Communication Interoperability for Lunar Missions

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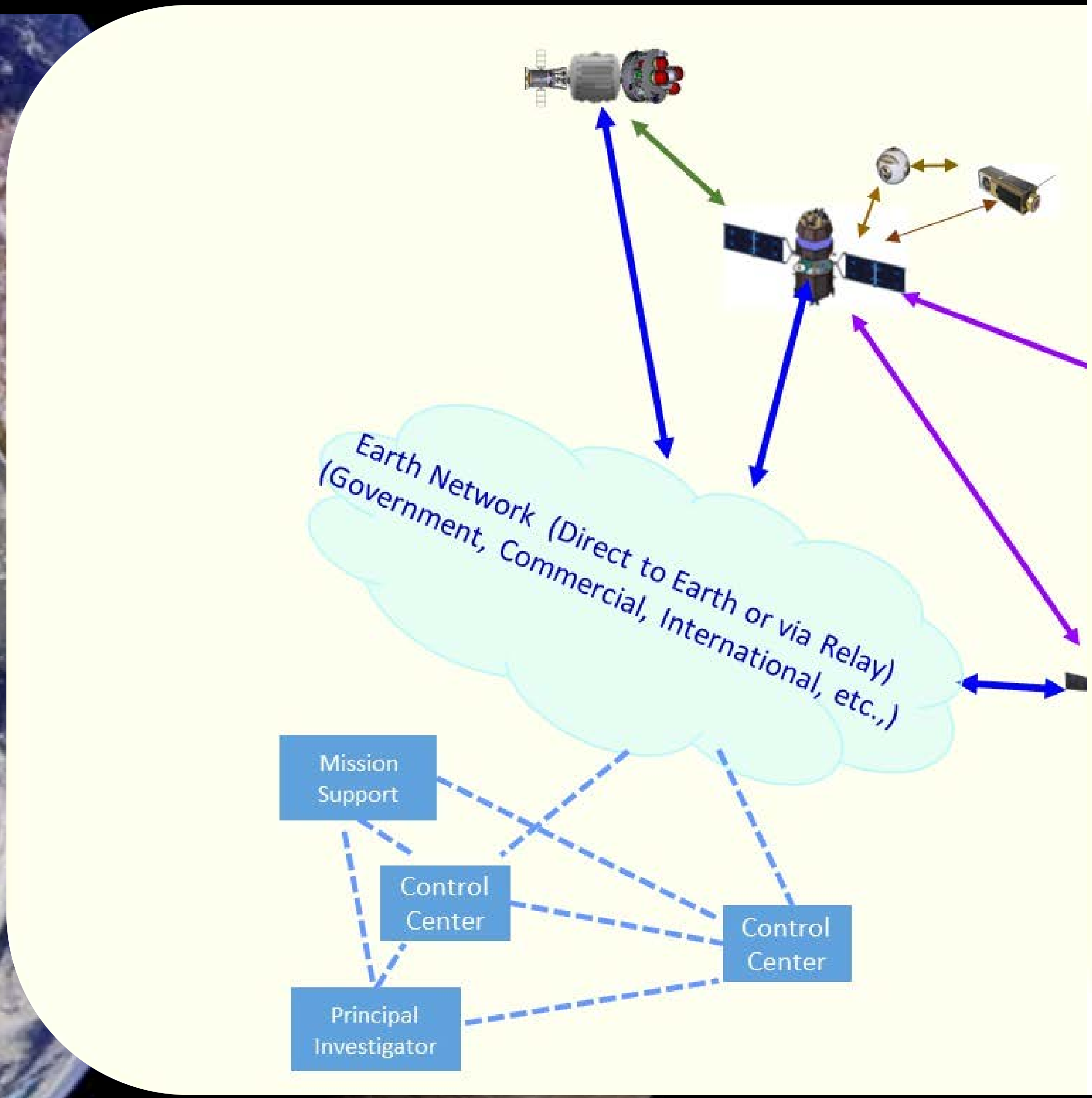
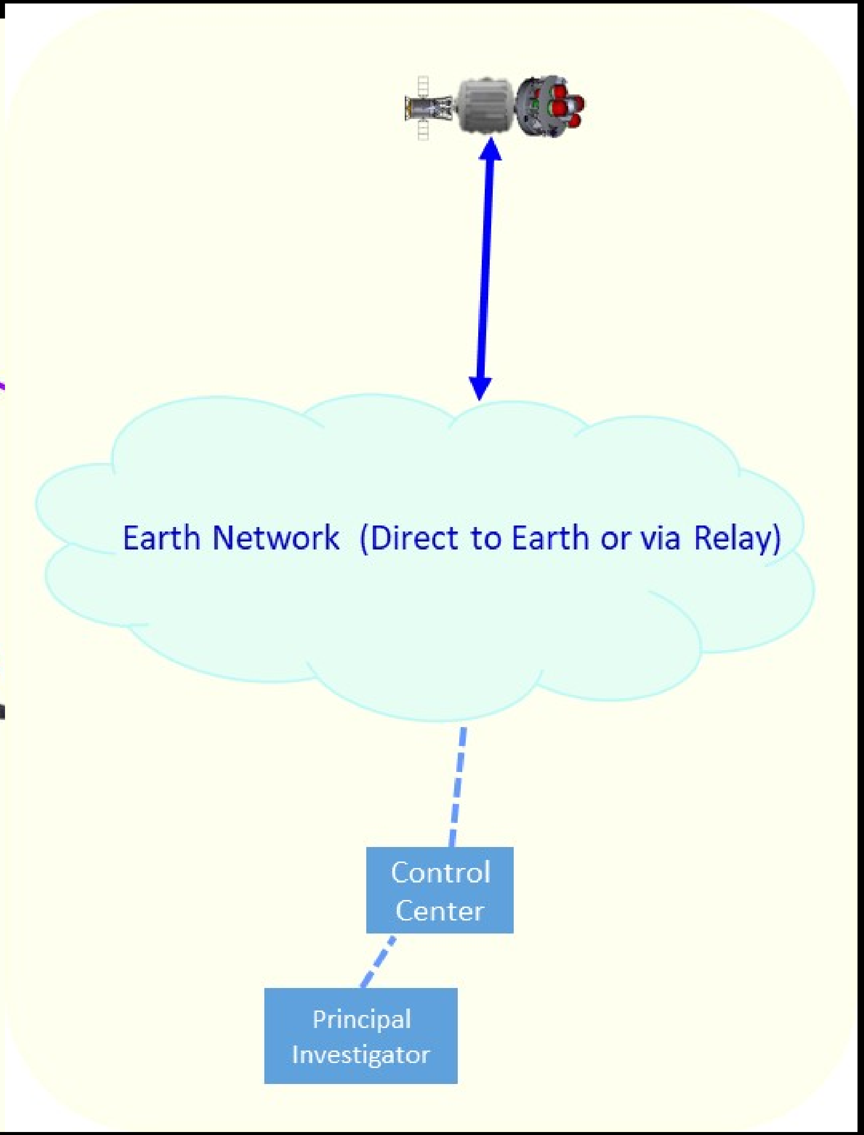
As Humans venture beyond earth orbit, missions are getting more complex





Future Exploration Missions

Large number (80+) of missions planned for the lunar region over the next decade

- Spanning a variety of scientific, exploration and commercial objectives

Based on a multi-mission “campaign” instead of individual missions

Partnerships with Commercial and international providers

Ability to operate over multiple phases and interfaces

Evolving networked architecture and capabilities

Compatibility with existing assets/infrastructure

System Integration across multiple levels

Key Challenges Driving Interoperability

- Evolving architecture
- Ability to operate over different mission phases, longer latencies
- Compatible with multiple interfaces
  - Ground and in-space infrastructure
  - Commercial, Government and international partner
- Forward compatibility, scalability and extensibility
- System integration across multiple levels
- Highly Reliable, sustainable operations
- Vehicle’s size, weight and power constraints

Key Benefits Driving Interoperability

Interoperable, cross supportable and compatible communications between space vehicles, ground infrastructure, etc. is critical to the success of human exploration

- Enables use of NASA, international partner, commercial assets interchangeably
- Makes efficient use of limited spectrum
- Decreases vehicle development and procurement costs
- Reduces operational and training complexity
- Lowers burden of ground infrastructure to support multiple configurations, protocols and standards

International Communication System Interoperability Standard (ICSIS)

NASA and it’s International Partners collaboratively established the International Communication System Interoperability Standard (ICSIS)

- **Purpose and Scope**
  - Defines the functional, interface and performance standards necessary to support interoperable and compatible communications between Cislunar Space Platforms (CSP) such as human exploration spacecraft and other lunar orbiting and surface vehicles and associated ground infrastructure.
  - The scope of the standard is for deep space human spaceflight missions and spacecraft that interface with human missions (i.e. visiting vehicles, landers, etc.), surface systems .
  - Where practicable, the document includes content relevant to future deep space human exploration missions.
    - Future revisions will update as needed for deep space human exploration missions

- **Status of Standard**
  - Baselined and signed off by NASA and International Partners in May, 2019
  - Baseline version available at:

    https://internationaldeepspacestandards.com/

International Communication System Interoperability Standard (ICSIS)

Document Content

- Defines protocols, standards and operational philosophies for communications and tracking between space vehicles, ground infrastructure, EVAs, free flyers, payloads, and surface systems
  - Radio frequency bands, modulation, coding and synchronization, framing;
  - Ranging;
  - Audio, video;
  - Network, transport, and security including Delay Tolerant Networking (DTN) protocol suite for secure end-to-end, networked communication

- Follows Interagency Operations Advisory Group (IOAG), Space Frequency Coordination Group (SFCG), and Consultative Committee on Space Data Systems (CCSDS) standards and recommendations
- Consistent with Interagency Operations Advisory (IOAG) Lunar Communications Architecture Working Group (LCAWG) study recommendations

International Communication System Interoperability Standard (ICSIS)

Key Trades: Frequency

1. Frequency for CSP - Earth TT&C Link (X-band vs. S-band): Selected X-band
    a. Spectrum: X-band is less congested that S-band
    b. Ground Station support: more assets supporting X-band
    c. X-band is Mars forward
    d. X-band offers mass and power advantages over S-band
    e. S-band links are more susceptible to multipath effects due to the lunar terrain/regolith than X-band

2. Frequency for CSP – Earth high rate links: Selected 22/26 GHz Ka-band over the use of 37-38/40-41 GHz
    a. Ground stations support and investments into 22/26 GHz Ka-band
    b. High implementation costs for developing hardware for space vehicles

International Communication System Interoperability Standard (ICSIS)

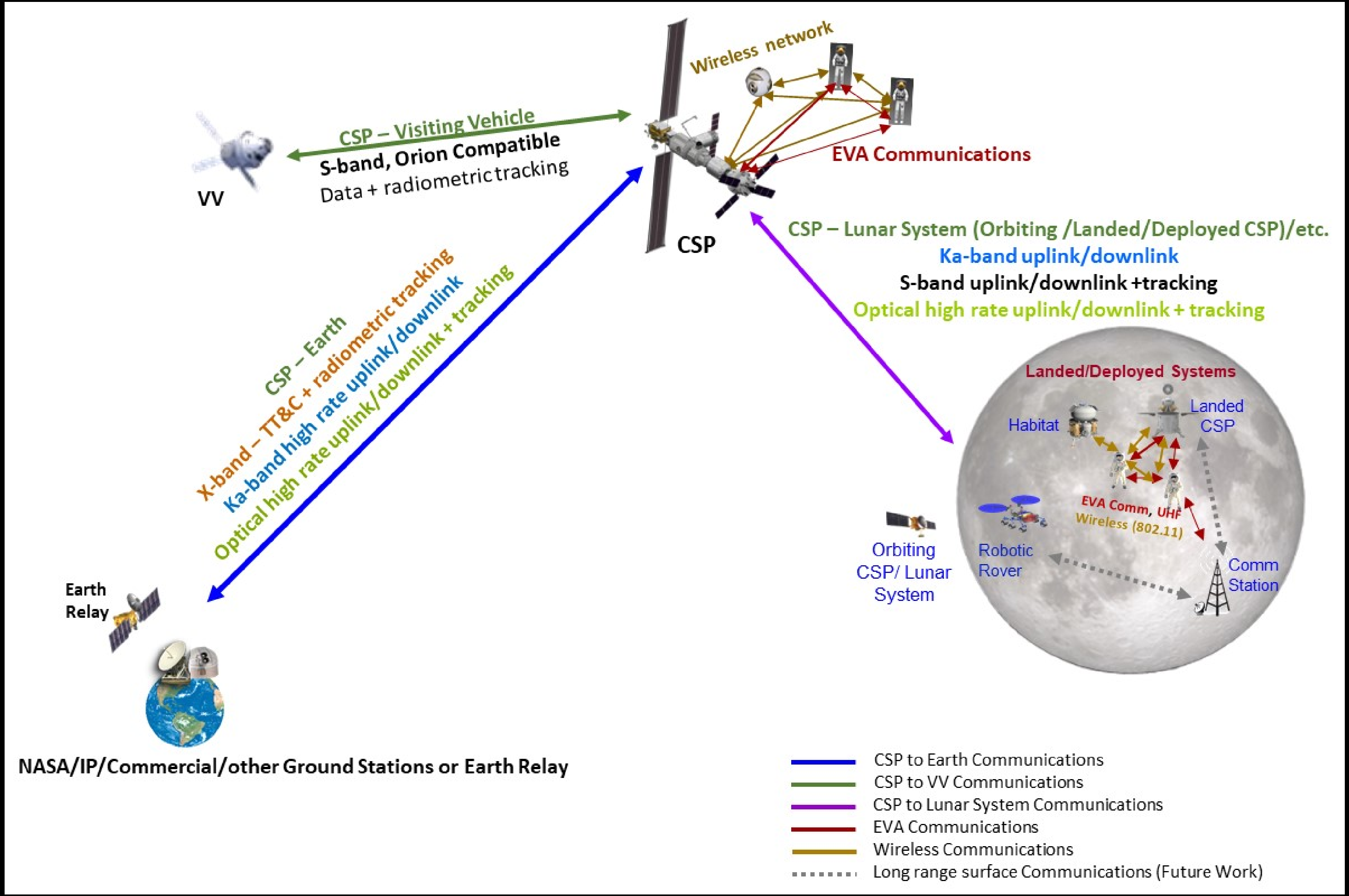
Key Trades (continued)

3. **Forward Error Correction Coding: Low Density Parity Check (LDPC)**
   a. **Selected LDPC codes for all links (Forward and Return, and Space-to-Space)**
   b. **Higher achievable coding performance.**
      - coding gain provided by the LDPC codes at rate 1/2, considering a BER of 10^{-6}, is ~1.4 dB more than that provided by concatenated Reed-Solomon/convolution codes

4. **Space Data Link Protocol: Advanced Orbiting System Space Data Link Protocol (AOS) or Unified Space Data Link Protocol (USLP), but not both**
   a. **ICSIS baseline is AOS**
      - **Once partners agree to implementation of USLP and the Ground Stations implement it, consider transitioning to USLP for future missions**

International Communication System Interoperability Standard (ICSIS)

Defines the "minimum" standards and protocols for communications for a "Cislunar Space Platform



International Communication System Interoperability Standard (ICSIS)

Salient Features: CSP – Earth RF Links

CSP - Earth					
Command and Telemetry					
Direction	Data Rate	Frequency	Modulation	Coding	Ranging
Uplink	<10 Msps	7190-7235 MHz	BPSK OQPSK PCM/PM/bi-phase-L -Modulation on residual carrier	LDPC coding rates $^{1}/_{2}$, $^{2}/_{3}$, $^{4}/_{5}$, $^{7}/_{8}$ uncoded	CCSDS PN Non-regenerative. Ranging chip rate: < 4 Mcps
Downlink	< 4 Msps	8450-8500 MHz	BPSK OQPSK PCM/PM/bi-phase-L -Modulation on residual carrier	LDPC coding rates $^{1}/_{2}$, $^{2}/_{3}$, $^{4}/_{5}$, $^{7}/_{8}$ uncoded	CCSDS PN Non-regenerative. Ranging chip rate: < 4 Mcps
High Data Rate					
Uplink	≤ 25 Msps	22.55-23.15 GHz	Filtered OQPSK with suppressed carrier	LDPC coding rates $^{1}/_{2}$, $^{2}/_{3}$, $^{4}/_{5}$, $^{7}/_{8}$ uncoded	None
Downlink	100 Msps+	25.5-27.0 GHz	Filtered OQPSK with suppressed carrier	LDPC coding rates $^{1}/_{2}$, $^{2}/_{3}$, $^{4}/_{5}$, $^{7}/_{8}$ uncoded	None

* The SFCG has recommended extension of the 22/26 GHz bands to 23.15-23.55 (Lunar Orbit to Lunar Surface) and 27-27.5 (Lunar Surface to Lunar Orbit) GHz to support CSP to/from Lunar System communication.

International Communication System Interoperability Standard (ICSIS)

Salient Features: CSP – Lunar Systems RF Links

CSP – Lunar Systems					
Direction	Data Rate	Frequency	Modulation	Coding	Ranging
CSP to Lunar System	Low rate	2025-2110 MHz	PCM/PM/bi-phase-L modulation on residual carrier	LDPC coding rates $^{1}/_{2}$, $^{2}/_{3}$, $^{4}/_{5}$, $^{7}/_{8}$ uncoded	CCSDS PN Non-regenerative. Ranging chip rate: < 4 Mcps
Lunar System to CSP	Low rate	2200-2290 MHz	PCM/PM/bi-phase-L modulation on residual carrier	LDPC coding rates $^{1}/_{2}$, $^{2}/_{3}$, $^{4}/_{5}$, $^{7}/_{8}$ uncoded	CCSDS PN Non-regenerative. Ranging chip rate: < 4 Mcps
CSP to Lunar System	High rate	22.55-23.15 GHz*	Filtered OQPSK – suppressed carrier	LDPC coding rates $^{1}/_{2}$, $^{2}/_{3}$, $^{4}/_{5}$, $^{7}/_{8}$ uncoded	None
Lunar System to CSP	High rate	25.5 – 27.0 GHz*	Filtered OQPSK – suppressed carrier	LDPC coding rates $^{1}/_{2}$, $^{2}/_{3}$, $^{4}/_{5}$, $^{7}/_{8}$ uncoded	None

* The SFCG has recommended extension of the 22/26 GHz bands to 23.15-23.55 (Lunar Orbit to Lunar Surface) and 27-27.5 (Lunar Surface to Lunar Orbit) GHz to support CSP to/from Lunar System communication.

International Communication System Interoperability Standard (ICSIS)

Salient Features: CSP – Visiting Vehicle RF Links

CSP – Visiting Vehicle					
Direction	Data Rate	Frequency	Modulation	Coding	Ranging
Point A transmit/ Point B receive	18 ksps – 20 Msps	2200-2290 MHz	Data Group 1 and 2 Balanced SQPN Spread Spectrum (I Only) Unbalanced QPSK Balanced SQPSK	LDPC coding Rate ½, uncoded	PN spreading for Data Group 1. None for Data Group 2.
Point B transmit/ Point A receive	18 ksps - 300 ksps	2025-2110 MHz	Spread Spectrum Unbalanced QPSK (10:1)	LDPC coding rate ½, uncoded	PN spreading

International Communication System Interoperability Standard (ICSIS)

Forward Work:

- Standards for Contingency Communications
- Standards for interfaces between ground stations and control centers
- Standards for Optical Communication
  - CCSDS Standards are in work
- Engage Industry partners
  - Adoption of the standards is critical to achieving the benefits of Interoperability

Acknowledgements:

- IOAG Lunar Communications Architecture Working Group and their co-chairs for working with us on that the standards in the ICSIS were consistent with the IOAG LCAWG study recommendations

- ICSIS development and splinter teams consisting of CSA, ESA, JAXA, NASA and RSA subject matter experts who participated in the development and review of the

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