Lunar Architecture Team –II
Communication & Navigation

Evolution of the Lunar Network

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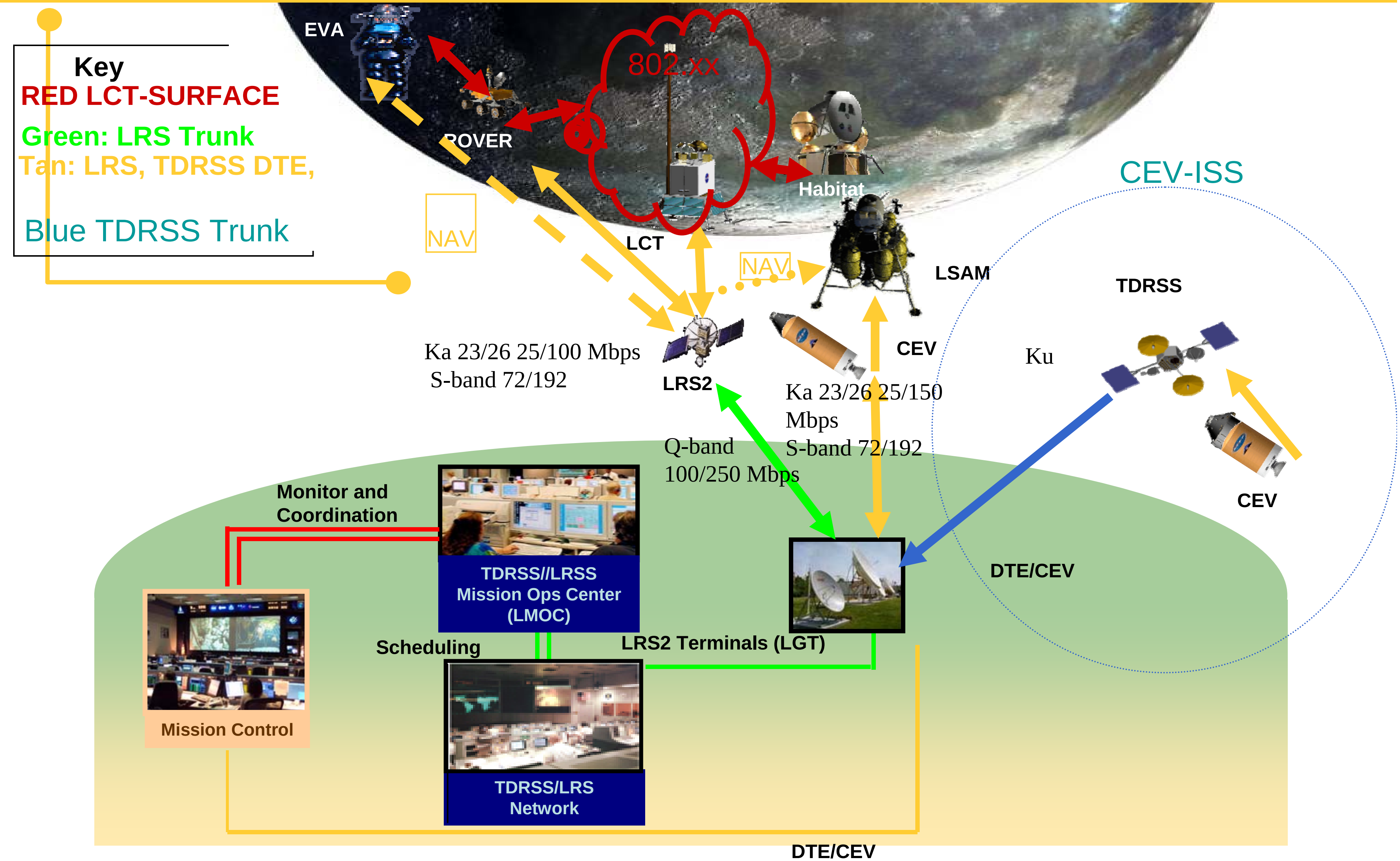
Architecture Summary

- 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 (included 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

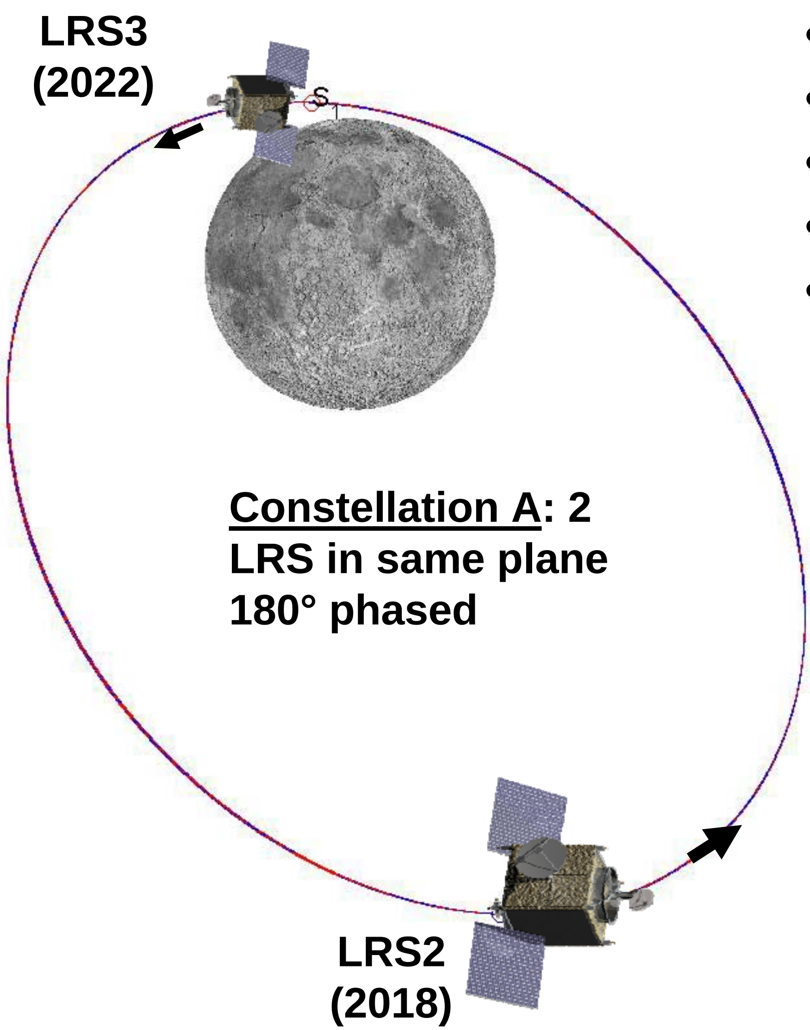
Com and Nav Architecture



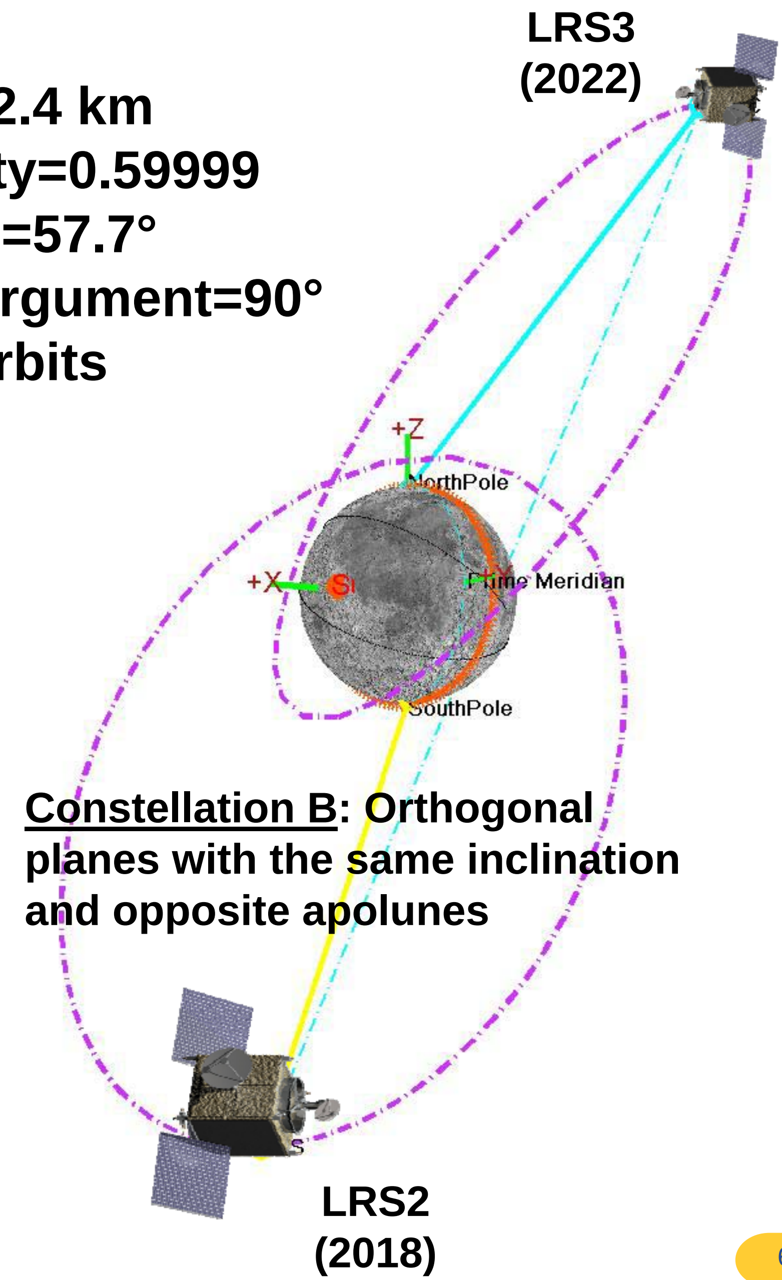
Conops of Lunar Relay Satellite (LRS)

- 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



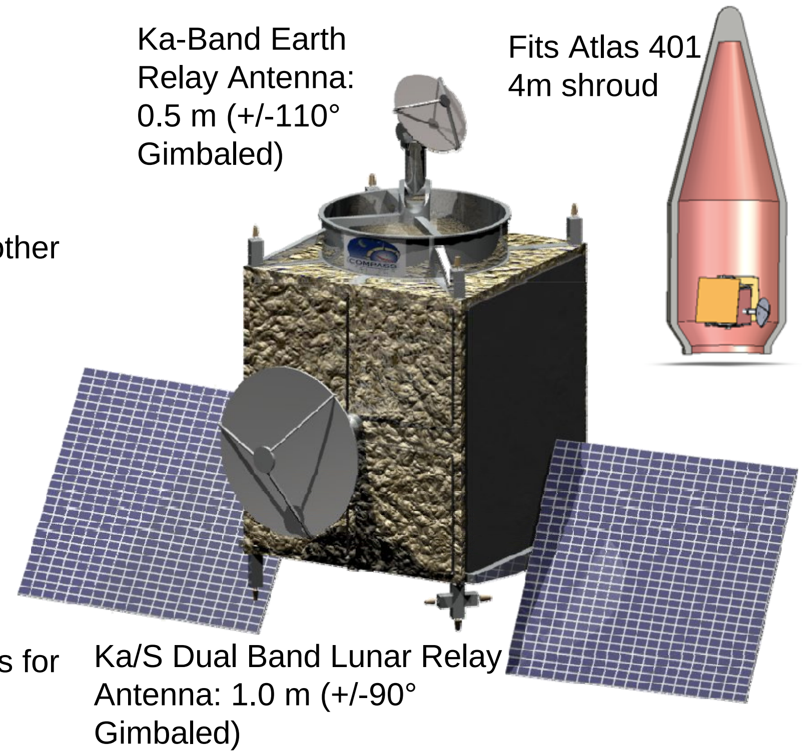
LRS:
- SMA= 6142.4 km
- Eccentricity=0.59999
- Inclination=57.7°
- Perilune Argument=90°
- 12-Hour Orbits

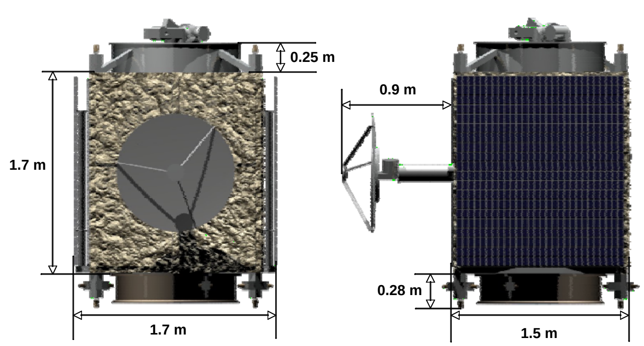


Note: LRS1 satellite proposed during LAT1 for LPRP support

Lunar Relay Satellite (LRS)

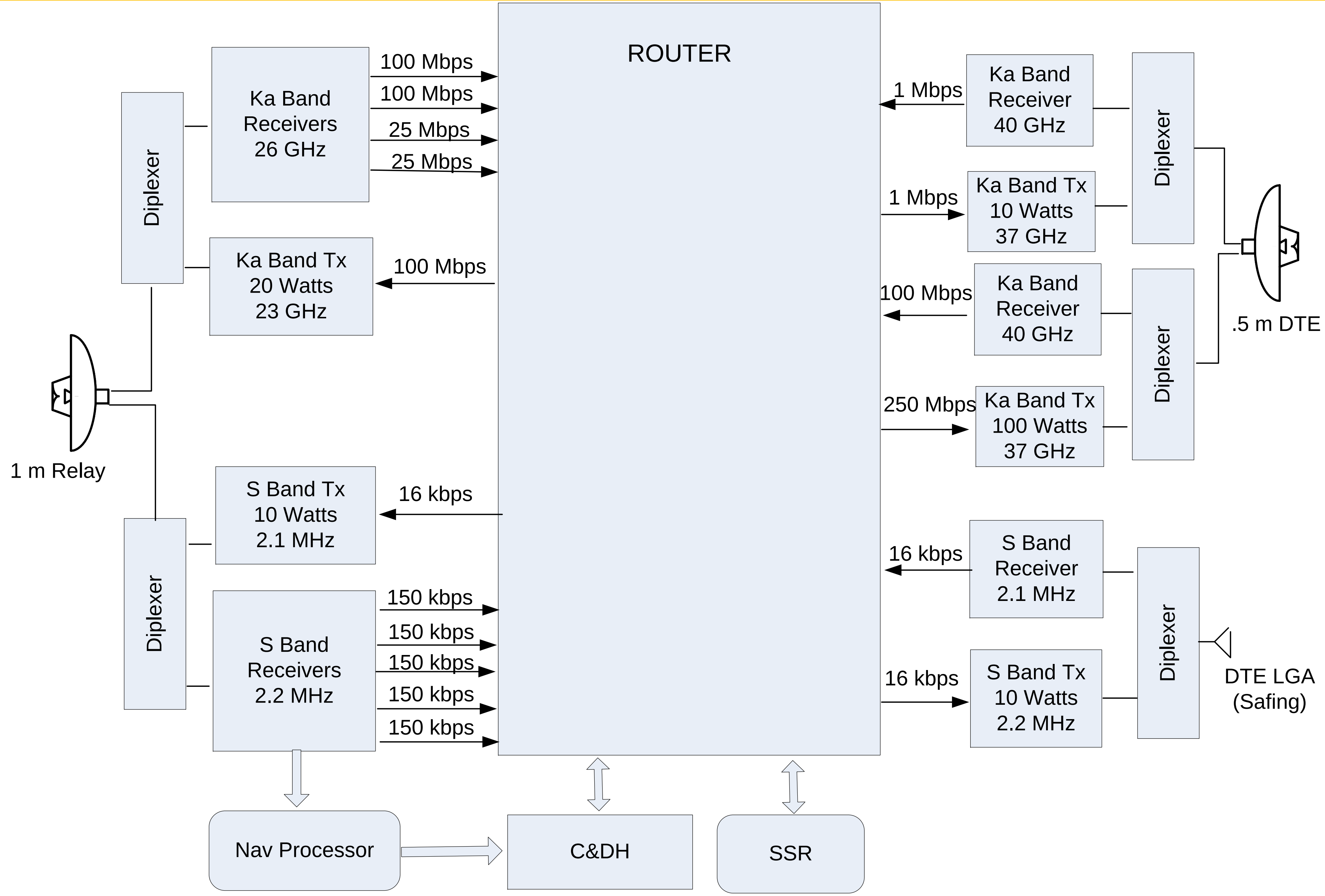
- Lunar comm relay, navigation & timing spacecraft
  - 2 LRS in 12 hr frozen elliptical lunar orbit
  - 7 year life with fuel for 10 years, Each LRS single fault tolerant
- Atlas 401 or Delta IV Medium: >60% launch margin
  - Options exists for dual launch or secondary payloads
- Communications and Navigation 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_f & 16x 0.5 lb_f 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 m^2 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





Description 1.8.3.1 & 1.8.3.2 Lunar Relay Satellite 1st Unit & 2nd	CBE Mass (kg)	Growth (kg)	Total Mass (kg)	Nominal Power (w)
Lunar Relay Satellite	1033.5	90.8	1124.2	683.6
Communications	79.4	2.4	81.8	494
Avionics	91.6	21.7	113.3	189.6
Structures & Mechanisms	180.5	25.1	205.6	0
Power System	72.6	22.2	94.8	0
Propulsion (Chemical)	21.8	1.7	23.5	0
* Propellant Management	72.9	10.9	83.9	0
* Propellant	467.3	0	467.3	0
Thermal Control	47.3	6.7	54	0

LRS Data Flow



General Concepts of Surface Operations

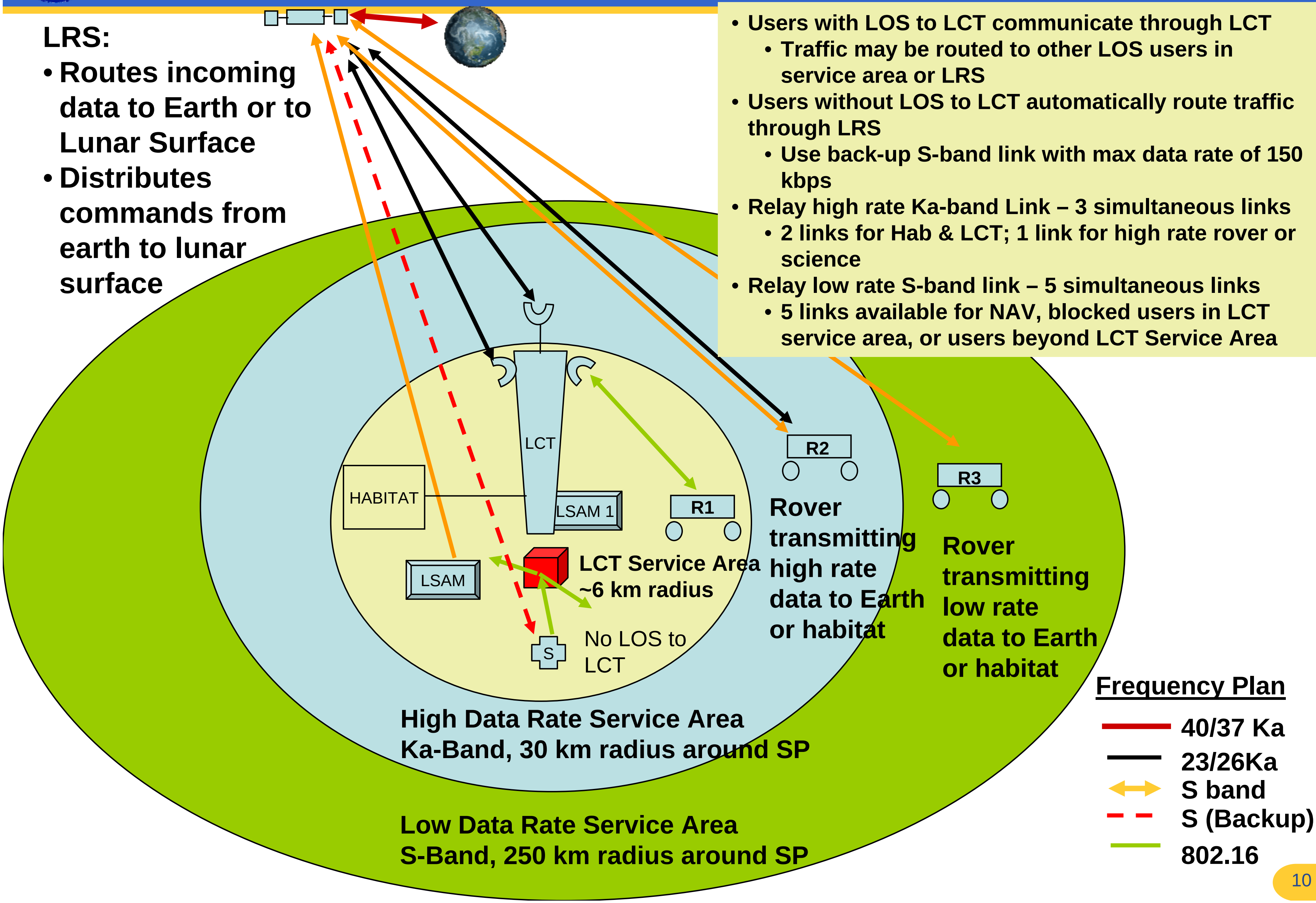
- Two zones exist: Within Line Of Sight (LOS) of the LCT and Beyond LOS
- Use Lunar Comms Terminal (LCT) within its LOS range around the Outpost Zone
  - Surface elements, like EVA suits and rovers, communicate to LCT to save power
  - LCT routes surface-surface data by wireless LAN and wired connections
  - 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)

General Concept of Operations

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



Surface network

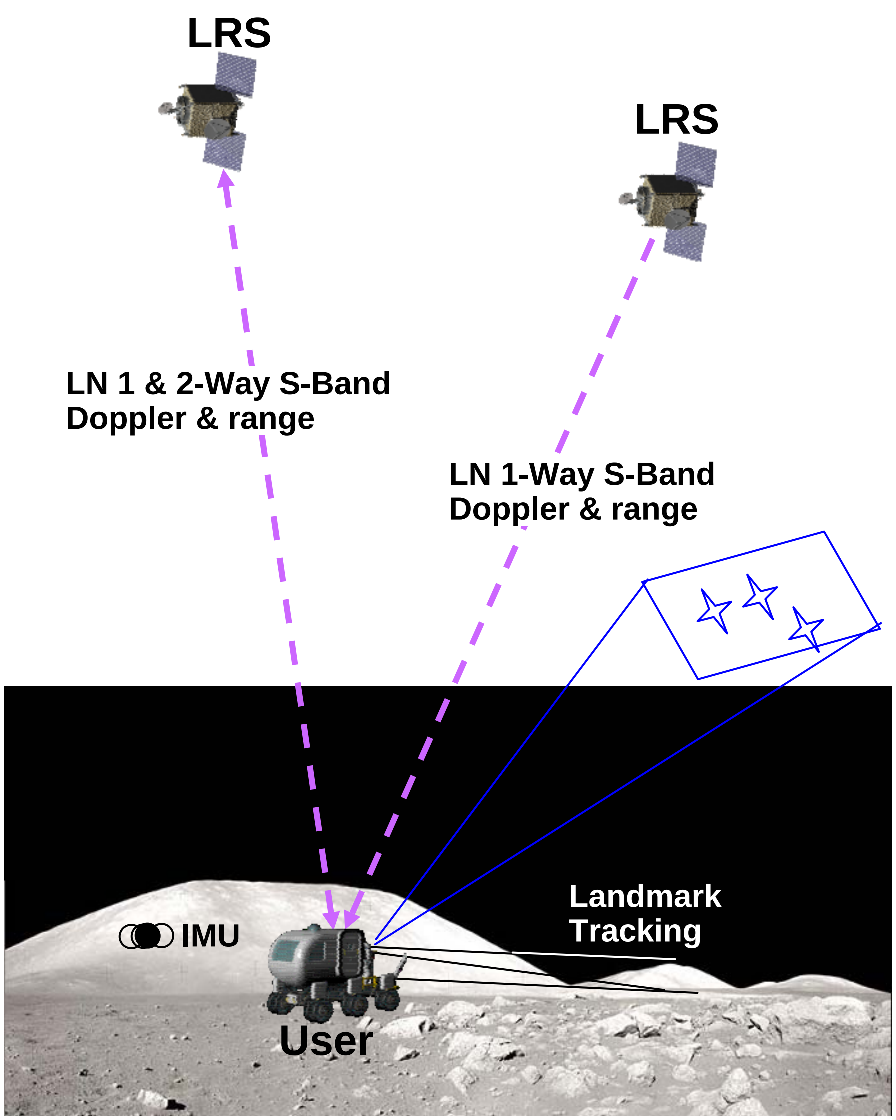
- Pockets of 802.XX networks connected via gateways
  - HAB
  - IRSU
  - Rover/ EVA
- Applications are based on IP Integration on IP layer
- HAB connected to LCT with Fiber (Ethernet) 100 mbps

- 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



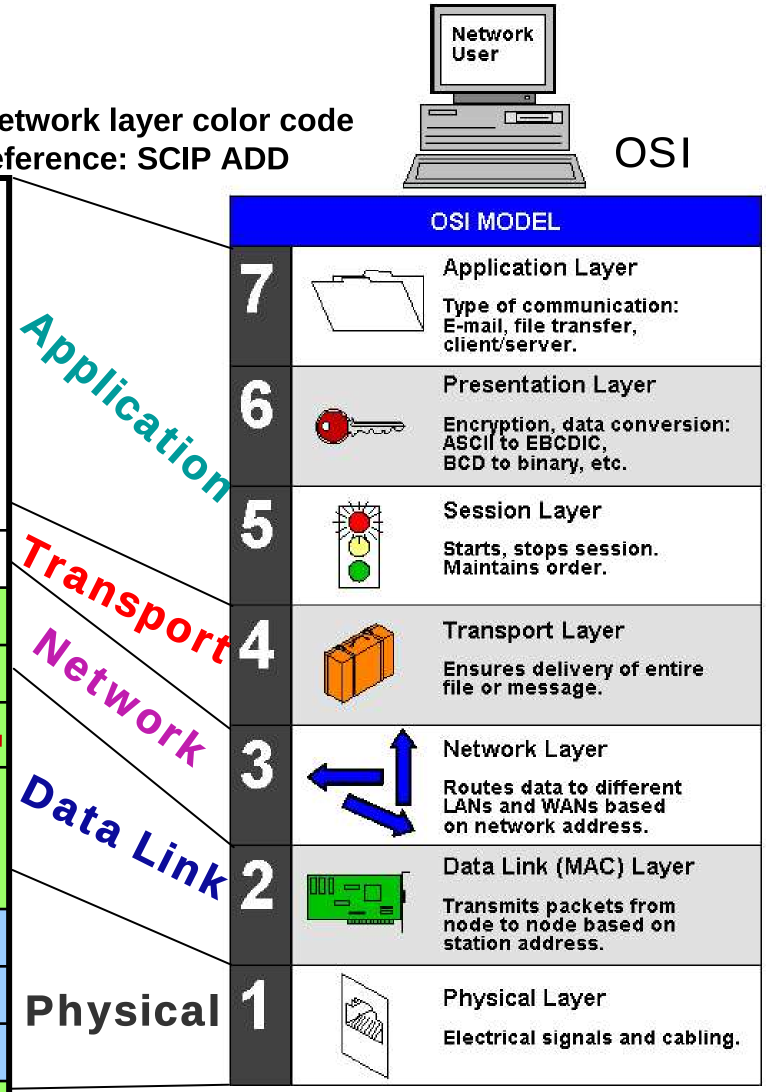
C3I Protocol Stack

C3I

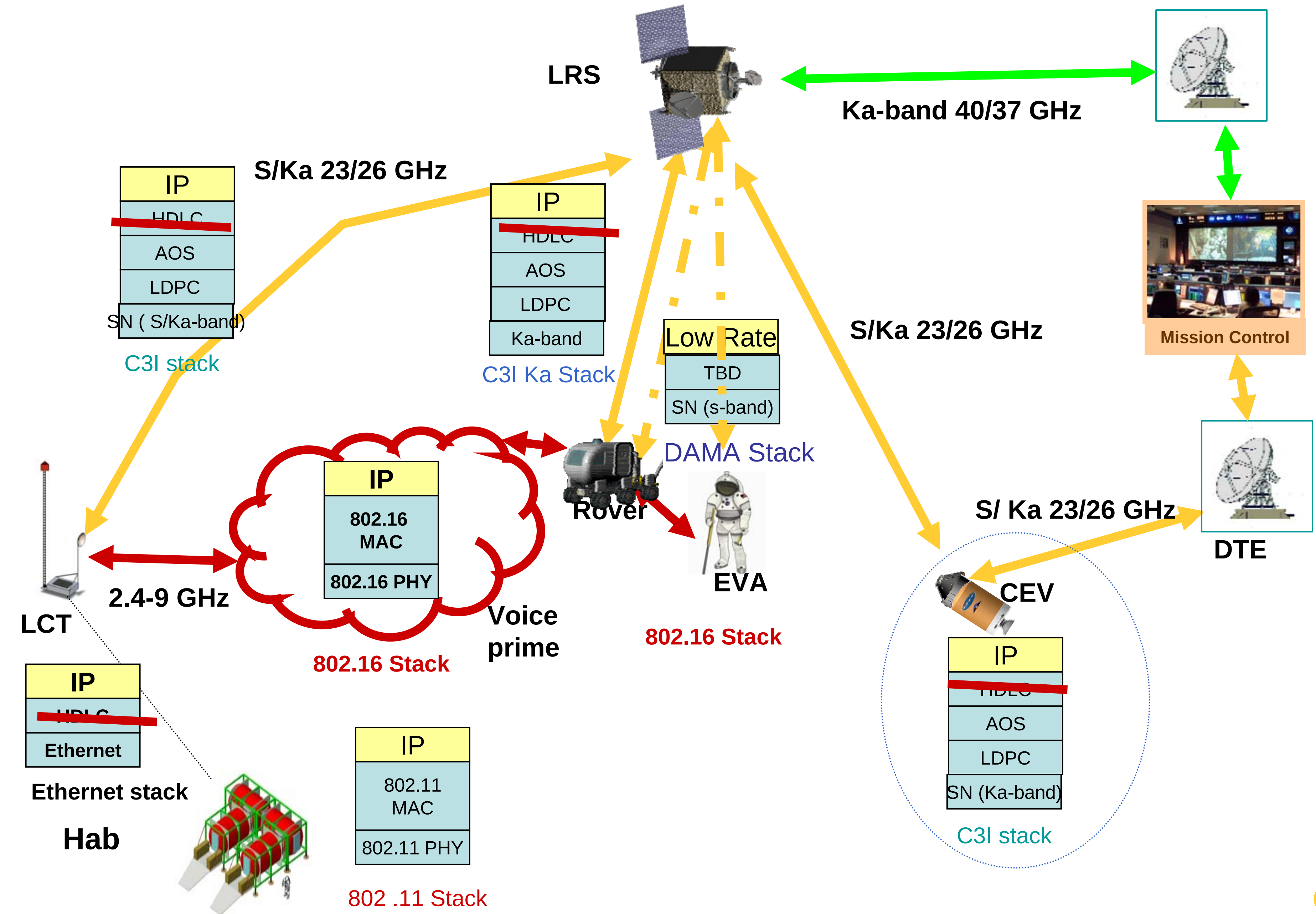
Voice (G.729)	Motion Imagery (ITUH.264, JPEG2000)	File Trans	Command	Telemetry	TBD (e.g. HTTP)
RTP		CFDP	DE		
UDP					TCP / SCPS-TP
IPv4 or IPv6					
IPSEC (tunnel)					
~~HDLC (synchronous) – ISO 13239 – RFC 2427 (Q.922)~~					
AOS (user-provided serial stream encapsulation through VCA service) - CCSDS 732.0.B.2 and 702.1.R.0					
LDPC Code – AR4JA Codes (Rate ½) – CCSDS Orange					
Bit Randomization – CCSDS 131.0.B.1					
ASM – CCSDS 131.0.B.1					
R/F Modulation					

Network layer color code reference: SCIP ADD

OSI



Surface Architecture – Network Protocols



Summary

- IP implementation has a major impact on NASA communication infra structure
- 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

Backup