LunaNet: a Flexible and Extensible Lunar Exploration Communications and Navigation Infrastructure and the Inclusion of SmallSat Platforms

By Kendall Mauldin
The LunaNet architecture is based on nodes capable of providing a combination of standard services.

There are three standard service types:

1. **Networking Services (Net):** Data transfer services capable of moving data between nodes in a single link or over a multi-node, end-to-end path.

2. **Position, Navigation, and Timing Services (PNT):** Services for position and velocity determination, and time synchronization and dissemination. This includes search and rescue location services.

3. **Science Utilization Services (Sci):** Services providing situational alerts and science measurements for human and asset safety and protection. Science instrument data will also allow for further research, increasing return on investment overall.
The LunaNet infrastructure may be comprised of nodes with varying degrees of service provision capabilities

1. Allows the LunaNet flight elements to range from SmallSats to larger spacecraft
2. For example, some orbiting elements may provide PNT services only, while others may primarily provide high rate communications links

The overall LunaNet infrastructure performance is the aggregation of all of the nodes.
1. User A communicates with User B over multiple nodes providing networking services.

2. Node 1 is simultaneously providing PNT and Science Utilization Services.

3. The combination of nodes could be a heterogenous set of assets:
   a. Commercial, Government, International, or other
   b. Spacecraft in any orbit or surface elements
   c. Dedicated spacecraft or hosted payloads
Any Link Provides LunaNet Access – Lunar Surface Direct with Earth

- A lunar surface mission connects to the LunaNet through links directly with Earth
- Data may still be routed to and from Earth destinations or back to lunar destinations
Any Link Provides LunaNet Access – Gateway as Access Point

- The Gateway provides relay between lunar surface and Earth or other lunar users, either real-time or store-and-forward
- Data is still formatted the same and routed to final destinations as in the DTE case
Any Link Provides LunaNet Access – Store and Forward Relay

• Lunar surface user exchanges data with other LunaNet users through relay, even when other users are not connected to relay

• Lunar surface user may also receive position, navigation, and timing services and situational alerts when out of contact with Earth
Any Link Provides LunaNet Access – Store and Forward Relay

- Relay forwards data to the network when Earth is in view
- Relay receives data for other lunar users not in view of Earth
LunaNet Services: PNT

PNT data will enable lunar assets to determine position and velocity, plan and execute maneuvers, organize trajectories, and maintain time.

Orbit determination can be used in combination with the following provided by the lunar architecture for PNT services:

- A common stable time and frequency reference source with synchronized distribution across all elements
- Radiometrics or optimetrics from each observable communication link
- Observability of GNSS signals
- Angular measurements to define plane-of-sky
- Imaging of nearby celestial body surface features

The LunaNet team is working with NASA’s Search and Rescue office to create a robust lunar search and rescue system that is capable of providing emergency location support for astronauts on the Moon, and eventually other planets.
LunaNet Services: Science Utilization

LunaNet:

1. Early warning of solar event onset
2. Utilization of soft X-ray and Solar Energetic Particle (SEP) monitoring via a heterogeneous configuration
   1. X-rays arrive in 8 minutes after event starts
   2. Arrival of Solar Energetic Particles (SEP) in 200 minutes after event starts
LunaNet is both flexible and extensible and will be continue to evolve after NASA develops the first instantiation of the architecture.

Lunar missions may be part of the LunaNet infrastructure, a LunaNet user, or even both.

A lunar mission can conduct its mission objectives while also acting as a LunaNet node or simply be a user of the architecture.

There is limited direct-to-Earth link availability once multiple assets are established within the lunar region, some SmallSat operations will need to be:

- More autonomous
- Act as data aggregation points
  - This will reduce the number of required connections with Earth
Since each part of the larger LunaNet infrastructure is not required to provide all LunaNet services, SmallSats may provide the ideal platform for deployment of specific capabilities.

Payload types include:

1. A networking services payload:
   a. providing Disruption Tolerant Networking Bundle Protocol network layer routing

2. A position, navigation, and timing payload:
   a. ranging devices, autonomous navigation processors, broadcast beacons, and time reference source / distribution modules.
   b. Broadcast beacons on many SmallSats can provide multiple signals that surface assets can use for surface location determination, etc.

3. Science Utilization SmallSats can carry science instruments or operational detectors that can contribute to the larger mission and provide situational alerts.
When selecting frequency bands for infrastructure SmallSats, it is recommended to utilize the following frequency band scheme to avoid interference, band-crowding, and to maximize interoperability.

Link types include:

1. **Earth-to-Moon**: The uplink from the Earth to cis-lunar, lunar orbit and lunar surface.

2. **Moon-to-Earth**: The downlink from the cis-lunar, lunar orbit and lunar surface to the Earth.

3. **Cross Link**: The link between two relay spacecraft.

4. **Proximity Link**: The link between a relay satellite and its relay service user.

<table>
<thead>
<tr>
<th>Link Type</th>
<th>Allocated Bands</th>
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<tbody>
<tr>
<td>Earth-to-Moon</td>
<td>X-band, Ka-Band, Optical</td>
</tr>
<tr>
<td>Moon-to-Earth</td>
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</tr>
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<td>Cross Link</td>
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SmallSats as Users

LunaNet will enable lunar SmallSat missions and allow them to dedicate more of their resources to their science payloads and overall objectives.

1. With LunaNet, SmallSats will not need to carry the capability to return all of their science data solely through long links back to Earth.

2. Each mission would be able to use the PNT services for autonomous guidance, navigation, and control.

3. Science Utilization Services could provide alerts that may allow placing sensitive instruments into safe mode or, perhaps, turning on science instruments designed to capture specific science events.

4. In order to receive all of these benefits, the SmallSat design needs to include interfaces that are compatible with the LunaNet architecture.
SmallSats as Users

SmallSats as users are more focused on the user interfaces to the larger LunaNet network.

1. Data rates may vary depending on the user node requirements and use cases.

2. Data rates can be tuned by the use case and the on-board communications system or link capabilities from the user node to the next available access point.

3. Data and link management may be considered:
   a. Part of scheduled operations (more deterministic)
   b. Part of opportunistic operations (less deterministic, event based)

Examples of types of data that a user payload may send or receive can include:

1. Status of onboard systems / instruments
2. Data from onboard science instruments or detectors
3. Raw data to be processed by other assets or systems
4. PNT information to be cross-linked to other assets
5. Event-based communications service requests
1. LunaNet is a flexible and scalable architecture for the provision of Network, PNT, and Science Utilization Services at the Moon.

2. The infrastructure can be built up over time as mission requirements and operations concepts evolve.

3. SmallSats can be providers or users of the LunaNet architecture.

4. Infrastructure nodes can be provided by any combination of NASA, commercial, or other partner systems.

5. The LunaNet architectural approach is applicable to any planetary body to establish the solar system internet.
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