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# A Lunar Lander – Low Moon Orbit Inter Satellite Data Relay System for ARTEMIS II Missions

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**Abstract**

The Mexican Space Agency is opening new facilities at Zacatecas State in Mexico. The AEM Zacatecas Regional Aero-Space Centre A Co-Working Space will be leased by Mexico City-Based Dereum Labs with which AEM has already an MoU, and Australian Company Space Industries will open an office at the same Unit under the Photon Innovation Hub at the Quantum City of Innovation and Science where New AEM Aero-Space Regional Centre is based. The presentation for the Symposium is a Summary of Taken Actions into a Three- Nations Collaborative Effort for the development of Ubiquitous Communications for Enterprise, Consumers and Government.

**Acronyms/Abbreviations**
Low Moon Orbit (LMO), Inter Satellite Data Relay System (IDRS).

## *1.* Introduction

The Low Moon Orbit (LMO) Inter Satellite Data Relay System (IDRS) for ARTEMIS II is an innovative space telecommunications technology that has been designed to facilitate the transmission of data between spacecraft in deep space. This system is part of the ARTEMIS II mission, which aims to conduct a detailed investigation of the Moon's environment and geology.

The LMO IDRS is based on a network of spacecrafts that are strategically placed in lunar orbit to provide reliable, high-bandwidth communication links between Earth and deep space missions as well as for Cis-Lunar Activities. These spacecrafts are equipped with advanced communication equipment that allows them to relay data to and from other spacecraft, as well as ground stations on Earth. This system is critical for enabling real-time communication with deep space missions and ensuring that mission data is transmitted back to Earth in a timely and efficient manner.

The LMO IDRS is based on a store-and-forward architecture, which means that data is temporarily stored on the relay spacecraft before being forwarded to its intended destination. This approach allows for efficient use of available bandwidth and enables data to be transmitted to Earth even when the spacecraft is not in direct line of sight with the ground station. The system is also designed to be fault-tolerant, with redundant components and backup systems to ensure continued operation in the event of a failure.

The ARTEMIS II mission is expected to generate a large amount of data, including images, video, and scientific measurements. The LMO IDRS will be critical for ensuring that this data is transmitted back to Earth in a timely manner, enabling scientists and engineers to analyze and use the data to gain insights into the Moon's environment and geology. In addition, the system will also support future deep space missions, providing a reliable and efficient means of communication between spacecraft and ground stations.

The development and deployment of the LMO IDRS represents a significant achievement in space telecommunications technology. The system is expected to play a critical role in enabling future deep space missions, providing reliable and high-bandwidth communication links that are essential for mission success. The technology has been developed through a collaboration between various organizations, including the Mexican Space Agency CREDEZ, which has contributed its expertise in space telecommunications to the project.

## *2.* A Three Nations, Collaborative Effort

During the summer of 2020, the Law Office of Foot Ansley in Bristol. Helped the Mexican Space Agency, Regional Aerospace center in Zacatecas, CREDEZ, the Australian Based Company Space Industries and the Mexican Start-Up Dereum Labs. To draft a collaborative three nation agreement (between Mexico, the UK and Australia) to cover, a high-level drafting, in order to provide sufficient provisions on licensing, any pre-existing intellectual property rights and/or newly created intellectual property rights for a joint deliverable for a A Lunar Lander – Low Moon Orbit Inter Satellite Data Relay System for ARTEMIS II. The implications, between being socio-economical, implied, Memorandums of Understanding (MoU), between all three entities, or parties involved, a potential grand funding agreement, governed by English law, but as some duties could be performed under Mexican Territory, also with Mexican Law Contractual terms and implications.

Being and interdisciplinary-interagency and public-private partnership development and submission, between 2 National Space Entities (UK Space Agency as representing Australian Space Industries Office in the UK) and 2 National Private Companies (Space Industries and Dereum Labs) from Australia-Mexico, doubts emerge, from the perspective of how to accomplish such a technical goal.

First:

- Submission and Joint Development between one space agency to another (Mexico-UK)
- Already established mechanisms of collaboration between National Agencies: AEM MoU Signed with UKSA
- Already established mechanism of collaboration between Public-Private Entities: AEM MoU Signed with Dereum Labs and UKSA MoU Signed with Space Industries.
- Collaborative Agreement between Two International Companies: Space Industries and Dereum Labs (Govern by International Private Law)
- A Mexican Space Agency and Private Company MoU (Space Industries) to perform Mexico Territory On-Site Work.
- And finally, the development of Scope of Joint Mission under the ARTEMIS ACCORDS for an Artemis II Mission Subproduct, focusing in In-Space Manufacturing and Space Telecommunications.
- A LMO IDRS Proof of Concept should be modelled as part of a Lunar Lander – Low Moon Orbit Inter Satellite Data Relay System for ARTEMIS II Mission.

### *2.1 Space Industries*

Space Industries is an Australian space technology company that is at the forefront of developing innovative space solutions. Founded in 2017 by David Grier and Rajat Kulshrestha, the company is based in Brisbane, Australia and has a strong focus on creating in-situ resource utilization (ISRU) technologies that will allow humans to live and work in space. Space Industries is focused on developing a range of technologies that are designed to enable humans to explore and utilize space resources. The company's flagship product is a modular mining and refining system that is capable of extracting and processing resources from the Moon, Mars, and other celestial bodies. The system is designed to be highly mobile and can be deployed on a range of different types of landers and rovers.

In addition to its mining and refining system, Space Industries is also working on a number of other projects, including a water recycling system that can be used in space habitats, a radiation shield that can protect astronauts from solar and cosmic radiation, and a 3D printing system that can be used to produce parts and tools in space. One of the company's most notable achievements to date is winning the NASA iTech competition in 2019. The iTech competition is designed to identify and showcase innovative technologies that have the potential to solve important challenges in space exploration and improve life on Earth. Space Industries was one of just ten companies selected from a pool of over 250 applicants to present its technology at the iTech forum in Las Vegas.

The technology that Space Industries presented at the iTech forum was its modular mining and refining system, which was recognized for its potential to enable sustained human exploration of the Moon, Mars, and other celestial bodies. The system was praised for its versatility and its ability to be adapted to a range of different mission profiles. Winning the NASA iTech competition was a significant achievement for Space Industries, as it provided the company with the opportunity to showcase its technology to a global audience of potential investors, partners, and customers. The win also provided validation for the company's approach to developing ISRU technologies that are focused on enabling long-term human exploration of space.

Since winning the iTech competition, Space Industries has continued to develop and refine its mining and refining system, as well as its other technologies. The company has also established partnerships with a range of organizations, including the Australian Space Agency, to further advance its work in space..

### *2.2 Mexican Space Agency – CREDEZ*

The Mexican Space Agency Regional Aerospace Center, also known as CREDEZ Zacatecas, is an advanced research and development facility that focuses on space telecommunications, space robotics, and space mining. The center is located in the Quantum City of Innovation and Science in Zacatecas, Mexico, which provides a unique environment for cutting-edge research and development. One of the main activities of CREDEZ Zacatecas is space telecommunications. The center is involved in the design and development of advanced communication technologies that can be used in space missions. This includes developing communication systems for satellites, deep space probes, and rovers. The center is also involved in the development of ground-based communication systems that can be used to track and communicate with spacecraft. The center's location in the Quantum City of Innovation and Science provides access to state-of-the-art facilities and expertise in this field, making it an ideal location for research and development in space telecommunications.

Another key area of focus for CREDEZ Zacatecas is space robotics. The center is involved in the design anddevelopment of robotic systems that can be used in space exploration and mining. This includes developing rovers and other autonomous vehicles that can be used to explore the surface of the Moon, Mars, and other celestial bodies. The center is also involved in the development of robotic mining systems that can be used to extract and process resources from the Moon and other celestial bodies. The Photon Innovation Hub, located within the Quantum City of Innovation and Science, provides access to advanced facilities for research and development in robotics, making it an ideal location for research and development in this field. In addition to its work in space telecommunications and space robotics, CREDEZ Zacatecas is also involved in space mining. The centre is focused on developing technologies that can be used to extract and process resources from the Moon and other celestial bodies. This includes developing mining and refining systems that can be used to extract and process water, helium-3, and other resources from the Moon. The centre is also involved in developing in-situ resource utilization (ISRU) technologies that can be used to create resources in space, such as propellant for spacecraft. The centre's location in the Quantum City of Innovation and Science provides access to a range of resources and expertise in mining and metallurgy, making it an ideal location for research and development in this field.

### *2.3 Dereum Labs*

Dereum Labs is a Mexican start-up that is focused on space exploration and lunar rover technologies. Founded in 2018, the company has quickly established itself as a leader in the development of cutting-edge technologies that are designed to support the exploration and exploitation of the Moon and other celestial bodies.

One of the main areas of focus for Dereum Labs is the development of lunar rover technologies. The company has developed a range of robotic systems that can be used to explore the surface of the Moon and other celestial bodies. These systems are designed to operate in harsh and challenging environments, and they are equipped with advanced sensors and other technologies that allow them to navigate and collect data from their surroundings. The company's lunar rover technologies have already been used in a few research missions, and they are widely recognized as some of the most advanced and reliable systems in the world. Another key area of focus for Dereum Labs is the development of space exploration technologies. The company is involved in the design and development of a range of systems that can be used to support human exploration of the Moon and other celestial bodies. These systems include habitats, power systems, and other critical infrastructure that will be needed to support long-term human presence on the Moon and beyond. The company's space exploration technologies are designed to be highly reliable, efficient, and sustainable, and they are built with the latest advancements in materials science, robotics, and other fields.

In addition to its work in lunar rover technologies and space exploration, Dereum Labs is also involved in the development of other advanced technologies that can be used in space. These include communications systems, robotics, and other systems that can be used to support a wide range of space exploration activities. The company's focus on innovation and collaboration has led to the development of several breakthrough technologies, and its team of highly skilled engineers and scientists is constantly pushing the boundaries of what is possible in the field of space exploration. Dereum Labs is also deeply committed to sustainability and environmental responsibility. The company is working to develop technologies that are both highly effective and environmentally friendly, and it is working to minimize the impact of its operations on the natural world. The company is also committed to social responsibility, and it is working to create economic opportunities for people in the communities where it operates.

One of the most exciting aspects of Dereum Labs is its focus on collaboration and partnerships. The company is actively seeking partnerships with other organizations, including universities, research institutions, and other start-ups, to develop new technologies and advance the field of space exploration. The company's partnerships are based on a shared vision of a future where humanity can explore and exploit the resources of the Moon and other celestial bodies in a sustainable and responsible manner.

## *3.* Method

The Artemis II mission, a part of NASA's Artemis program, aims to land the first woman and the next man on the lunar surface by 2024. The mission is a crucial steppingstone towards establishing sustainable human exploration and habitation on the Moon. The mission requires a reliable communication system for the lunar lander in the low moon orbit, and this is where the inter-satellite data relay system for Artemis II missions comes in. The communication system must be robust enough to facilitate the exchange of critical data between the lunar lander and the command center on Earth.

One critical aspect of the Artemis program is the development of an Inter Satellite Data Relay System (IDRS). This system will provide a critical communications link between spacecraft and ground stations on Earth, allowing real-time data and voice communications between the two. The IDRS is an essential component of the program, as it will enable NASA to communicate with its spacecraft in real time, regardless of their location.

The implementation of an IDRS will significantly enhance the effectiveness of the Artemis program. Currently, spacecraft rely on ground stations to relay data to and from Earth. However, this approach is limited by the availability of ground stations and the line-of-sight limitations of radio communication. An IDRS will eliminate these limitations, providing near-continuous communication between spacecraft and Earth.

The IDRS is being developed in phases, with the initial phase involving the launch of two spacecraft equipped with IDRS capabilities. These spacecrafts, known as the Laser Communications Relay Demonstration (LCRD) and the Deep Space Optical Communications (DSOC) system, will provide high-bandwidth communication links between the lunar surface and Earth. The LCRD spacecraft will be launched in 2024, and the DSOC system will be launched in 2026.

### *3.1 Theory*

Artemis I and the United Networks:

The Artemis I mission served as a technology demonstration of NASA's United Network, which is a suite of communication and data transmission technologies. The United Network consists of a collection of ground-based and space-based communication assets that are designed to enable communication and data transmission between different space missions, including the Artemis program. The United Network comprises the following components:

Deep Space Network (DSN): The DSN is a set of ground-based antennas that are strategically located across the globe to ensure continuous communication with spacecraft on deep space missions. The DSN has been used to communicate with spacecraft such as the Voyager probes, the Mars rovers, and the Cassini mission.

Tracking and Data Relay Satellite System (TDRSS): TDRSS is a constellation of geostationary satellites that provide continuous communication coverage for low Earth orbit (LEO) and geostationary Earth orbit (GEO) missions. TDRSS provides critical support for NASA's human spaceflight program, including the International Space Station (ISS).

Space Network (SN): The SN is a network of communication satellites that provides a high-bandwidth data transfer capability for space missions. The SN is designed to support a wide range of spacecraft, including the Hubble Space Telescope, the Chandra X-ray Observatory, and the Lunar Reconnaissance Orbiter.

#### *3.1.1 Inter-satellite Data Relay System:*

The inter-satellite data relay system (IDRS) is a network of communication satellites that are specifically designed to provide data transfer capability for deep space missions. The IDRS is a crucial component of the United Network and will be essential for the Artemis II mission.

The IDRS comprises a constellation of satellites in a halo orbit around the Moon. The halo orbit is a unique orbit that provides continuous coverage of the lunar surface while remaining stable over time. The satellites in the IDRS constellation will be equipped with high-gain antennas that will enable them to communicate with the lunar lander and the Earth-based ground stations. The IDRS will act as a relay system that will receive and transmit data between the lunar lander and the ground stations on Earth.

#### *3.1.2 Delay and Disruption Tolerant Networking (DTN):*

DTN is a communication architecture that is designed to overcome the challenges of deep space communication, such as long delays and disruptions in connectivity. DTN is based on the store-and-forward paradigm, which means that data is stored at intermediate nodes until a path to the destination is available.

DTN is ideally suited for deep space missions where the communication links are not continuous, and there are long periods of disconnection. In the case of the Artemis II mission, the DTN architecture will be used to facilitate data transfer between the lunar lander and the Earth-based ground stations.

### *3.2 DTN Protocol Implementation*

DTN is a networking protocol designed for environments where network connectivity is not continuous, such as deep space or remote terrestrial locations. It was originally developed by NASA's Jet Propulsion Laboratory (JPL) for interplanetary missions, where communication links are characterized by long propagation delays, high bit error rates, and unpredictable outages.

DTN provides a way to exchange information in such environments by breaking it down into smaller bundles that can be stored, forwarded, and retransmitted later when a connection becomes available. It is based on the concept of "store-and-forward" networking, where messages are stored at intermediate nodes until a suitable destination becomes available.

### *3.3 DTN Architecture*

The DTN architecture consists of several components that work together to provide reliable communication in a challenging environment. These components include:

Bundle Protocol (BP) - BP is the core of the DTN architecture, and it provides a standardized way to bundle data for transmission. It includes mechanisms for fragmentation, reassembly, and error correction.

Bundle Protocol Agent (BPA) - BPA is responsible for handling the transmission and reception of bundles. It implements the BP protocol and manages the routing of bundles between nodes.

Bundle Protocol Router (BPR) - BPR is responsible for routing bundles through the network. It maintains a routing table that maps destinations to the next hop along the path.

Custody Transfer Protocol (CTP) - CTP is a mechanism for ensuring reliable delivery of bundles in the face of network disruptions. It enables nodes to transfer custody of a bundle to a neighboring node if it cannot be delivered to the intended destination.

Security Services - DTN provides several security services, including authentication, confidentiality, and integrity. These services ensure that bundles are protected from unauthorized access and tampering.

### *3.4 Advantages of DTN for Deep Space Missions*

Reliability - DTN is designed to operate in environments with high levels of network disruption. By breaking data into smaller bundles and storing them at intermediate nodes, DTN ensures that data can be reliably transmitted even in the face of network outages.

Robustness - DTN is a highly robust protocol that can handle high bit error rates and long propagation delays. It includes mechanisms for retransmission and error correction, which ensure that data is accurately transmitted even in noisy channels.

Flexibility - DTN is a flexible protocol that can be adapted to a wide range of communication scenarios. It supports both unicast and multicast communication, and it can be used to transmit different types of data, including text, images, and video.

Scalability - DTN is a scalable protocol that can be used to build networks of any size. It can be used to connect a small number of nodes or to create a large-scale network with thousands of nodes.

Security - DTN provides robust security services that ensure that data is protected from unauthorized access and tampering. This is particularly important for deep space missions, where data is often sensitive and confidential.

### *3.5 Interplanetary Internet*

In 2004, NASA's Jet Propulsion Laboratory (JPL) launched the first interplanetary Internet system, which used DTN protocols to transmit data from deep space to Earth. This system was used to send commands to the Mars rovers Spirit and Opportunity, as well as to receive scientific data from the rovers. The DTN protocols allowed the system to cope with the long delays and disruptions in communication that occur over interplanetary distances.

Deep Impact Mission
In 2005, NASA's Deep Impact spacecraft used DTN protocols to send data back to Earth after it successfully impacted the comet Tempel 1. The spacecraft was equipped with a special DTN router that was designed to cope with the long delays and disruptions in communication that occur over interplanetary distances.

Lunar Atmosphere and Dust Environment Explorer (LADEE)
In 2013, NASA's LADEE mission used DTN protocols to transmit data from the spacecraft to Earth. The mission was designed to study the atmosphere and dust environment around the Moon, and the use of DTN protocols allowed the mission to cope with the long delays and disruptions in communication that occur over interplanetary distances.

Mars Science Laboratory (MSL)
In 2012, NASA's MSL mission used DTN protocols to transmit data from the Mars rover Curiosity to Earth. The mission was designed to study the geology and climate of Mars, and the use of DTN protocols allowed the mission to cope with the long delays and disruptions in communication that occur over interplanetary distances.

Europa Clipper
In 2024, NASA's Europa Clipper mission will use DTN protocols to transmit data from the spacecraft to Earth. The mission is designed to study the habitability of Jupiter's moon Europa, and the use of DTN protocols will allow the mission to cope with the long delays and disruptions in communication that occur over interplanetary distances.

## 4. Discussion: *A Path for Optical Communications?*

The ARTEMIS II lunar lander mission is one of the most ambitious endeavours in the history of space exploration. As a joint project between NASA and the European Space Agency (ESA), it aims to land astronauts on the Moon by 2024, setting the stage for a long-term lunar presence and paving the way for future crewed missions to Mars and beyond. One of the key challenges of the mission is to establish reliable communication between the spacecraft and Earth, as well as between different spacecraft in cislunar space. This is where the Optical Cislunar Inter Satellite Data Relay System (OCISDRS) comes in.

The OCISDRS is a cutting-edge communication system that utilizes optical lasers to transmit data between spacecraft in cislunar space. Unlike traditional radio frequency (RF) communication, which is limited by atmospheric interference and distance, optical communication is highly efficient and can transmit data at much higher speeds over longer distances. This makes it ideal for deep space missions where communication links are critical for success.

The OCISDRS will be an essential part of the ARTEMIS II lunar lander mission, providing reliable communication links between the lunar lander, the Orion spacecraft, and Earth. The system will consist of a network of relay satellites in lunar orbit, each equipped with high-powered optical communication systems that can transmit data at speeds of up to 100 Gbps. These satellites will act as data relays, receiving and retransmitting data between the lunar lander, the Orion spacecraft, and Earth.

One of the key advantages of the OCISDRS is its high data rate. This will allow the ARTEMIS II mission to transmit large amounts of data in real-time, enabling scientists and engineers on Earth to monitor the health and status of the spacecraft, as well as collect scientific data from the lunar surface. This data will be critical for planning future missions and understanding the geology and environment of the Moon.

Another advantage of the OCISDRS is its reliability. Because optical communication is less affected by atmospheric interference and other sources of noise, it can provide a more consistent and stable communication link than traditional RF systems. This is especially important for deep space missions where communication links can be disrupted by solar storms, cosmic rays, and other sources of interference.

## 6. Conclusions

The OCISDRS is also highly scalable, meaning that it can be expanded and upgraded as needed to support future missions. As new spacecraft are launched and new scientific objectives are identified, the system can be adapted to meet the changing needs of the mission.

Of course, the OCISDRS is not without its challenges. One of the key obstacles is the need for precise pointing and tracking of the optical communication links. Because the laser beams used for communication are highly focused and directional, they require a high degree of accuracy to maintain a stable connection. This requires advanced tracking and pointing systems, as well as specialized software to compensate for spacecraft movement and other factors.

Despite these challenges, the OCISDRS represents a significant leap forward in deep space communication technology. By leveraging the power of optical communication, the ARTEMIS II mission will be able to establish reliable, high-speed communication links between the Moon, Earth, and spacecraft in cislunar space. This will enable a wide range of scientific and exploratory activities, helping to unlock the secrets of the Moon and pave the way for future missions to the outer planets and beyond.

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