)	Classification
ML-COM-02	Service Orchestration and interoperable Network Management	750 kEUR	R
Objective:	The objective of this activity is to analyse, develop and evaluate concepts for the coordination of the provisioning of communication services to multiple users and across different communication providers. This includes planning and scheduling of communication resources, network management and the provision of user-initiated services.		
Targeted Improvements:	Automatic service provisioning for multiple users and coordination between different service providers		
Description:	While the provisioning of communication service can initially rely on manual processes and coordination between users, serving larger user bases should be supported by increasing automation in planning and scheduling the required resources taking agreed Service Level Agreements into account. Furthermore, as multiple communication service providers are expected to be operational for Lunar communication based on the LunaNet Interoperability specification, coordination between these providers for interoperable use of communication resources is required. Dedicated network monitoring and management functions are expected to evolve. To guarantee secure exchange of data, concepts for security management including exchange of credentials across terrestrial and space networks need to be developed. The activity will analyse and develop concepts for the planning and scheduling of communication sessions based on inputs from multiple users. Such planning and scheduling will eventually include communication resources of other providers and related coordination (the user of one communication infrastructure transparently using another infrastructure, like roaming' in terrestrial cellular networks). In addition, the integration of ad-hoc, user-initiated services (i.e., a Lunar asset autonomously requesting a communication session) shall be investigated. Network Management based on proposed standards should be considered to monitor and control service provisioning. Security and the management of security shall be considered as a cross-cutting concern, as it is required for all steps, including service negotiation, service provisioning and management. In particular, the secure exchange of credentials with service users and across network providers shall be studied. The developed concepts shall be demonstrated in a simulated environment and recommendations towards implementation shall be provided.		
Deliverables:	Documentation, simulation environment with implemented concepts and summary report providing recommendations		
Estimated current TRL:	2		
Target TRL:	4		
Technology harmonised:	No		
Dependency:	N/A		
S/W Clause:	ESA Community License		
Service Domain:	TEL		
Technology Domain:	06 - RF Systems, Payloads and Technologies		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
ML-COM-03	Architecture for local proximity communications on the Moon surface	1000	R
Objective:	To define a system level network architecture for local proximity communications on the Moon surface		
Targeted Improvements:	TRL raising of terrestrial wireless networking protocols for usage in Moon scenarios.		
Description:	The objective of this activity is to define a system level network architecture for local proximity communications on the Moon surface, considering user connection management, authentication, data traffic routing, as well as interoperability with users from other agencies. A previous activity (e.g. TDE High Data Rate, Adaptive, Internetworked Proximity Communications for Space) has recommended the usage of terrestrial protocols (3GPP and 802.11) in different use cases/scenario on the Moon surface. In the framework of this activity, a breadboard based on COTS hardware has been developed with the aim to demonstrate data rates achievable with these protocols under different channel conditions. Starting from reference network architectures for 3GPP and 802.11, this activity will investigate where to allocate the network functions/network elements required to deploy a surface network (authentication server, user data repository, etc.) either on the Moon surface, or in Moon orbit, or on Earth. An additional objective will be to investigate the usage of surface communications signals to augment surface PNT functions. Finally, the aim will be to design a scaled EM of the full surface network solution up to TRL 5, increasing the maturity of the technology for the identified scenarios and proposing an architecture that will be portable to a future flight hardware. The breadboard will demonstrate authentication on the network, surface-to-surface or surface-to-Earth routing of the user data, handover between different base stations, roaming between different networks. The resulting hardware could be flown opportunistically as payload on a future mission to the Moon to raise the TRL of this technology.		
Deliverables:	Documentation and Breadboard/EM model of network cards (access points and user terminals)		
Estimated current TRL:	3		
Target TRL:	5		
Technology harmonised:	No		
Dependency:	N/A		
S/W Clause:	ESA Community License		
Service Domain:	TEL		
Technology Domain:	06 - RF Systems, Payloads and Technologies		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
ML-COM-04	Multibeam reconfigurable user terminal antenna for continuous connectivity on the Moon	1500	R
Objective:	To develop and test a multi-beam reconfigurable user terminal antenna for assets on the Lunar surface with multi-orbit connectivity.		
Targeted Improvements:	Development of a new class of multi-beam reconfigurable ground terminal antenna for Lunar assets		
Description:	In the future, several constellations in Lunar orbit might be available and users could be able to reach several relays simultaneously. The satellites orbiting the moon will not be in a stationary orbit, thus imposing reconfigurability requirements on Ka-band terminals for assets on the Lunar surface. Multi-beam operation will enable make-before-break capabilities, which allows to maintain connectivity while the terminal switches from a satellite to the other. These characteristics will enable the terminal to connect to satellites in any orbit since the beam can be flexibly reconfigured to point to any desired direction and to connect simultaneously to two (or more) different satellites. In this activity, a multi-beam phased array antenna able to provide a broadband connectivity with communication relay satellites in Lunar orbit shall be developed. A Ka-band operational frequency shall be considered as defined by the Lunanet Interoperability Specification and the Moonlight programme. The terminal antenna shall support transmit and receive operations either with a single or a dual-aperture solution. In the first part, a phased array antenna shall be developed. In the second part, a scaled representative demonstrator of the antenna shall be manufactured and tested.		
Deliverables:	Documentation and hardware demonstrator		
Estimated current TRL:	3		
Target TRL:	5		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	TEL		
Technology Domain:	07 - Electromagnetic Technologies and Techniques		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
ML-COM-05	LunaNet S-band communication user terminal transceiver	1500	R
Objective:	To design, develop and test an engineering model of a LunaNet compatible S-band communication terminal.		
Targeted Improvements:	New capability within the ESA Member States to develop Lunanet user terminals to support ESA and non-ESA missions		
Description:	The LunaNet framework aims to define the specifications required to achieve interoperability among different LunaNet Service Providers (LNSP). As part of the LunaNet Interoperability Specification (LNIS), ESA and NASA have defined the list of services that might be provided by LNSP including data relay services in S-band. The S-band data relay capabilities provided by LNSP compatible with LunaNet will ease the operations of Lunar missions, covering a variety of user scenarios: - Fixed Lunar surface users (facilities, assets) - Mobile Lunar surface users (rovers, vehicles, extra-vehicular activities) - Lunar landers. Advancing the user technology is considered key to secure the adoption of Moonlight and LunaNet services, in particular it is critical to have user terminals at engineering model level, reducing the non-recurrent costs of future user missions. The unit developed within this activity will consider the LunaNet specifications and ensure sufficient level of re-configurability to accommodate specific implementations from different LNSP. The solution shall be based on a scalable and upgradable (flexible) platform focusing primarily on Moonlight communications and upgradable to other relay missions (Lunar Pathfinder, LunaNet, …) without hardware modification of the core radio. The core radio should be based on flexible architecture, that can be adapted to different use cases (e.g. small/large rover, crewed lander, small/large orbiters) and with different classes of size, weight, and power. Leveraging emerging digital processing technologies, and considering high levels of hardware, firmware / software integration within state-of-the-art FPGAs, System in Package (SiP) and System on Chip (SoC), will enable a collective improvement in digital back-end processing capabilities and efficiency of design. The activity shall cover the design, development, manufacturing, and validation of a full Engineering Model (EM) of an S-Band communications user terminal transceiver Engineering Model (including RF, digital elements and any required software). Further to that a roadmap for the development of the subsequent qualification and flight models shall be presented.		
Deliverables:	Documentation, Engineering Model		
Estimated current TRL:	3-4		
Target TRL:	6		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	Yes (standard IPR regime applies)		
Service Domain:	TEL		
Technology Domain:	06 - RF Systems, Payloads and Technologies		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
ML-PNT-01	Earth-based field-testing facility of Moonlight/Lunanet PNT signals using drones	1000	R
Objective:	The objective of this activity is to define, develop and validate a test facility that generates LCNS PNT-like signals on Earth through the use of real RF broadcast signal from moving drones.		
Targeted Improvements:	New facility that will allow to simulate realistic LCNS PNT services Signals on Earth in Lunar environmental representative conditions.		
Description:	Moonlight/LCNS will provide game changing capabilities in cislunar space by means of accurate PNT services. To support the acceptance, adoption and exploitation of future Moonlight PNT services, it would be of high interest to have available an Earth-based field-testing reliable facility emulating the Moonlight PNT constellation and their associated RF/PNT signals/messages emission. For this facility the use of drones, acting as the LCNS satellite nodes, is here proposed. If properly conceived, this facility shall allow emulating faithfully the actual movement/position/geometry (DOP) of the Moonlight LCNS satellites with respect to the users; replicate the associated RF signals format, power levels and associated characteristics (e.g. RF modulation, frequencies, Doppler ranges; attenuation effects; etc); provide the Moonlight AFS Signal messages as per the Moonlight defined SiS ICD protocols; and providing the designed Moonlight expected performances (e.g. with a good characterisation of the actual Orbit and clock on-board accuracies; age of data effects; etc). This unique facility had a high interest in support to multiple scenarios, such as: - the characterisation of realistic Moonlight achievable PNT performances to potential interested users; - the testing, qualification and performance assessment of Moonlight LCNS receivers (alone or when integrated with other sensors on Lunar surface conditions); - the assessment (prior to launch) with all hardware-sensors in the loop of Lunar rover models PNT performances using Moonlight - the preparation/support of Lunar PNT interoperability tests among different space agencies; - to assess/trade-off potential Moonlight PNT system evolutions; - to assess/test/validate potential Lunar surface specific mission scenarios; - the evaluation of Moonlight PNT local augmentation solutions; - to support astronaut training and operations using Moonlight PNT services. This activity shall cover the conception, design, development, testing, qualifications and initial operation of this facility. The drones Moonlight constellation facility could then be used in areas that emulate Lunar surface conditions (e.g., Mont Etna in Italy) to provide a realistic Moonlight PNT complete testing environment.		
Deliverables:	Qualified and operational Earth-based Moonlight PNT facility, including 1 year of operational support		
Estimated current TRL:	3		
Target TRL:	9		
Technology harmonised:	NO		
Dependency:	None		
S/W Clause:	NO		
Service Domain:	NAV		
Technology Domain:	06 – RF Systems, Payloads and Technologies		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
ML-PNT-02	Miniaturised LunaNet PNT user terminal receiver	1000	R
Objective:	The objective of this activity is to define, develop and validate an EM of a LunaNet PNT user terminal covering the LANS service		
Targeted Improvements:	New capability within the ESA member states to develop user terminals to support ESA and non-ESA missions		
Description:	The LunaNet framework aims to define the specifications required to achieve interoperability among different LunaNet Service Providers (LNSP). As part of the LunaNet Interoperability Specification (LNIS), ESA and NASA have defined the list of services that might be provided by LNSP and, with the PNT services, the Lunar Augmented Navigation Service (LANS) has been defined. LANS is very similar to Earth GNSS and it allows a user to computed its position, velocity and time using broadcasted signals. LNIS provides a detailed specification of the signal characteristics, allowing to use the same receiver with multiple LNSP, easing the adoption of this service for future Lunar missions. On Earth GNSS spaceborne receivers' market has increased significantly in the last 20 years, being now the de facto the sole equipment for satellite GNC and orbit determination in LEO, GTO and GEO. It is expected that the same will happen in cislunar space, so early development of engineer models within ESA member states is key to secure market share and secure that the necessary user technology is available to support future ESA and ESA member stated Lunar exploration missions. Effort will need to be devoted to reducing the SwaP of the unit, this is important considering the high cost of launch (euro/kg) in cislunar space and the expected limited size and power for some Lunar missions. The target is to have a single hardware unit that can be used in multiple user missions covering orbital, landers and surface users. Part of the software is considered generic and applicable to all users, however the specific navigation engine within the software will need to be adapted to the user (an orbital user will have a very different navigation software with respect to a surface user). For this activity, in addition to the standard navigation algorithm applicable to every user scenario, the navigation software will be focused on Lunar orbiters, targeting the implementation of real time reduced dynamic solution. The development of specific sensor and/or data fusion algorithm expected to be adopted for landers and surface operation will be covered in other activities. The activity shall cover the design, development, manufacturing, and validation of a full Engineering Model (EM) of an S-Band user terminal receiver (including RF, digital elements and any required software). Further to that a roadmap for the development of the subsequent qualification and flight models shall be presented. Expected duration 12-18 months.		
Deliverables:	Documentation, EM		
Estimated current TRL:	4		
Target TRL:	6		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	Yes (standard IPR regime applies)		
Service Domain:	NAV		
Technology Domain:	06 – RF Systems, Payloads and Technologies		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
ML-PNT-03	Lunar local Moonlight/LunaNet augmentation system	2000	R
Objective:	The objective of this activity is to define, develop and verify an EM of a Lunar surface element that augments Moonlight LCNS to facilitates robust metre-level user positioning in the local Lunar area		
Targeted Improvements:	New capability related to high accuracy and robust Lunar PNT not existing today in ESA Member States		
Description:	There is widespread use of various differential and augmentation techniques on Earth to supplement, monitor and correct satellite-based navigation signals to great effect and as such it is considered a mature technology that has great potential to be leveraged on the Moon. This potential is even further enhanced for Moonlight due to the lack of an atmosphere on the Moon which is one of the main drivers for the augmentation performance in terms of baseline range and latency on Earth. The ability of the augmentation system to support safety-of-life type applications is also a critical asset when considering crewed operations on and around the Moon. Further benefits can also be realised if the augmentation system payload forms part of a larger selenocentric reference station on the surface of the Moon. This is both in terms of deepening the potential scientific knowledge of the Lunar reference frames and Lunar geodesy and geodynamics in general as well as by leveraging the multi-technique capabilities of the station to improve the position and clock knowledge of the augmentation system and thus improve its performance. Initial studies as part of NAVISP EL1-062 activity have shown that this potential is realisable with a relatively simple and low SWaP payload and will demonstrate the critical functionalities in an EBB, allowing to reach TRL 4. This proposed activity then aims to further raise the technology to TRL 6 with the definition, development and verification of an Engineering Model of the augmentation system and associated user terminal (GSE) in terms of HW and SW algorithms and then demonstrate the system ops concept and user performance in different scenarios. This activity shall cover the design, development, and validation of a full Engineering Model of the required augmentation system elements (including any necessary software and hardware). Further to that, a roadmap for the development of the subsequent qualification and flight models shall be presented. Expected duration 18 months		
Deliverables:	Documentation, EM, GSE		
Estimated current TRL:	4		
Target TRL:	6		
Technology harmonised:	No		
Dependency:	NAVISP EL1-062 outputs needed to define requirements for EM Lunanet Standardisation documents and Moonlight SiS ICD need to be defined.		
S/W Clause:	Yes (standard IPR regime applies)		
Service Domain:	NAV		
Technology Domain:	06 - RF Systems, Payloads and Technologies		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
ML-PNT-04	Enhancing the selenodetic reference frames and Lunar reference time	500	R
Objective:	Support the Agency in the international endeavour to define the interoperability standards in terms of selenodetic reference frames and Lunar reference time and on the definition of a mid and long-term strategy for enhancement of the selenodetic reference frames and Lunar reference time, including potential experimentation and the set-up of dedicated cislunar infrastructures.		
Targeted Improvements:	Achieve a commonly internationally accepted Lunar selenocentric reference system and a common Lunar reference time, its associated governance and potential international cislunar support infrastructure.		
Description:	There is high consensus on the importance of converging towards a commonly internationally accepted Lunar selenocentric reference system and a common Lunar reference time. The defined Lunar selenocentric reference system shall describe procedures for creating reference frames suitable for use with measurements on cislunar space. Specific realisations of the defined selenodetic reference frame and a reference Lunar physical time aligned to the Lunar reference time should then be regularly generated and maintained as a result of international cooperation. All this is essential as reference to the future operational Moonlight LCNS System and necessary also to ensure interoperability with other Lunar navigation systems. These will also foster a large number of research opportunities and applications in the cislunar space. This activity is conceived as a framework activity to support to ESA in these fields, including: • Provision of expert support in the context of ESA participation on relevant international discussion • Support the drafting/review of related conventions and standardisation documents. • Understand the necessary links/synergies between the Lunar reference frames (selenodetic and timing) and Earth-based equivalent ones; • Support ESA on the discussions concerning future international governance of these Lunar references and on the identification of a potential and significant European contribution; • Definition of a mid- and long-term strategy for the enhancement of the realisations of Selenocentric reference frames and Lunar reference time; • Provide concepts and associated requirements for a reference international selenocentric reference stations which could be systematically and progressively installed on the Lunar surface to support the Lunar selenocentric reference frame realisations improvement. This could include, potentially, Moonlight PNT surveyed receivers, laser retroreflectors and Lunar surface VLBI transmitters. • Assess how the Moonlight PNT services (and its panned evolutions) may support the actual realisation of the Lunar reference frames and Lunar reference times; • Conceive how specific atomic clocks on Lunar orbit or Lunar surface could contribute towards the generation of a reference physical Lunar clock providing a physical realisation aligned to the defined international Lunar reference time. • Elaborate on possible experiments exploiting Earth and Lunar clocks for scientific research, such as general relativity • Assess how laser ranging emitted from Lunar orbiters, exploiting Moonlight PNT precise orbiting positioning, may be used against surface LRRs in support to Lunar geodesy and reference frames improvement. Conceive a possible experimental set-up and associated Mission requirements; • Assess all lessons learned from this exercise and its possible extrapolation to Martian conditions;		
Deliverables:	Technical Support, contribution to international groups and provision of associated documentation.		
Estimated current TRL:	N/A		
Target TRL:	N/A		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	NAV		
Technology Domain:	06 - RF Systems, Payloads and Technologies		

Activity Ref.	Activity Title	Budget (kEuro)	Classification
ML-PNT-05	Combined communications and navigation user terminal S-band antenna	750	R
Objective:	The objective of this activity is to develop a dual band self-diplexing antenna for cislunar space users in order to support the communication and navigation service simultaneously		
Targeted Improvements:	New technology development currently not available in Europe for Moon comms and navigation application		
Description:	In recent years, the Moon has gained international attention and it is now considered the main short-term objective of global space exploration, as reflected in the Global Space Exploration roadmap issued by the ISECG. The ESA Moonlight programme and all the other contributors to the LunaNet Framework (e.g. NASA LCRNS and JAXA LNSS) aim to provide communication and navigation services to all Lunar missions. Users that wish to exploit both services will require equipment such as user terminals and, at the same time, will require miniaturisation and synergies in order to reduce as much as possible the SWaP of the equipment. At the same time, the Moonlight services aim to provide the basis for "over-the-top" services that exploit the basic navigation and data relay capabilities. In this context, a specific antenna supporting both comms and navigation service will be a significant easiness in the utilisation of the Moonlight (and more generally LunaNet) services and will open the door to additional applications such as the concept of differential GNSS on the Moon. This concept will require the deployment of one (or more) differential reference station(s) (similar to RTK stations on Earth) that generates corrections to be sent to the user terminals. So, requiring reception of navigation signals as well as the capability to perform bi-directional communication. The antenna will require high stability in terms of RF performance vs temperature and shall be designed and developed in order to receive the signal without severe deformation. Multipath effect mitigation solutions should be analysed in order to minimise the impact of the surrounding environment on the overall antenna performance. At the same time, the antenna can also be used for Lunar missions such as landers or surface rovers, allowing to cover both communication and navigation needs. The activity shall cover the design, development, and validation of a full Engineering Model (EM) for the combined communications and navigation user terminal S-Band antenna (including RF, digital elements and any required software). Further to that a roadmap for the development of the subsequent qualification and flight models shall be presented.		
Deliverables:	Detailed design report, Test Report, Final Report, EM		
Estimated current TRL:	4		
Target TRL:	6		
Technology harmonised:	No		
Dependency:	None		
S/W Clause:	No		
Service Domain:	NAV/TEL		
Technology Domain:	07 - Electromagnetic Technologies and Techniques		