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Interplanetary networks

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Literature

- Zhao, Kanglian, and Qinyu Zhang. "Network protocol architectures for future deep-space internetworking", Science China Information Sciences 61, no. 4, pp 1-16, 2018.
 - The whole article

Today's lecture: Data communication in space, general concepts and technologies.



Scenario: The Moon Village

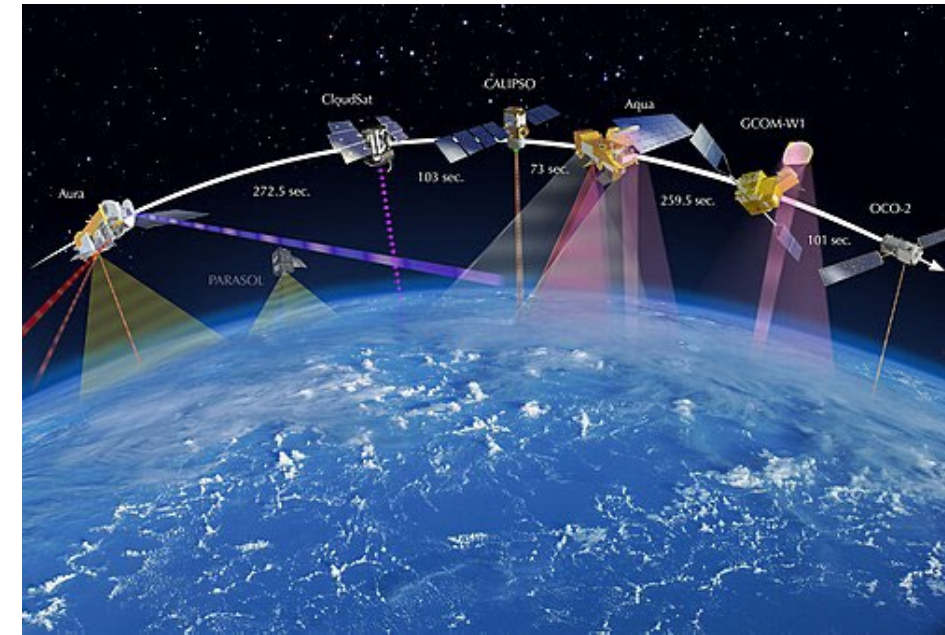
The Moon Village Association is a non-government organization that gathers different stakeholders that want to develop a permanent habitat, also called the Moon Village, on the moon. Your task is to develop Internet access for the Moon Village. The residents of the Moon Village should be able to access the most common Internet applications, as WWW, email, some gaming applications, video streaming, online meetings, etc. Also, they should be able to communicate with each other, and with star ships that are within communication range.

Your budget is basically infinite, and you can use any technology available within 30 years (since this is a project that will run for a long time).



Examples of satellite systems near Earth

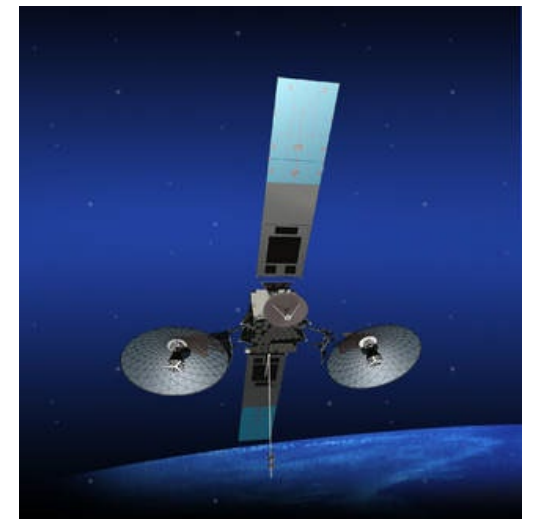
- **Starlink, Iridium and Argos**
 - Starlink satellites are planned to be used as relays for outer space communication.
- **Earth observation satellite systems**
 - Designed for Earth observations from orbit (civilian and military).
 - Most commonly are **Earth imaging satellites** and **Weather satellites**.
- **NASA's Space Communications and Navigation program (SCaN)**, serves as the program office for all of NASA's space communications activities.
 - **Near Space Network (NSN)** for near-Earth space missions.
 - **Deep Space Network (DSN)** for outer space missions.



NASA Near Space Network

The Near Space Network (NSN) includes several parts:

- World-wide Ground stations (NASA Complexes)
- Provision of telemetry, commanding, ground-based tracking, data and communications services to a wide range of customers with satellites on low-earth orbit (LEO), geostationary orbit (GEO), highly elliptical orbit (HEO), and Lunar orbit.
- A constellation of GEO satellites named the Tracking Data Relay Satellites (TDRS). TDRS provides communication relay links between its ground facilities and orbiting satellites below GEO.
 - Also called **the Space network**.
 - Used, for example, for communication with ISS.



NASA Deep Space Network

The **Deep Space Network** (DSN) supports NASA and non-NASA deep-space missions.

DSN consists of giant radio antennas all over the world.

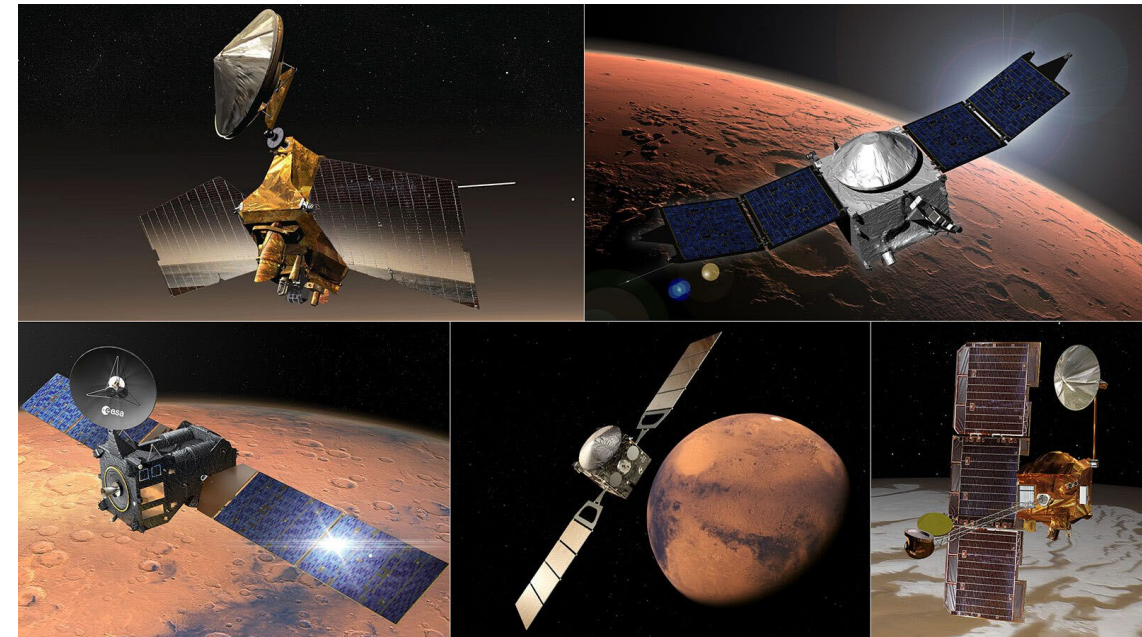
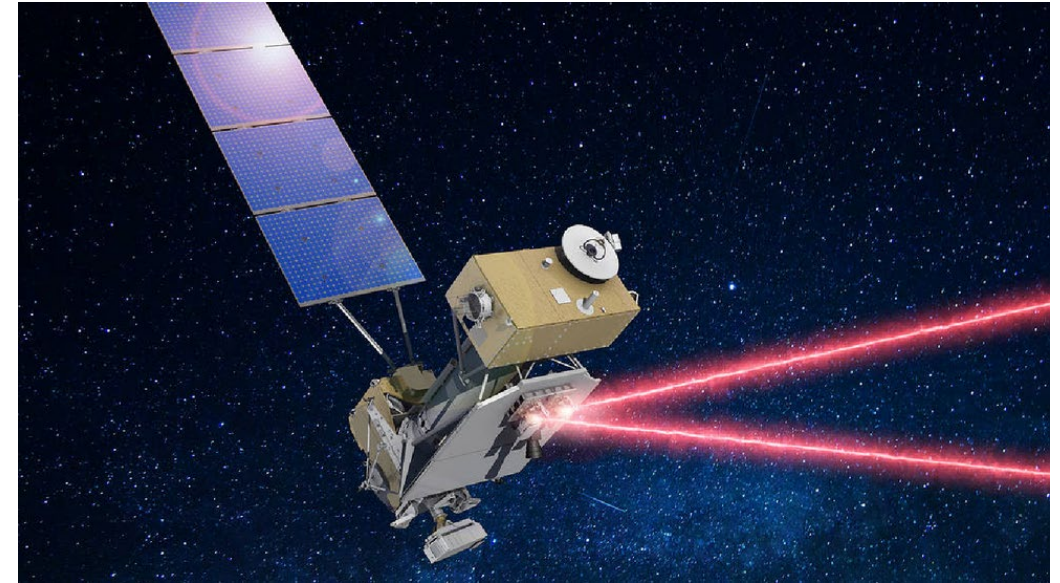
DSN also provides radar and radio astronomy observations that improve our understanding of the solar system and the larger universe.



Space relays

Space Relays are used to "bend" the path of a data transmission. Relay satellites are crucial in space communication, since planets move and communication links require line-of-sight to be reliable due to the long distances, both for radio and optical links.

The **Mars Relay Network** includes five spacecrafts that can connect Earth with Mars. They transmit commands from Earth to surface missions and receive science data back from them.



NASA LunaNet

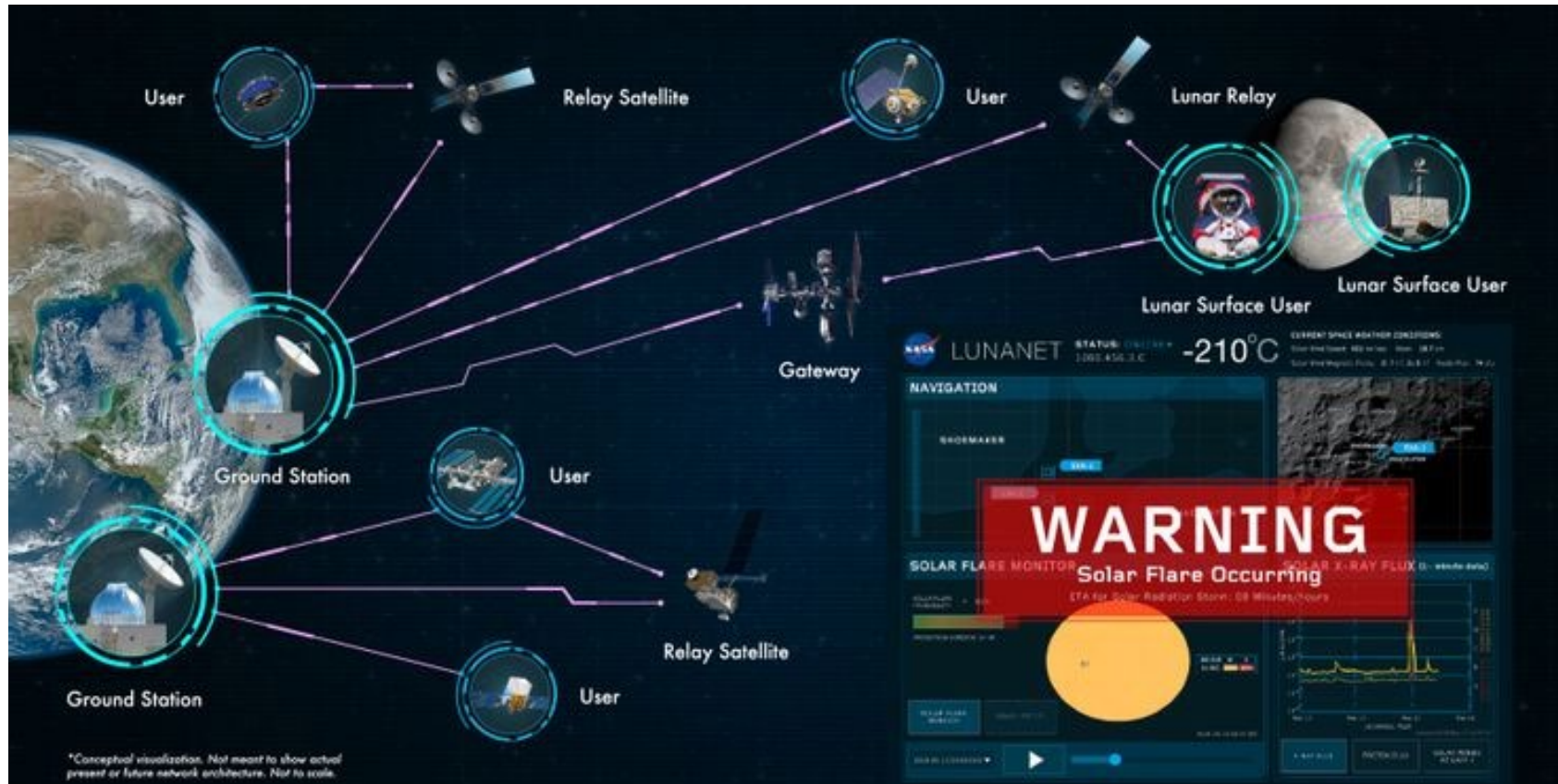
LunaNet is planned to provide Internet-like capabilities to the Moon for the NASA mission Artemis, bringing people to the Moon.

- LunaNet will provide users with four services: networking; positioning, navigation and timing; detection and information; and science.
- With LunaNet in place, users will experience an operational environment similar to that experienced by Internet users on Earth.



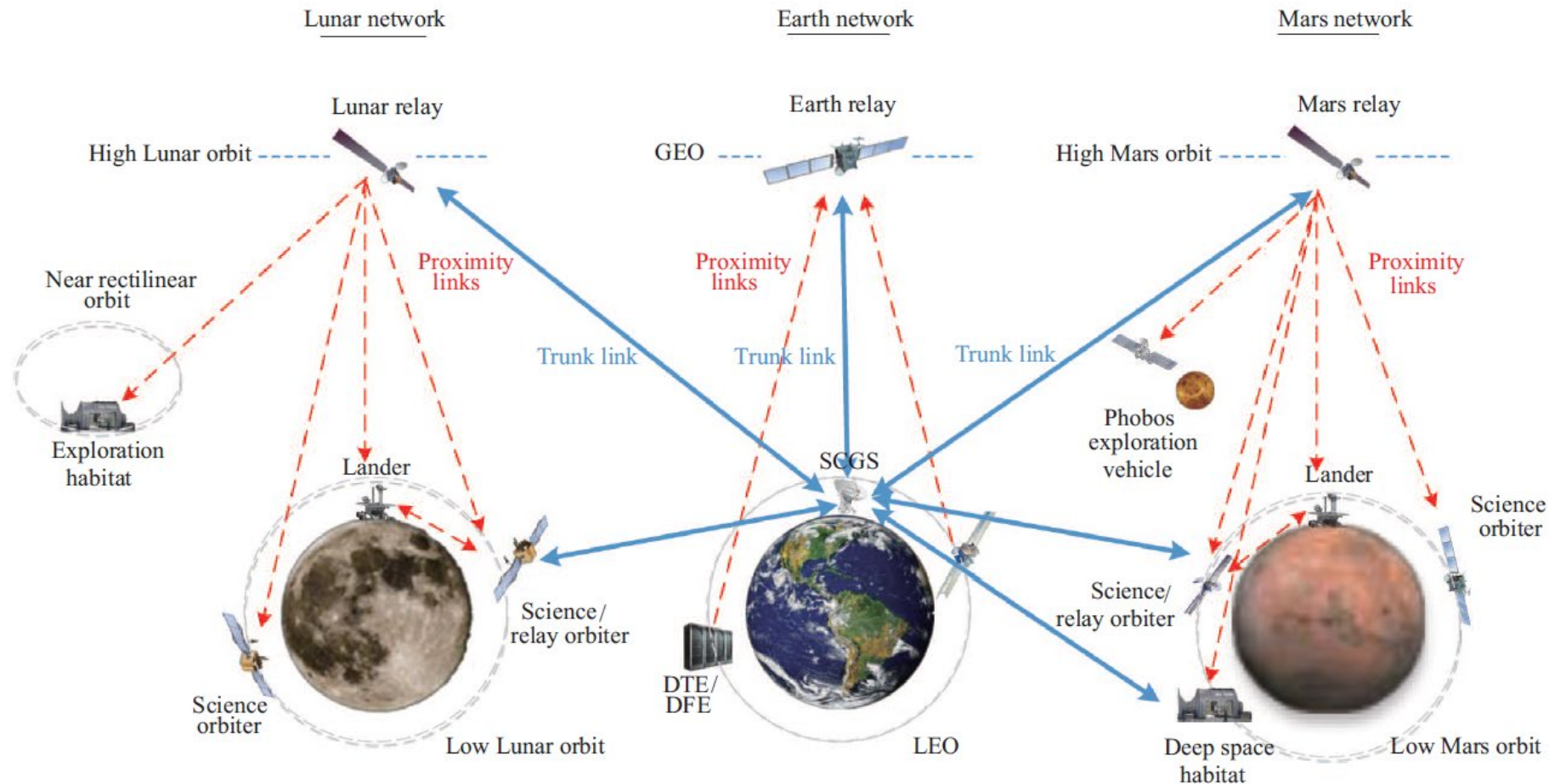
NASA LunaNet

LunaNet is based on a **DTN**, using multiple DTN nodes on the Moon, on satellites, and ground stations, ultimately creating a robust network. Each node can store and re-route data to find the best optimal path for it to reach destinations.



NASA Next-Generation Space Relay Architecture

NASA are working towards a **Next-generation space relay architecture**, which will be a true “network of planetary networks”.

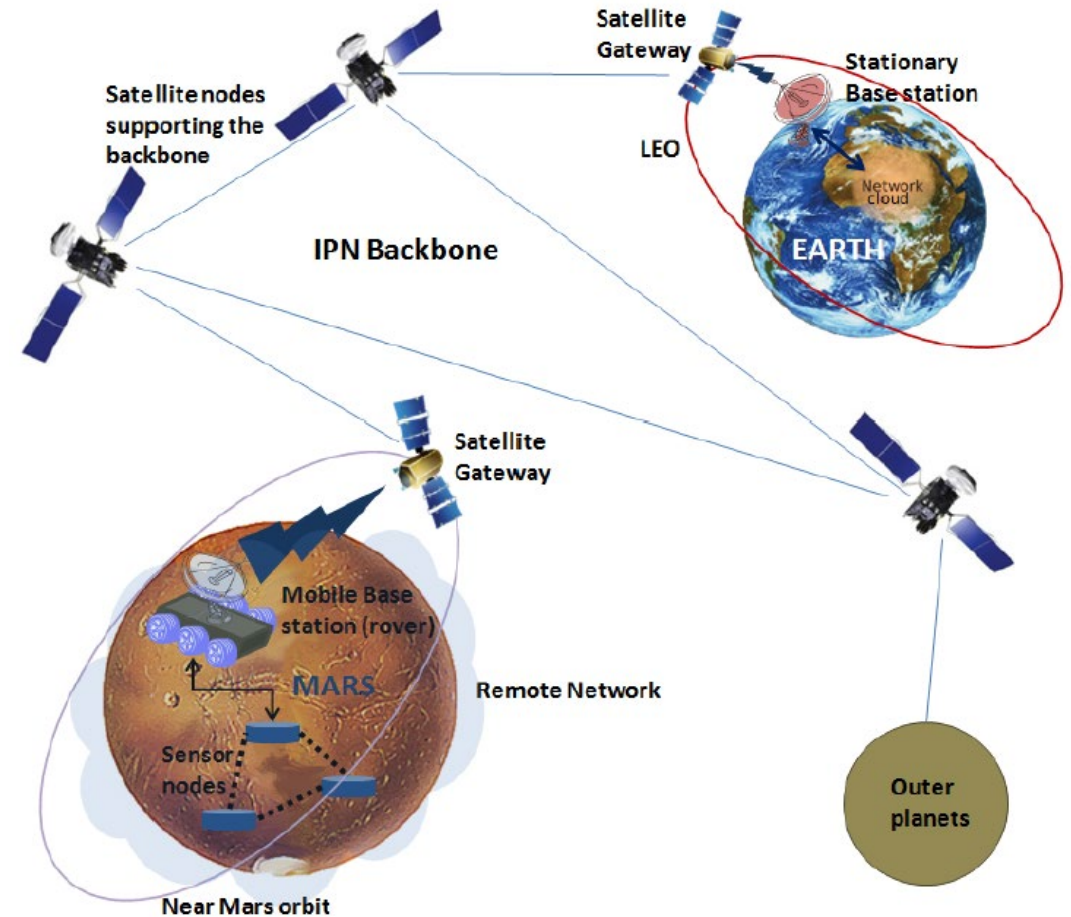


Deep-space communication

Deep-space communication can be characterized as

- impaired dynamic links with very long delay and disruption
- highly asymmetric channel rates
- high error rates

Therefore, deep-space nodes can cooperate through space internetworking for better connections, more communication opportunities and broader bandwidth.



Consultative Committee for Space Data Systems (CCSDS)

- The Consultative Committee for Space Data Systems (CCSDS) is a multi-national forum for the development of communications & data systems standards for spaceflight.
- The CCSDS was formed in 1982 by the major space agencies of the world.
- CCSDS is the most important standard-developing organization (SDO) in the field of space internetworking.
- The **Space Internetworking Service Area (SIS)** is fully dedicated on space network protocol architectures.

Communication technologies in outer space

For data communication in outer space, there are two available technologies:

- RF communication
- Optical communication

Characteristics for RF communication in space

- **Beam divergence:** High beam spreads over long distances.
- **Antenna sizes and costs:** Large antennas are needed to capture faint signals. These cannot be too heavy, and the cost is high.
- **Antenna coverage:** Radio communication allow a large coverage from a single point transmit. Close communication is ideal with radio signals.
- **Power consumption** is quite high.
- There are **standardized frequency bands** for radio communication from earth to space.

Characteristics for Optical communication in space

- **Beam divergence:** Small beam spread over long distances.
- **Antenna size and cost:** Antennas designed to receive optical signals are smaller than for radio, and thereby lighter and potentially cheaper.
- **Antenna coverage:** Optical communication is essentially a point-to-point communication. It also requires a high precision pointing accuracy.
- **Efficient power consumption** for larger volumes of data.
- Currently, there are **no standards** for optical communication in space.

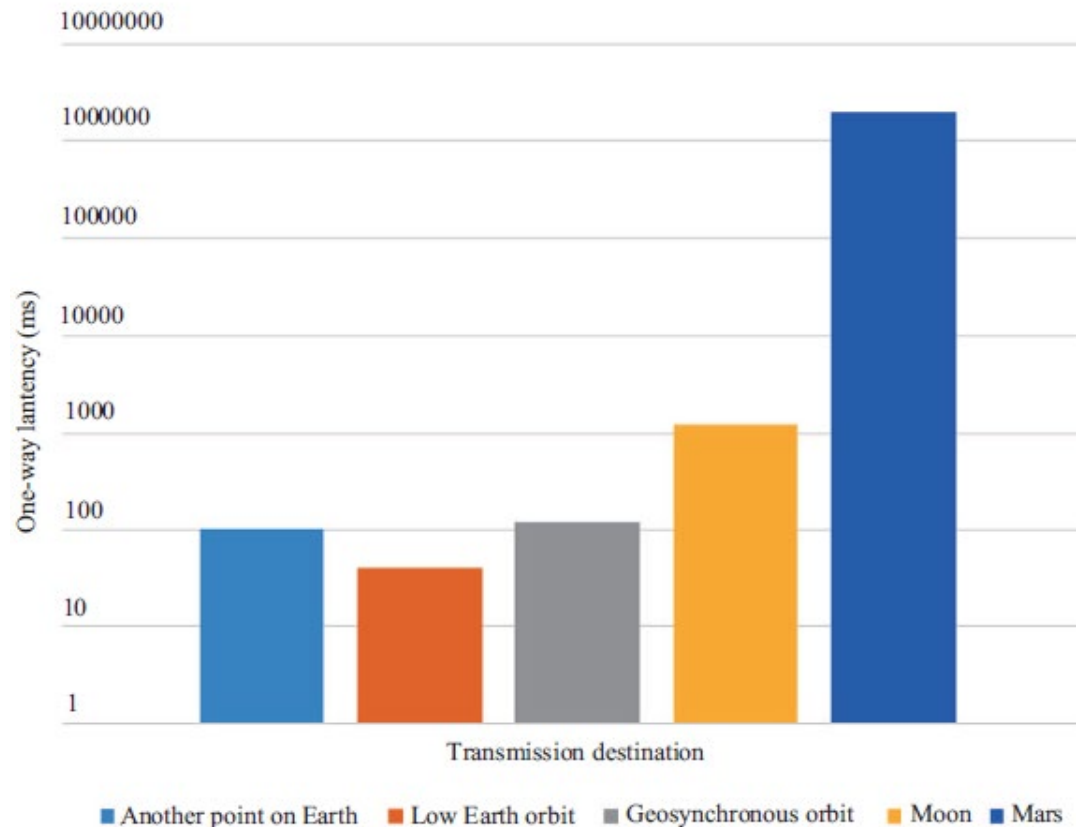
Constraints and challenges in deep-space internetworking: Link level

The extremely long distance between two nodes (e.g., from Earth to Mars) in deep-space causes most of the problems in the link level.

- Extremely long propagation delays
- High error rate
- Limited data rate
- Asymmetric channel rates
- Intermittent connectivity

Propagation delays for deep-space communication (from Earth)

The propagation delays can be long when communicating beyond Earth.



CCDCS Standard: Space link

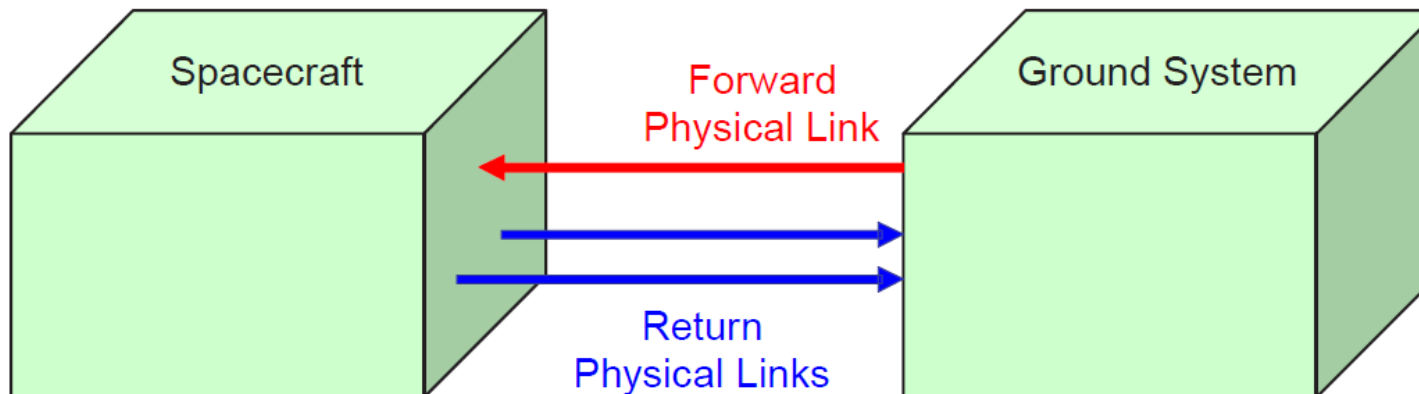
- A **space link** is defined to be a **communications link** between a spacecraft (which may be a lander or a rover on a distant planet) and its associated ground system or between two spacecrafts.
- A space link consists of **one or more Physical Channels** in one or both directions. A Physical Channel is defined to be a stream of bits transferred over a space link in a single direction.
- A **Space Data Link Protocol** provides **one-way transfer** from the sending end to the receiving end of a Physical Channel.
- CCSDS has **standardized several data link layer protocols** used in different scenarios.

Space data link protocols

A **space data link protocol** handles data communication in one direction (**simplex**).

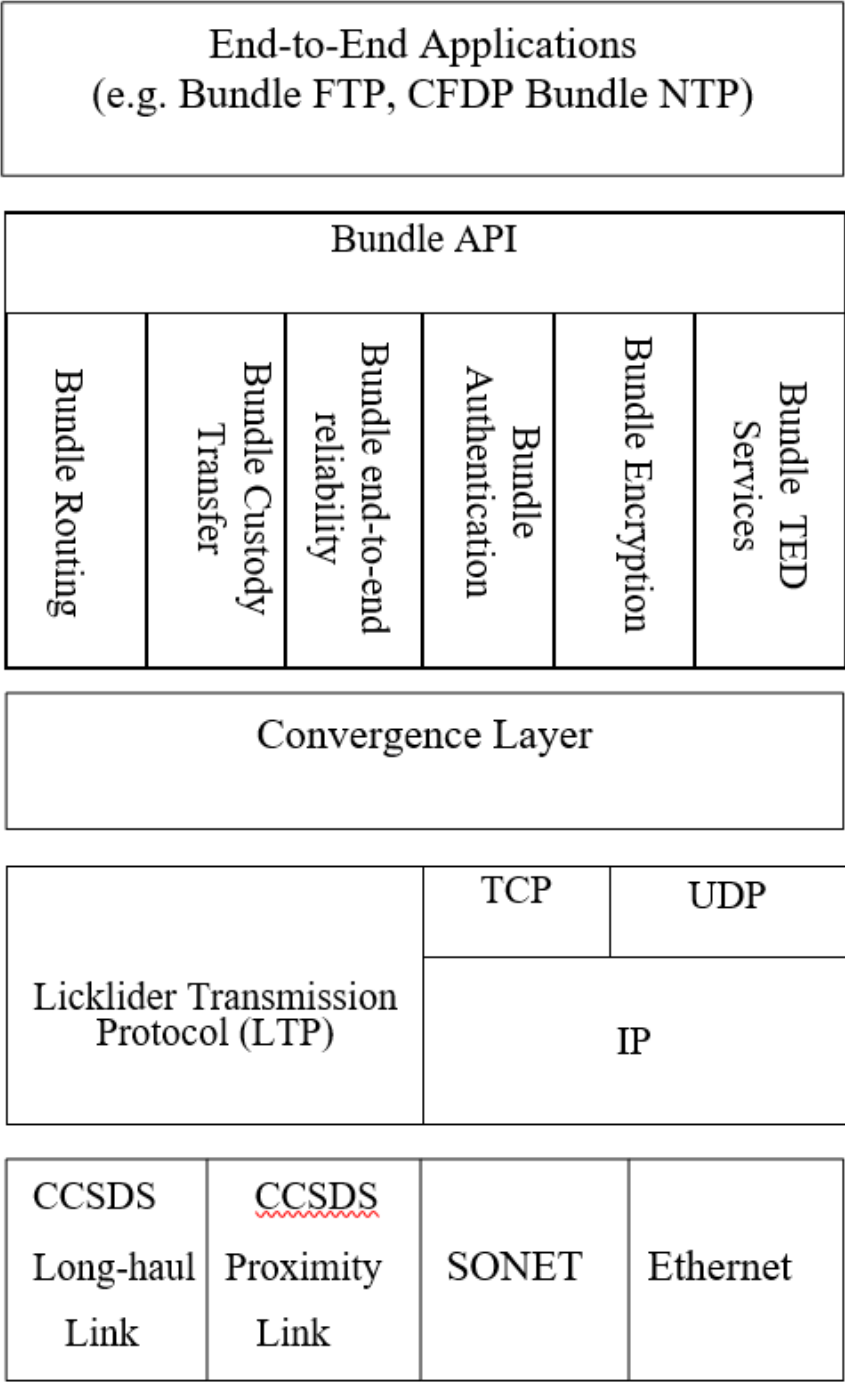
The communication link (space link) between two space entities can include several physical channels/links.

On a given Physical Channel, only one **Space Data Link Protocol** must be used.



Licklider Transmission Protocol

- **Licklider Transmission Protocol (LTP)** is a protocol for use in deep space links.
- LTP can be seen as TCP/UDP for space.
- LTP is often used together with the Bundle Protocol.
- The LTP engine stores data in a queue, checks whether the link towards the destination is available and if so, starts the transmission.
- If the link is not available, the data remains in queue and transmission starts as soon as a so-called “link state cue” arrives.

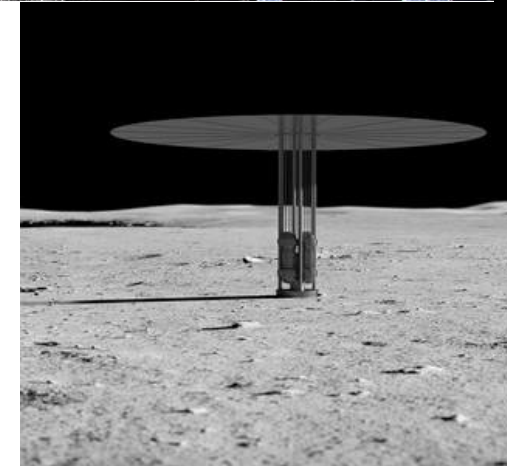
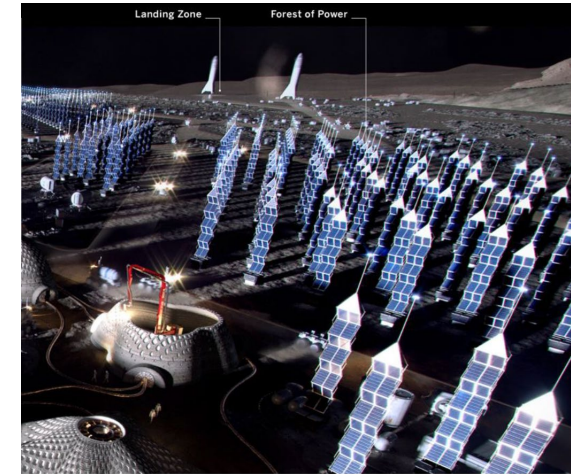


LTP operation

- The **application divides its data to send into two parts** (either part may have a size of 0):
- a **red part**: It contains data that has to be transported reliably, has to be acknowledged by the receiver, and has to be held available until acknowledged.
- a **green part**. It contains data that does not require reliable transport. Since reception of this data is not acknowledged, it can be discarded after transmission.
- The receiver issues a report segment for the sender once it received the “end of red data” segment, and all data is complete. This starts an **ACK procedure**, so that the sender can inform the application that all **red data** has been successfully transmitted.

Power generation in space?

- **Solar power:** Many satellites and spacecrafts are equipped with solar panels and rechargeable batteries. Also, there are plans to deploy solar panels on the Moon and Mars. Limitations to solar cell use include diminished efficacy in deep-space applications, no generation during eclipse periods, high surface area, mass, and cost.
- **Nuclear power:** The concluded **Kilopower project** developed preliminary concepts and technologies that could be used for an affordable nuclear power system to enable long-duration stays on planetary surfaces.
- **Hydrogen fuel cells** can be small, light and reliable, with high energy conversion efficiency. They also allow missions to launch with a safe, storable, low pressure and non-toxic fuel source.



System design?

The Moon Village Association is a non-government organization that gathers different stakeholders that want to develop a permanent habitat, also called the Moon Village, on the moon. Your task is to develop Internet access for the Moon Village. The residents of the Moon Village should be able to access the most common Internet applications, as WWW, email, some gaming applications, video streaming, online meetings, etc. Also, they should be able to communicate with each other, and with star ships that are within communication range.

Your budget is basically infinite, and you can use any technology available within 30 years (since this is a project that will run for a long time).



Some basic facts

- The average distance to Earth from the village will be about 382.500km, meaning 1.3 seconds of latency between the gateway on Earth and the one on the Moon.
- The Moon is always facing the same side towards the Earth.
- Asteroids are falling on the Moon frequently. Over a 150 hour period, 102 hits have been registered on the Earth-facing side of the moon.
- Size of the Moon Village? ESA study have assumed 4 people and support of Mission Duration up to 500 consecutive days (revised to 300 days based on the crew radiation exposure assessment) for a given crew. But we should of course think bigger 😊



Solution suggestions

This scenario basically includes three parts:

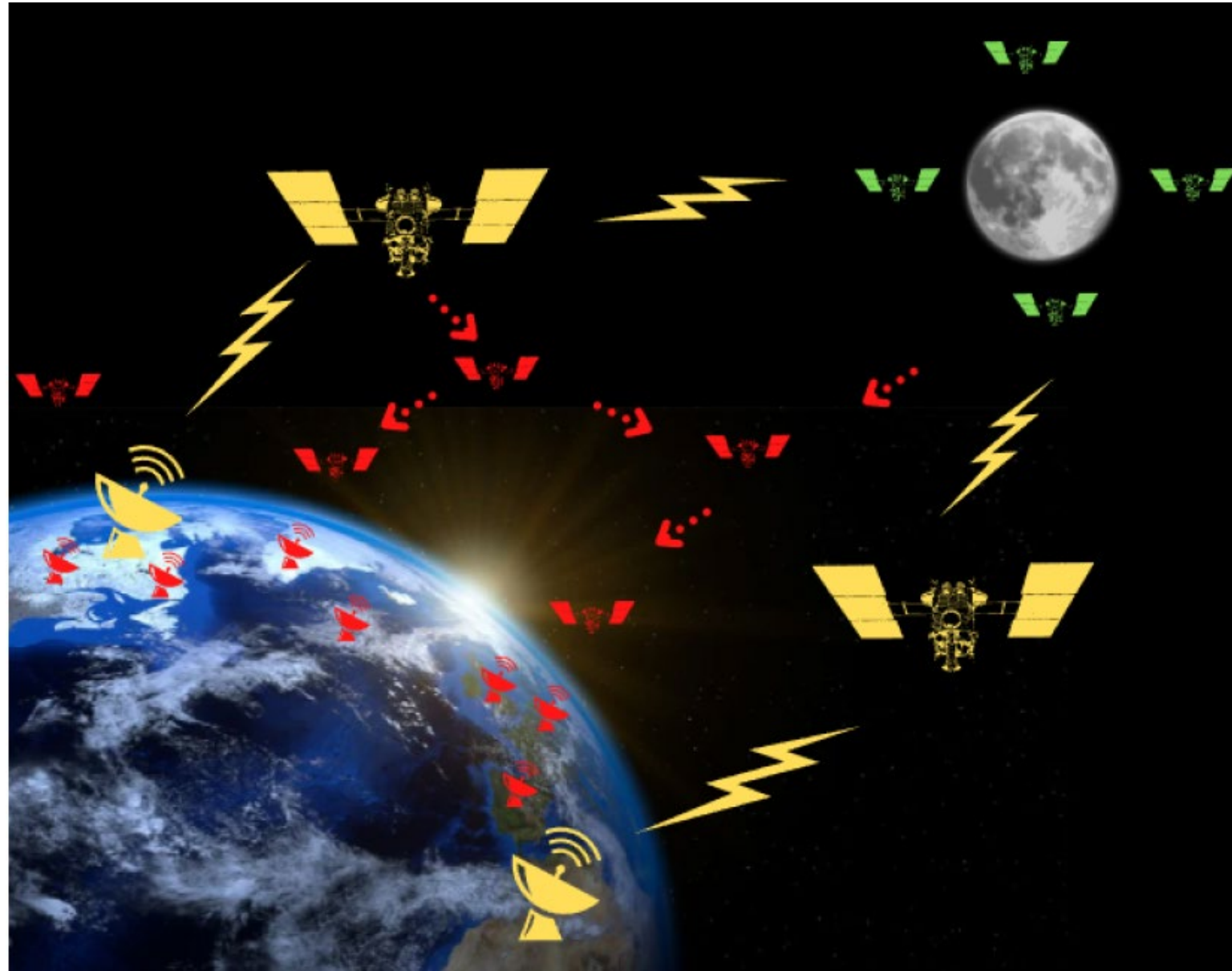
1. Data communication between the Moon and Earth.
2. Data communication on the Moon.
3. Internet system architecture – how do Moon habitants get access to Internet applications?

Also:

- The power supply must be solved.

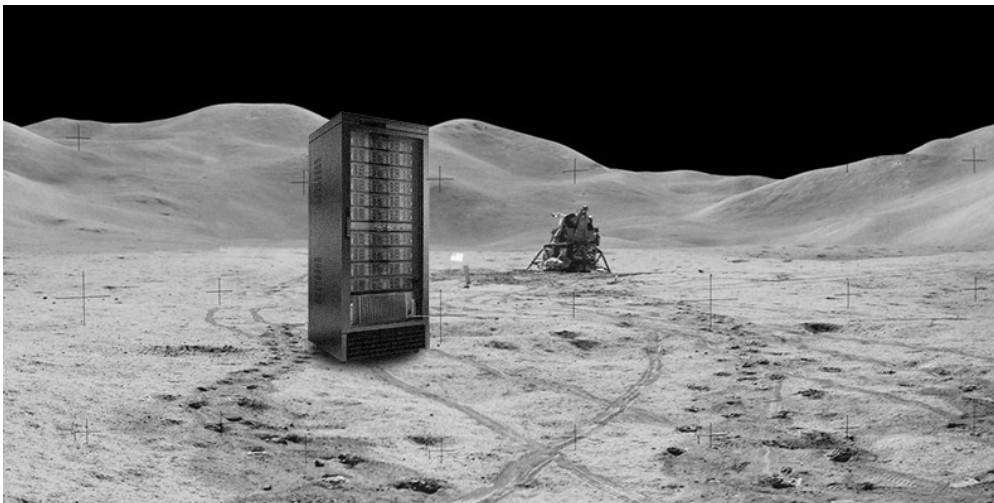
Data communication between Earth and Moon

- You need to propose a network architecture for the communication between the Earth and the Moon.
- This should be done using relay satellites, due to the movements of the planets.
- A DTN architecture should be used to solve the delay and disturbance problems.



Data network on the Moon and the Internet solution

- You need to provide a solution for the data network on the Moon. The figure to the right shows Nokia's planned 4G base station on the Moon. The figure to the left shows a planned data center on the Moon. Both are part of the LunaNet project.
- You should probably suggest a few gateways for backhaul connection to the Earth (DTN Routers).
- **You need to discuss how you plan to do with the Internet access over a DTN, since conversational protocols probably will not work efficiently.**





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