Lunar Architecture Team – Communication & Navigation

Evolution of the Lunar Network

Jonathan Gal-Edd
Architecture Summary

• Architecture elements
  — TDRSS – Relay (ISS –Phase), up to GEO
  — Direct to Earth (DTE) Ground stations (Lunar Phase), orbiting assets
  — Lunar Relay Satellite (LRS) system (Lunar Phase)
    • Up to 250 km from Hab
    • Nav for orbiting assets
  — Lunar surface (Lunar Phase)
    • Lunar Communication tower UP TO 6 km
  — User radios

• New Lunar capabilities
  — In- SITU Communication
  — In- SITU navigation
  — Surface network
  — CEV support beyond LEO
  — Contingency/dissimilar EVA voice
Challenges in implementing the Lunar Architecture

- Lunar architecture requires use of all existing NASA networks:
  - Currently LaGrange point serves as demarcation between DSN, GN, and SN
  - Existing NASA networks provide services in a different way:
    - SN: Bent Pipe – Bit service
    - DSN Packet service (including level 0 processing)
    - SN nav signal based on Pseudo Noise (PN) implementation
    - DSN uses tone ranging
  - Currently LaGrange point is dividing: point between GN and DSN
    - SN, GN up to Lunar (LRO)
    - DSN LaGrange and beyond: MAP, SOHO, JWST

- Requires implementation of IP currently not supported by either network
- Space implementation of IP is challenging
  - Terrestrial implementation of IP are due to a large extent on Fiber optic backbone that supports high date rates with low error and fast and sophisticated routers
- Space implementation
  - Typical space link 10e-5, requires coding for 10e-7
  - Power limited: Routers and RF equipment is power hungry
- View of Earth from Lunar south pole limited to 14 days a month and requires use of Lunar Relay
Conops of Lunar Relay Satellite (LRS)

- **Surface Users:**
  - Each LRS provides services 8 out of 12 hours for a large region (roughly a hemisphere)
  - Two LRS provide periodic coverage of entire Moon for Sortie support

- **Orbital Users:**
  - LRS tracks Earth, CEV/Lander in orbit, and Lander during descent and ascent with a High Gain Antenna for S and K/Ka-band communications
  - Provides farside coverage of CEV & Lander including critical events

- **LRS “flying router “**
  - Implements C3I Interoperability Spec protocols including security
  - Buffers data up to 300 GB
  - Receives data from Earth to lunar surface up to 100 Mbps
  - Transfers data from lunar surface to Earth up to 250 Mbps
  - Provides 1 & 2-way ranging & Doppler tracking services
Sortie Support

**LRS:**
- SMA = 6142.4 km
- Eccentricity = 0.59999
- Inclination = 57.7°
- Perilune Argument = 90°
- 12-Hour Orbits

**Constellation A:**
- 2 LRS in same plane
- 180° phased

**Constellation B:**
- Orthogonal planes with the same inclination and opposite apolunes

**Note:** LRS1 satellite proposed during LAT1 for LPRP support
Lunar Relay Satellite (LRS)

- Lunar comm relay, navigation & timing spacecraft
  - 2 LRS in 12 hr frozen elliptical lunar orbit
  - 7 year life with fuel for 10 years, Each LRS single fault tolerant
- Atlas 401 or Delta IV Medium: >60% launch margin
  - Options exists for dual launch or secondary payloads
- Communications and Navigation Payloads
  - 2x100 Mbps high rate links from Surface, 2x25 Mbps low rate from other surface; Fully IP-routed
  - 2-way ranging to up to 5 users simultaneously
  - 24 hr Store & Forward with 300 GB
- Prop: Pressure Fed Hydrazine, 2x100 lb_&_ & 16x 0.5 lb_&_ thrusters
- C&DH: command, control, health management
- Attitude Control & Navigation
  - 20 Nms momentum storage in 4 reactions wheels
  - 12 sun sensors, 2 star trackers, 2 IMUs
- Power: 1040 W Average Power Load (30% margin)
  - 2 1-Axis Solar Arrays, 28% efficient triple-junction cells, 4.7 m² area
  - 137 Ah BOL Li-ion batteries, 2.5 hr eclipse at full power, reduced ops for 5 hr eclipses
- Thermal: Heat Pipe-Radiator System, Hydrazine Heaters
- Mechanical: Al-Li Panel around a central thrust-tube

<table>
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<tr>
<th>Description</th>
<th>CBE Mass</th>
<th>Growth</th>
<th>Total Mass</th>
<th>Nominal Power</th>
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LRS Data Flow

Ka Band Receivers
26 GHz

Ka Band Tx
20 Watts
23 GHz

S Band Tx
10 Watts
2.1 MHz

S Band Receivers
2.2 MHz

Diplexer

Nav Processor

C&DH

SSR

1 m Relay

.5 m DTE

DTE LGA
(Safing)

Ka Band Receiver
40 GHz

Ka Band Tx
10 Watts
37 GHz

Ka Band Receiver
40 GHz

Ka Band Tx
100 Watts
37 GHz

S Band Receiver
2.1 MHz

S Band Receiver
2.1 MHz

S Band Tx
10 Watts
2.2 MHz

S Band Tx
10 Watts
2.2 MHz

S Band
Receivers
2.2 MHz

100 Mbps
25 Mbps
25 Mbps

100 Mbps

16 kbps

16 kbps

16 kbps

16 kbps

150 kbps
150 kbps
150 kbps
150 kbps

150 kbps
150 kbps
150 kbps
150 kbps

1 Mbps

1 Mbps

1 Mbps

100 Mbps

250 Mbps

16 kbps

16 kbps

16 kbps

16 kbps

16 kbps

1 Mbps

100 Mbps

100 Mbps

250 Mbps
General Concepts of Surface Operations

- Two zones exist: Within Line Of Sight (LOS) of the LCT and Beyond LOS
  - Use Lunar Comms Terminal (LCT) within its LOS range around the Outpost Zone
    - Surface elements, like EVA suits and rovers, communicate to LCT to save power
    - LCT routes surface-surface data by wireless LAN and wired connections
    - LCT routes surface-Earth data using LRS and/or DTE at K-band
    - LCT provides radiometric tracking services at S-band for orbiting & landing users, and for surface navigation by surface elements
    - Power is supplied to it through the surface power network
    - First LCT on LSAM 1 or 2 as separable unit deployed for good visibility
    - May be part of the Hab or Lander for mass/power savings if terrain allows
  - Outside of LCT range, use the Lunar Relay Satellite (LRS)
    - Surface elements, like EVA suits and rovers, communicate to LRS through S-band (low-medium rate data) or Ka-band for higher data rates
- Surface comms have redundancy and multiple communications paths to meet Human Rating requirements
- LRS supplies contingency voice using a dissimilar radio
- The system supports autonomous & teleoperated robotic movement, e.g., to ISRU plant (known location & route) or on science excursion (off-road wandering)
LRS:
• Routes incoming data to Earth or to Lunar Surface
• Distributes commands from earth to lunar surface

• Users with LOS to LCT communicate through LCT
  • Traffic may be routed to other LOS users in service area or LRS
  • Users without LOS to LCT automatically route traffic through LRS
    • Use back-up S-band link with max data rate of 150 kbps
    • Relay high rate Ka-band Link – 3 simultaneous links
      • 2 links for Hab & LCT; 1 link for high rate rover or science
    • Relay low rate S-band link – 5 simultaneous links
      • 5 links available for NAV, blocked users in LCT service area, or users beyond LCT Service Area

Rovers:
• Rover transmitting high rate data to Earth or habitat
• Rover transmitting low rate data to Earth or habitat

Frequency Plan:
- 40/37 Ka
- 23/26 Ka
- S band
- S (Backup)
- 802.16
Surface network

- Pockets of 802.XX networks connected via gateways
  - HAB
  - IRSU
  - Rover/EVA
- Applications are based on IP Integration on IP layer
- HAB connected to LCT with Fiber (Ethernet) 100 mbps

- Lunar WLAN (LCT to Rover) is based on 802.16:
  - EVA/rover use 802.16
  - LCT (fixed) and Rover (mobile) serve as 802.16 network hubs and Ka gateway to LRS.
  - Hab will be using 802.11 for internal network and close vicinity

- Mobility NAV/Pointing:
  - Rover/EVA NAV provided by LRS over S-band
  - Rover needs to maintain pointing to LRS for Ka (S-band under consideration)
  - EVA dissimilar voice has only 2.4 Kb to LRS
Surface Mobility Excursion Navigation

- Surface mobility may involve excursions that are 500+ km from the outpost
  - Farside trek has no DTE or LCT
  - Position knowledge < 30 m needed to navigate to desirable spots and back home
  - IMU insufficient for in-situ navigation (1200 m long term accuracy)
- LN tracking and imaging required
  - Roving navigation requires periodic stops to obtain in-situ static position fixes ~every 30-60 min
- In-situ static positioning fixes require
  - LN radiometric tracking to obtain inertial position
  - Landmark tracking coupled with star tracking to obtain map relative position
  - Combined process resolves the ‘map tie’ error between inertial and map relative solutions
  - Static position to < 10 m in a few minutes
- Roving navigation is initialized via the static position fix and then continues with real time navigation processing
  - IMU data is dead reckoning velocity
  - LN radiometric tracking to solve for position and velocity and ‘disciplining’ IMU drift
  - Image data not taken while roving
<table>
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<tr>
<th>Voice (G.729)</th>
<th>Motion Imager (ITUH.264, JPEG2000)</th>
<th>File Trans</th>
<th>Command</th>
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Network layer color code reference: SCIP ADD

C3I Protocol Stack

OSI Model

- **Application Layer**: Type of communication: E-mail, file transfer, client/server.
- **Presentation Layer**: Encryption, data conversion: ASCII to EBCDIC, BCD to binary, etc.
- **Session Layer**: Starts, stops session, maintains order.
- **Transport Layer**: Ensures delivery of entire file or message.
- **Network Layer**: Routes data to different LANs and WANs based on network address.
- **Data Link (MAC) Layer**: Transmits packets from node to node based on station address.
- **Physical Layer**: Electrical signals and cabling.
Summary

• IP implementation has a major impact on NASA communication infrastructure
• Requires “seamless“ integration of existing NASA network provider to
• LAT2 has defined an architecture to be used as a starting point
  — Trades are needed to better define implementation:
    • S vs ka
    • Move user burden to Relay
    • More Bent Pipe