Delay Tolerant Networking & The Interplanetary Internet

Network systems... *in spaaaace*

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CSCI 5273

Goals

1. Gain a firm understanding of the challenges to networking across interplanetary distances.
2. Identify the shortcomings of standard Internet protocols in addressing these challenges and operating amidst these constraints.
3. Survey the current research, implementations, and standards that seek to overcome these challenges.
4. Simulate an interplanetary network to observe the various behaviors of networks in the presence of these obstacles.
5. ~~Implement and evaluate a custom retransmission scheme for DTN~~

Agenda

Space Communication

- Sat comm basics
- Challenges of space communications
- The InterPlaNetary Internet
- Shortcomings of TCP/IP

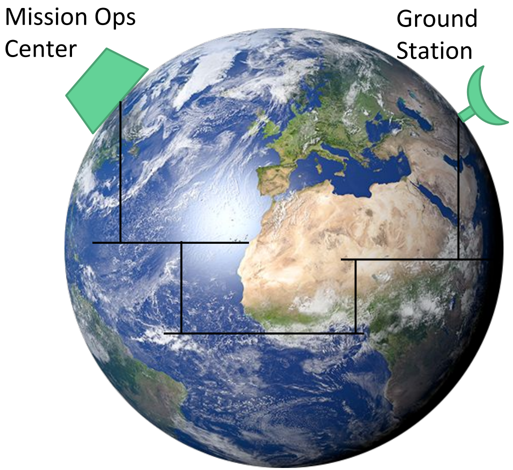
Delay/Disruption-Tolerant Networking

- History
- Principles
- Bundle Protocol
- CCSDS File Delivery Protocol
- Licklider Transmission Protocol
- ION

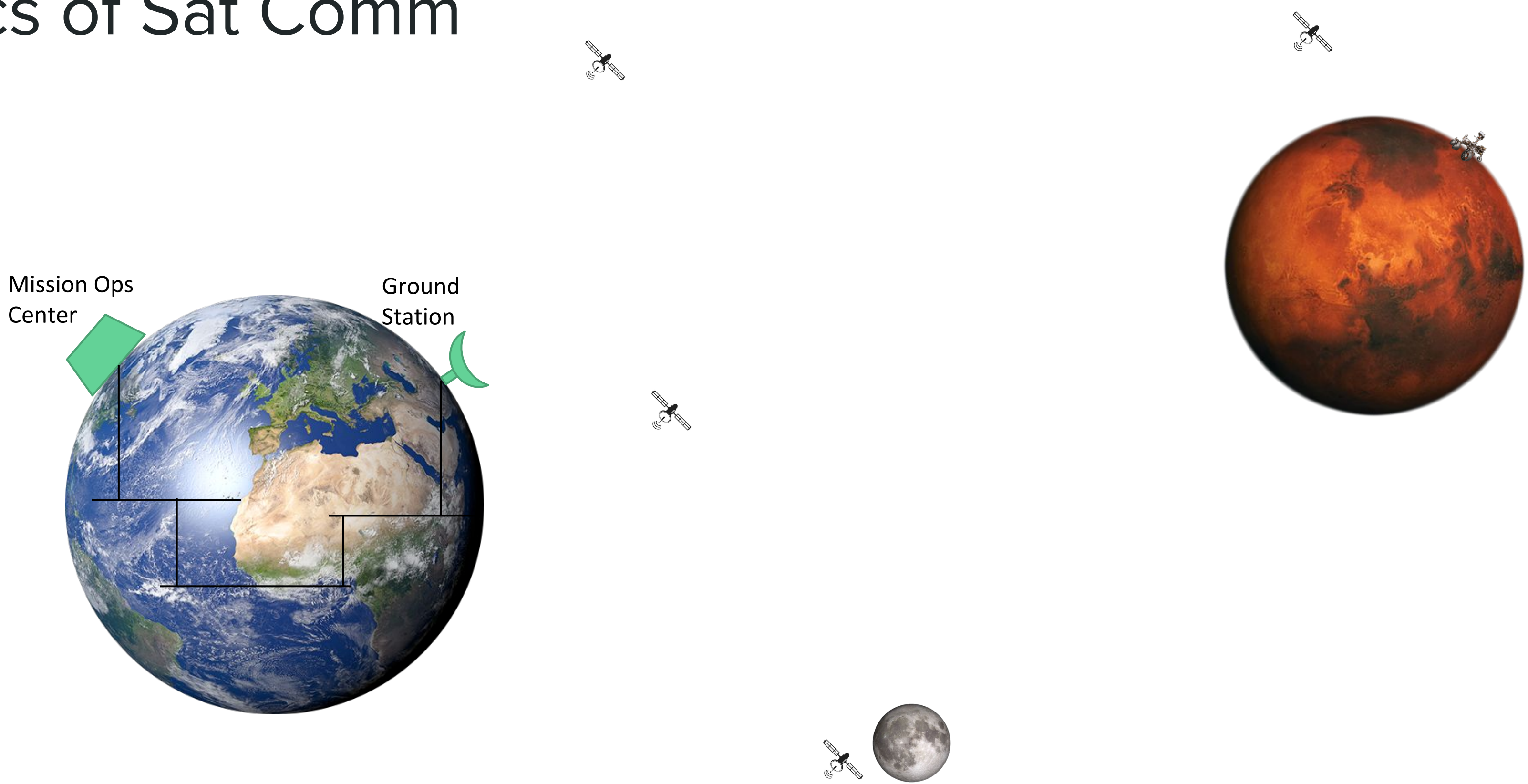
Demo

Space Communication

Basics of Satellite Communication



Basics of Sat Comm



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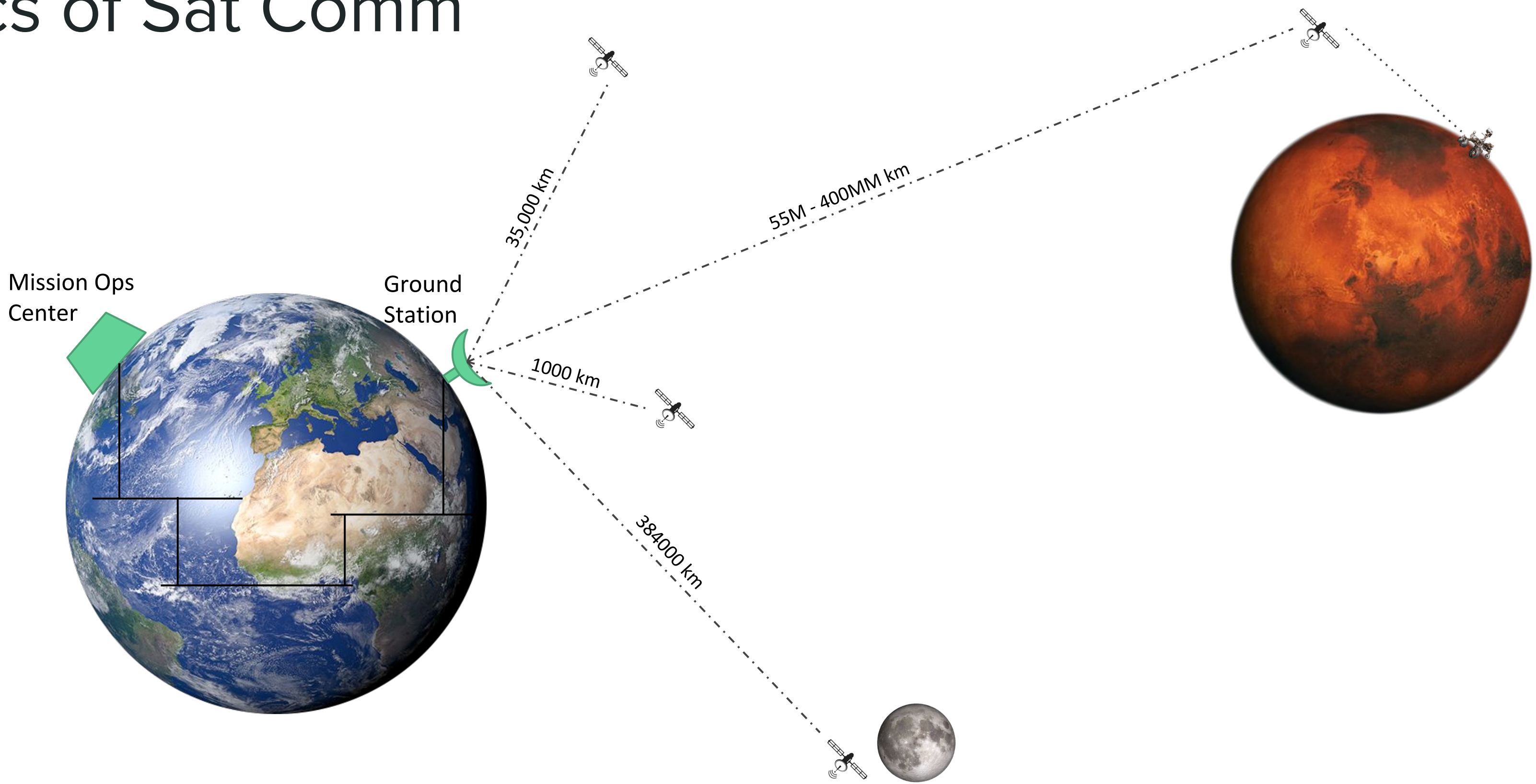
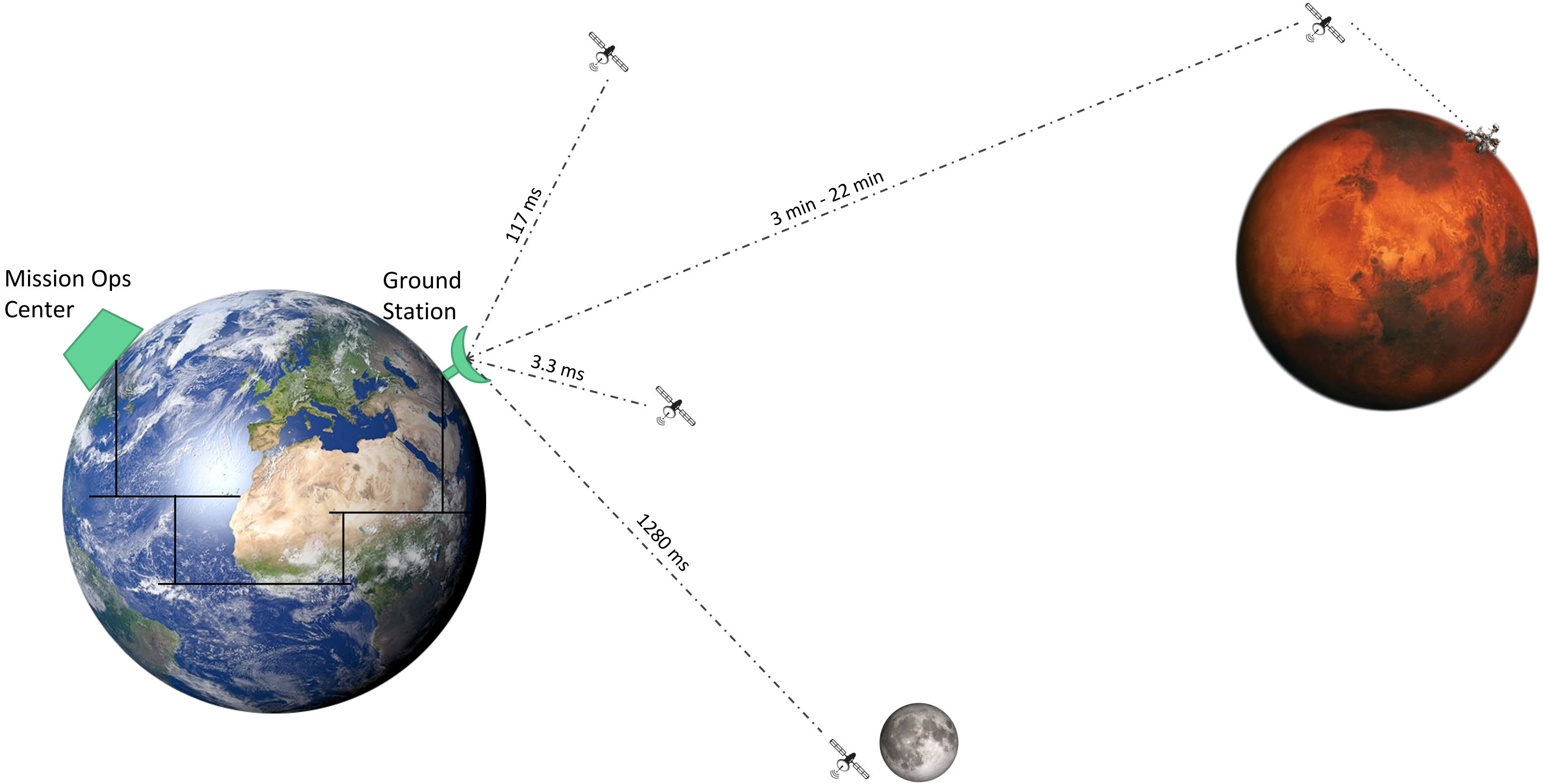
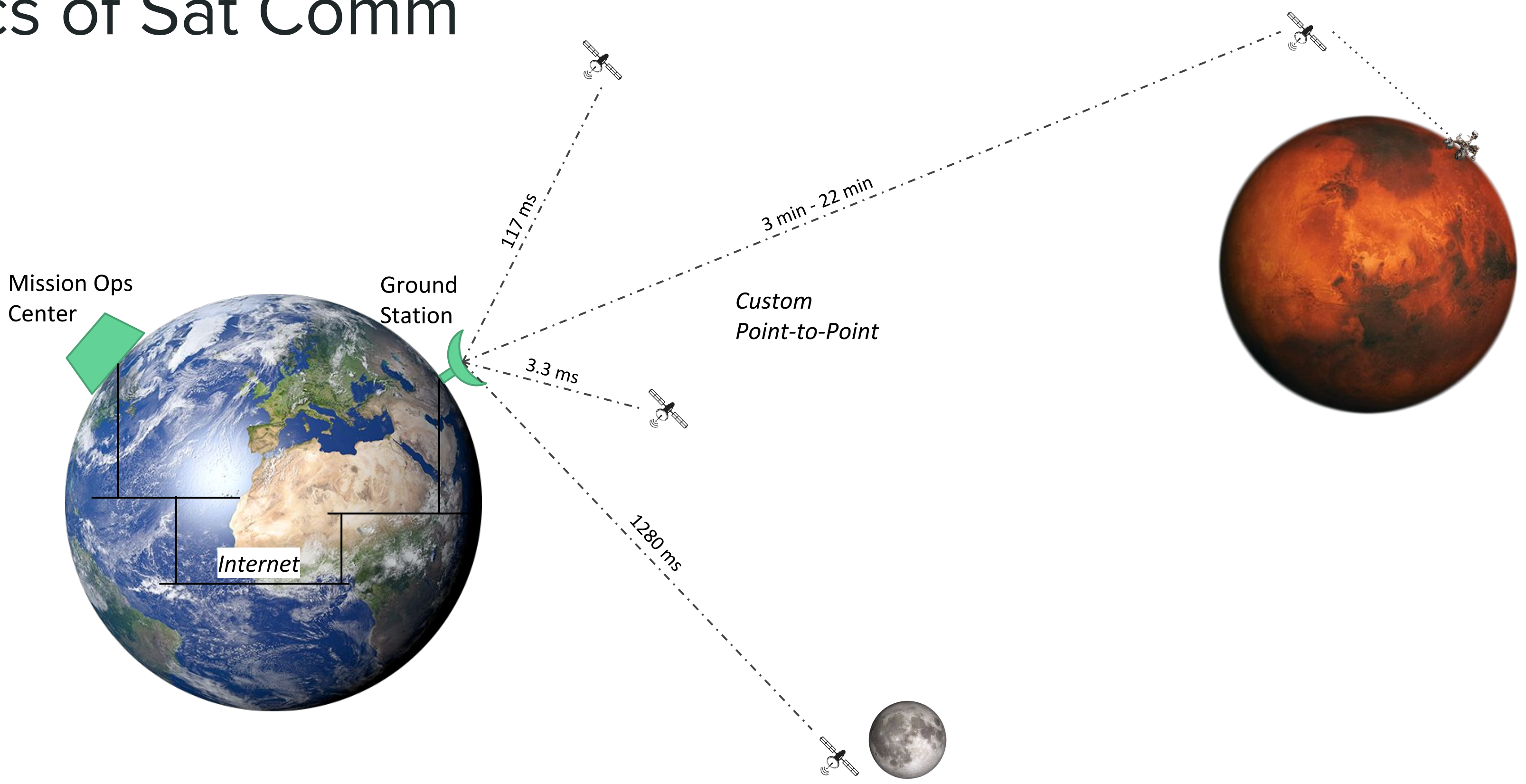



Mission Ops
Center
Ground
Station
117 ms
3 min - 22 min
3.3 ms
1280 ms

Basics of Sat Comm



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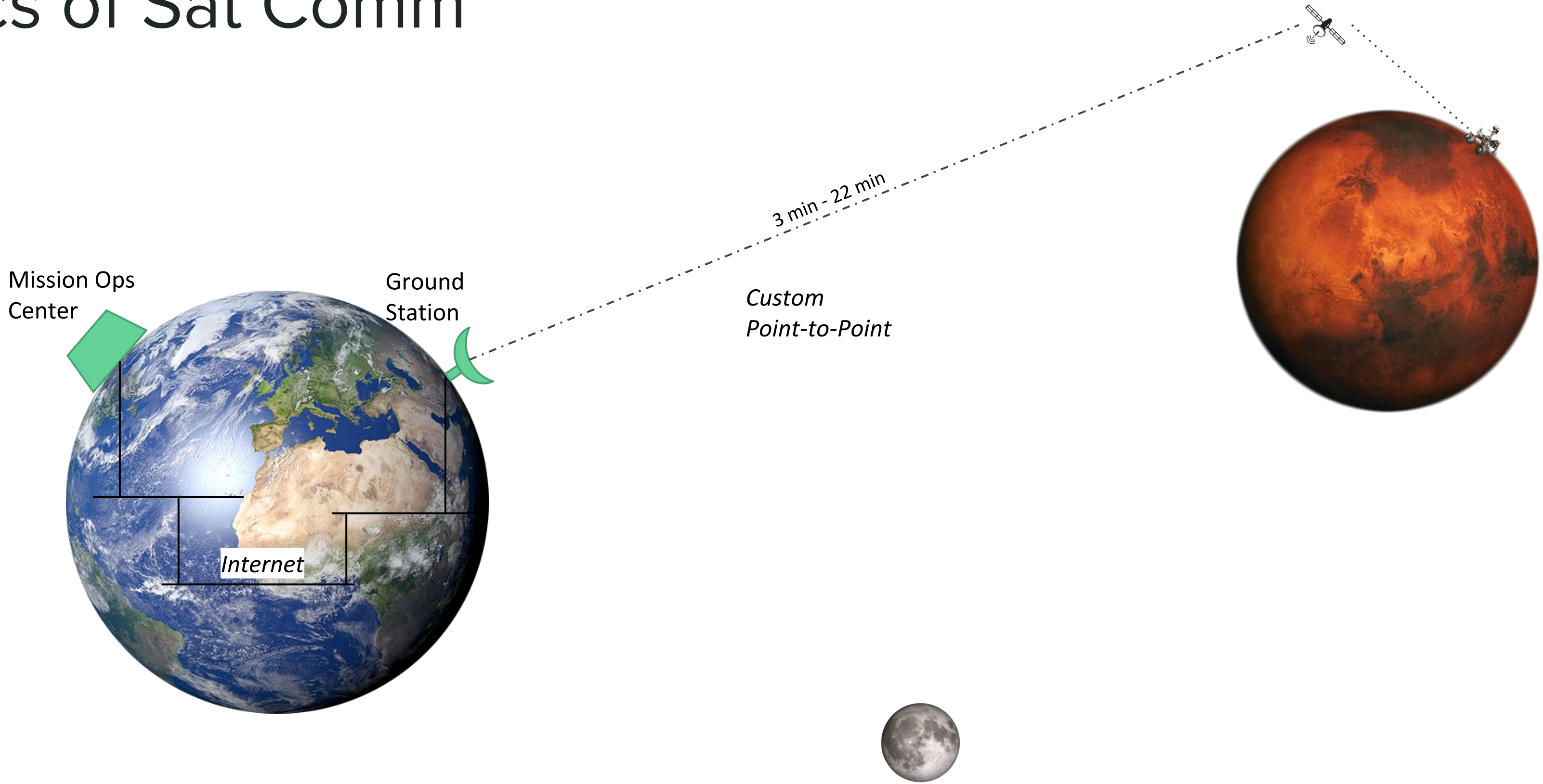


Terrestrial Link: TCP/IP over Internet

- Short propagation delays
- High data rates
- Continuous end-to-end connectivity
- On-demand access (high congestion)

Space Link:

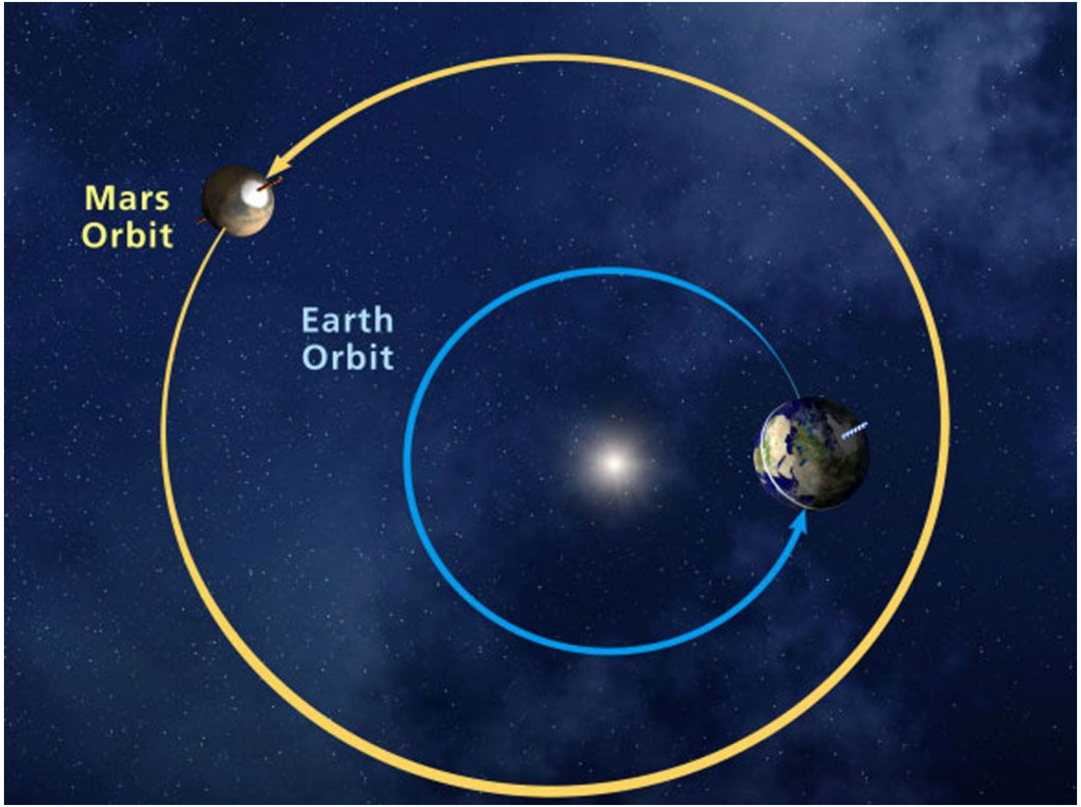
70m (DSN)

3m (MRO)

Space Link: Constraints / Challenges

- Long and variable propagation delays

Variable Delay



source: https://www.calacademy.org/

Space Link: Constraints / Challenges

- Long and variable propagation delays
- Low data rates (8bps - 6Mbps)

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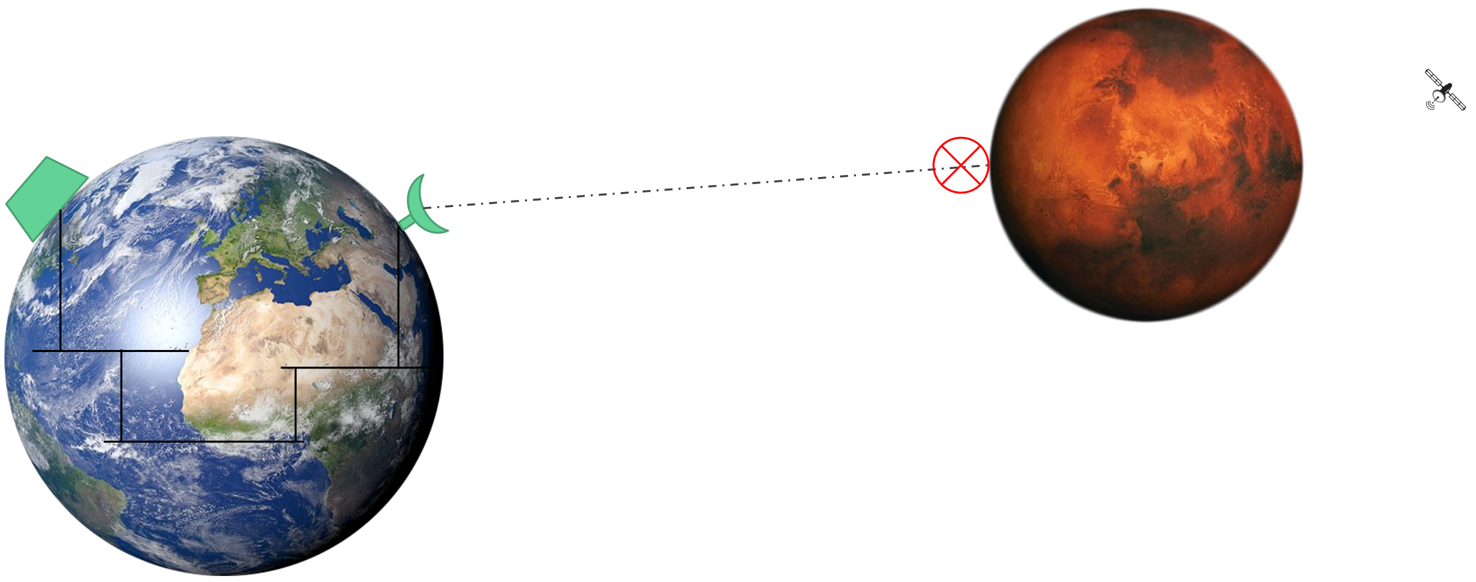
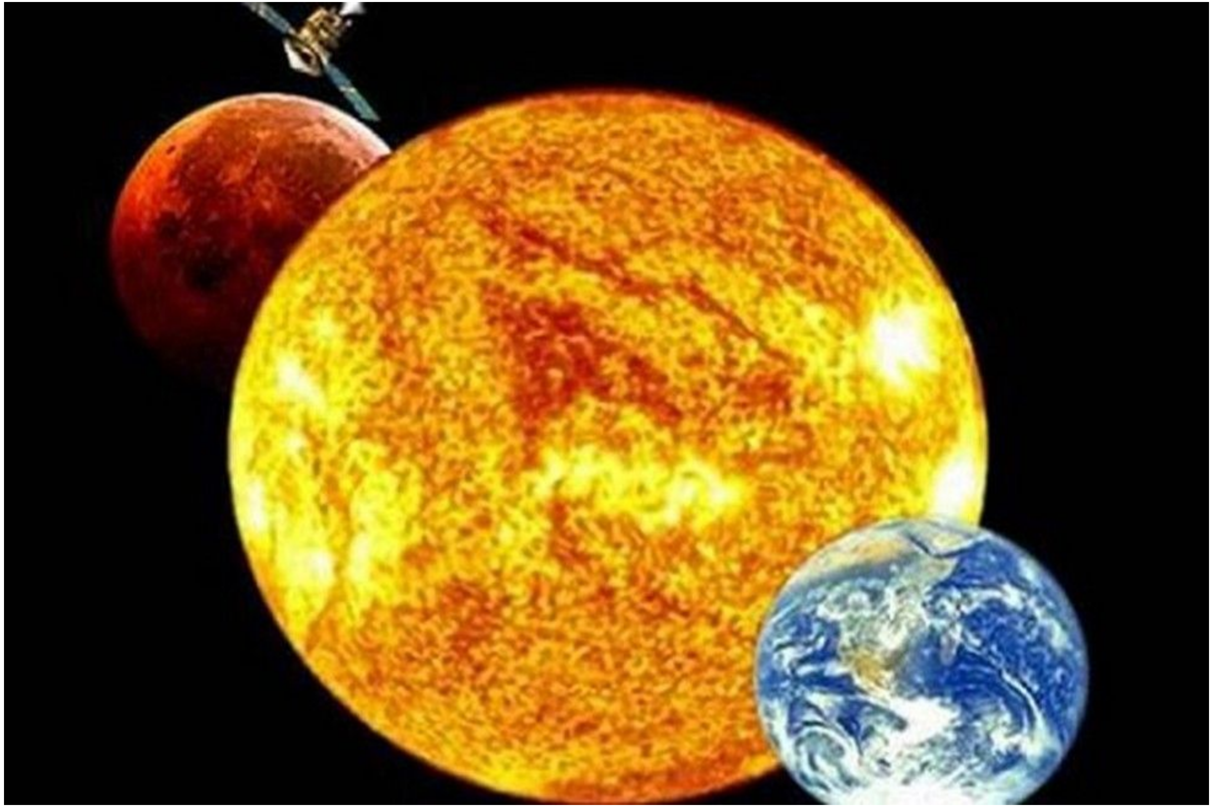
Intermittent Connectivity



Intermittent Connectivity



source: https://www.vajiramias.com

Space Link: Constraints / Challenges

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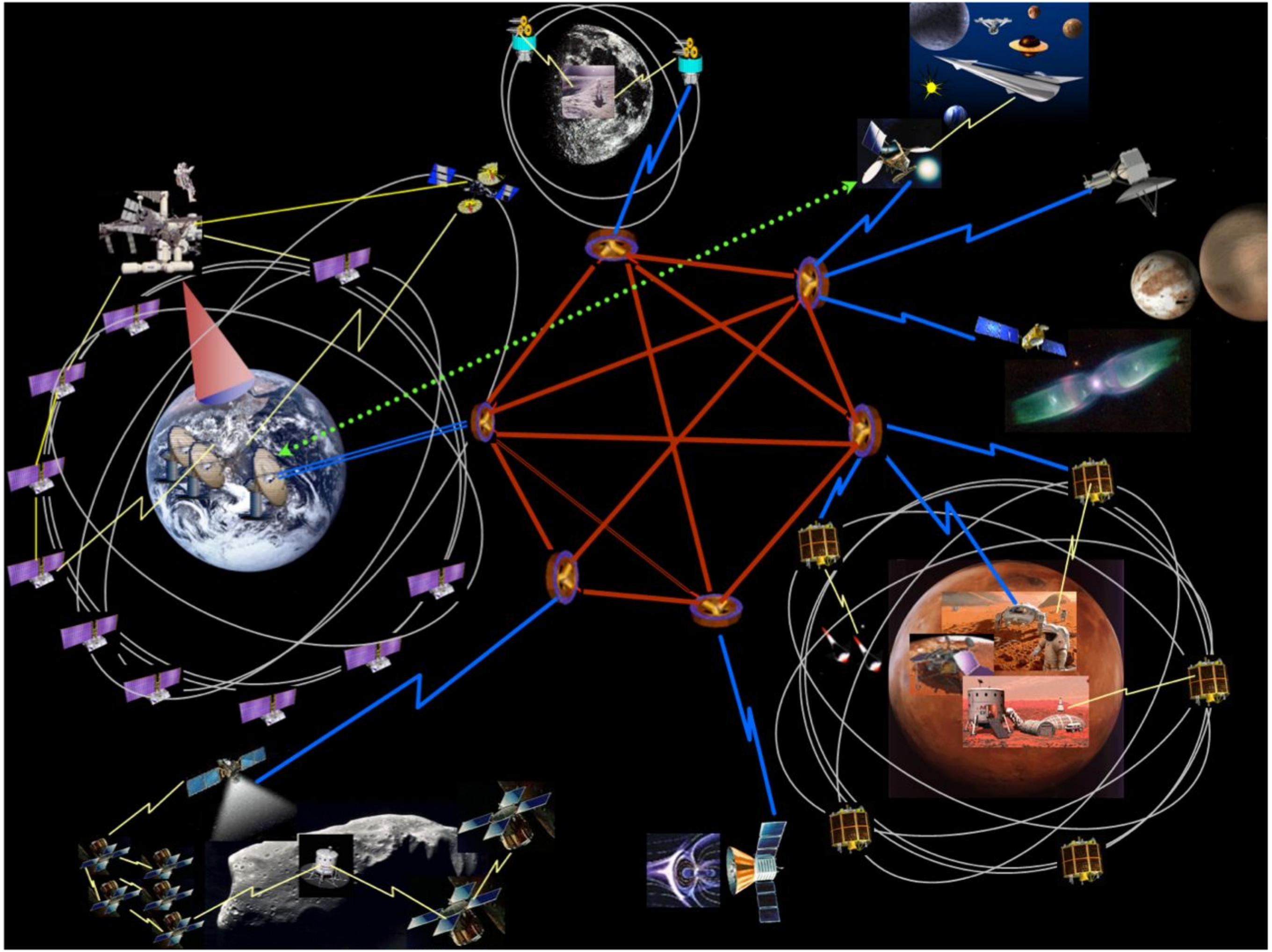
- Centrally managed access (no congestion)

InterPlaNetary (IPN) Internet Vision

A store and forward network of internets to interconnect nodes across interplanetary distances, in the presence of high error rates and frequent disruption.



source: https://www.nasa.gov/

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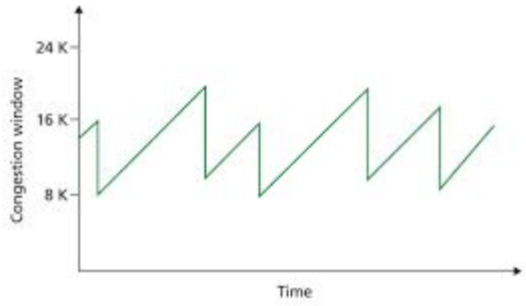

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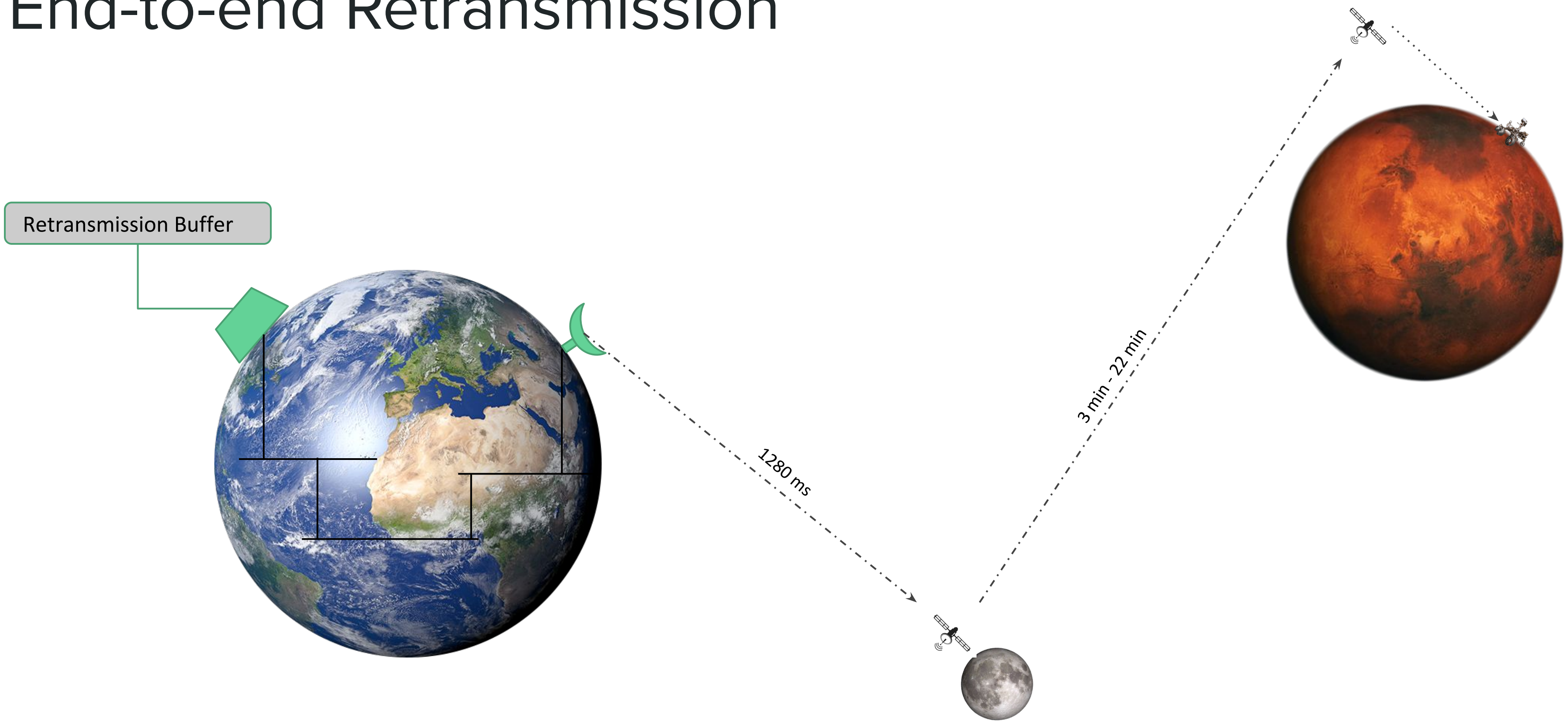
  - Delays release of retransmission buffer and increases capacity requirements

End-to-end Retransmission



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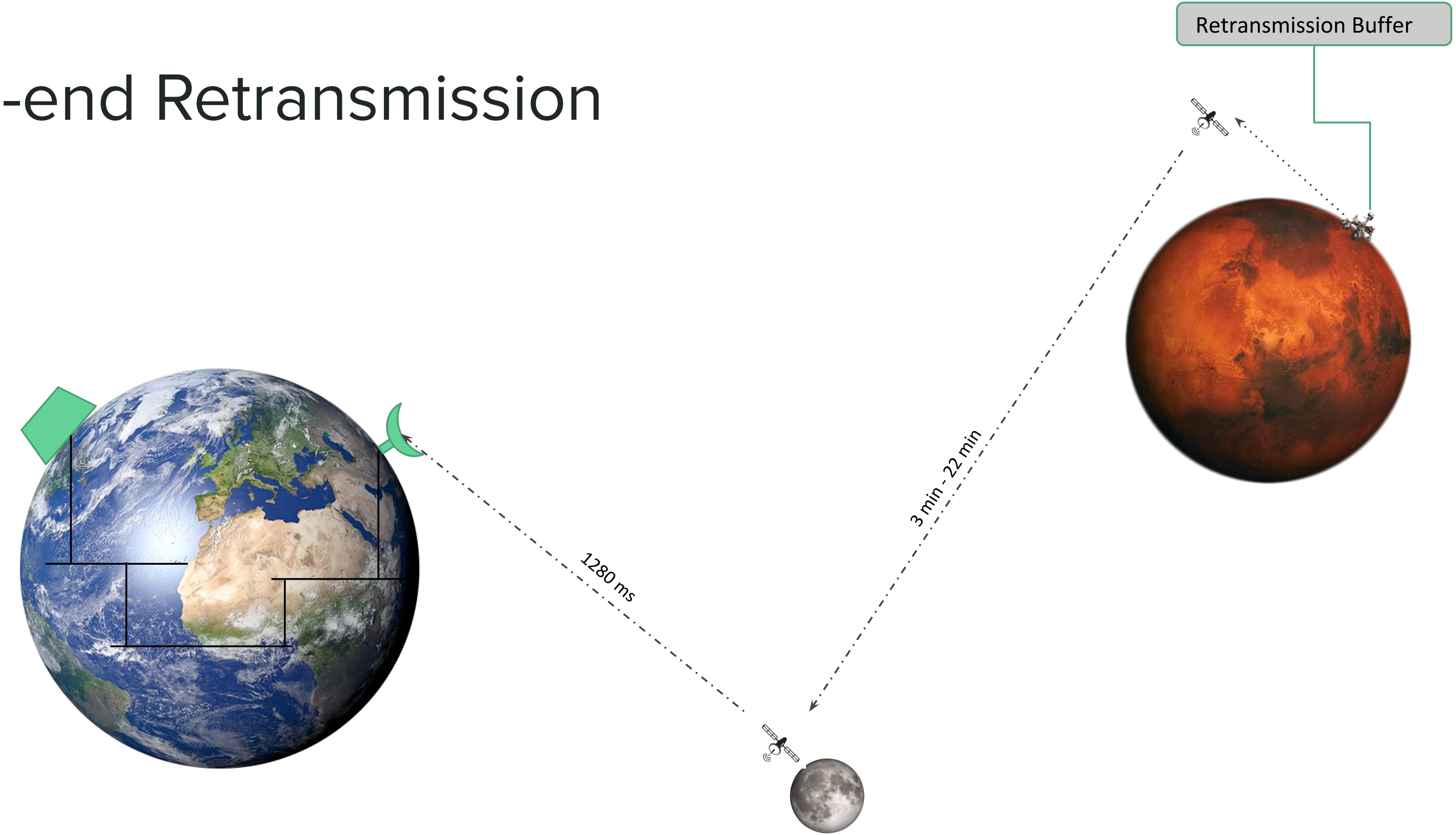

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- Routing protocols (BGP, OSPF, etc.) rely on timely connectivity updates
  - Could result in grossly inaccurate routing tables

Need an overlay network to bridge between different network stacks across environment boundaries

One with **no** expectation of:

- Continuous connectivity
- Low latency
- Low error rates
- Low congestion
- High transmit rates
- Symmetrical links
- Same-order arrival

Delay/Disruption-Tolerant Networking

History

- 1973 - Cerf & Kahn pioneer TCP
- 1990 - Cerf & JPL adapt Internet procolos for space missions
- 1998 - Internet Research Task Force (IRTF) launches Interplanetary Internet Research Group (IPNRG)
- 2001 - “IPN: Architectural Definition” published by IPNRG (Cerf, Burleigh, et. al.)
    - “Bundling” is born
- 2002 - “Delay-Tolerant Network Architecture: The Evolving Interplanetary Internet” published by IPNRG
    - Generalized IPN architecture; IPNRG becomes DTNRG
- 2007 - RFC 4838: “Delay-Tolerant Networking Architecture” published
    - Bundle Protocol formalized with RFC 5050

History (cont’)

- 2007 - CCSDS 727.0-B-4: “CCSDS File Delivery Protocol (CFDP)” published
- 2008 - RFC’s 5325/5326/5327: “Licklider Transmission Protocol” published
  - Formalized DTN retransmission-based reliability; derived from CFDP
- 2008 - Flight demonstration of DTN on Deep Impact (EPOXI) mission
- 2010 - On-orbit demonstration of DTN on EO-1 spacecraft
- 2011 - NASA/JPL begin development of Interplanetary Overlay Network (ION)
  - First implementation of DTN by a space agency
- 2015 - CCSDS 734.1-B-1: “Licklider Transmission Protocol (LTP)” published
  - Standardized LTP for use in space data systems
- 2015 - CCSDS 734.2-B-1: “Bundle Protocol (BP)” published
  - Standardized BP for use in space data systems
- 2016 - ISS begins testing NASA’s DTN implementation, ION

Future

- 2020+ - Full CCSDS standardization of protocols and deployment in all future NASA missions

DTN - Principles

Postal Communication

- Not conversational
- Data should be atomic units of work
  - *Bundles*

Tiered Functionality

- Leverage localized protocol stack optimizations

Terseness

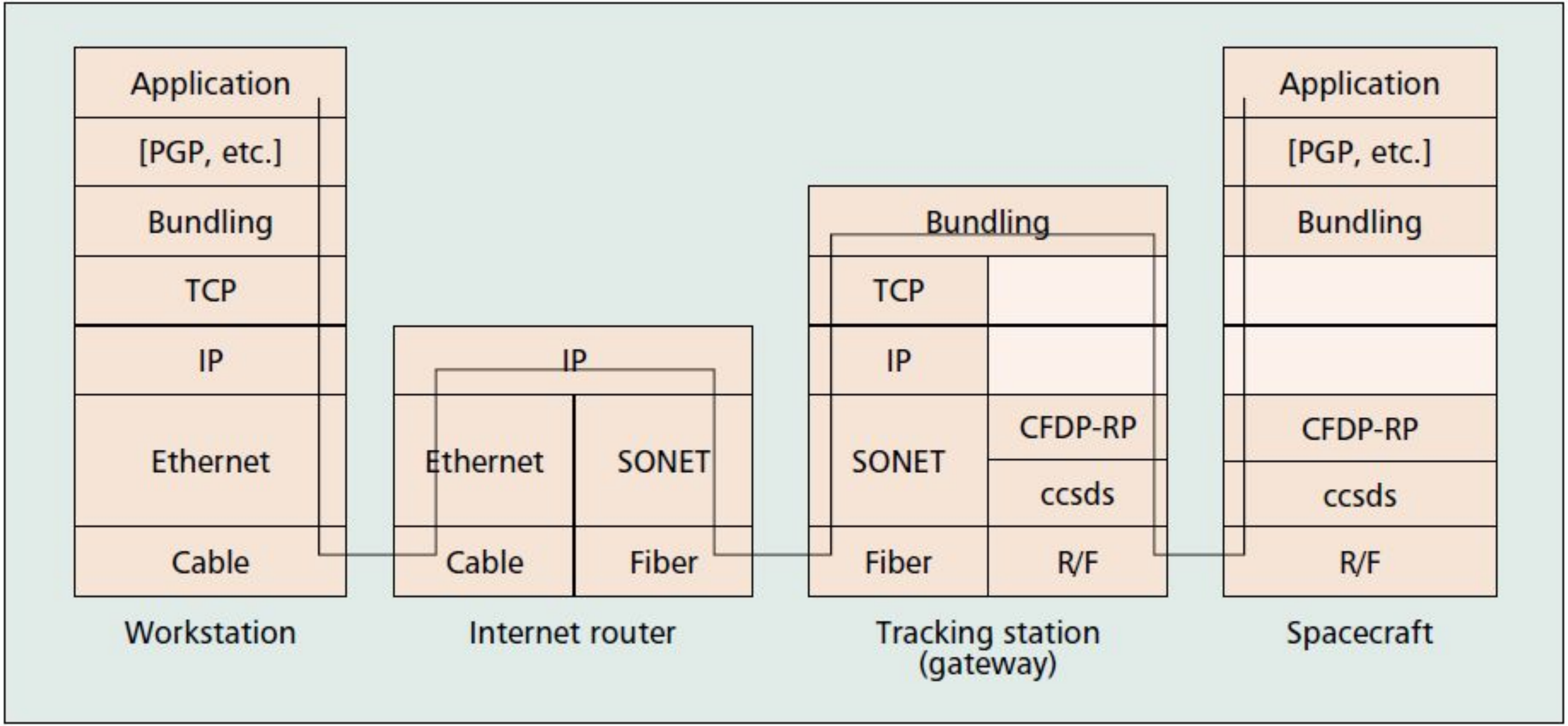
- Minimize bandwidth (even by sacrificing processing)

Bundle Protocol (BP)

Application layer overlay network

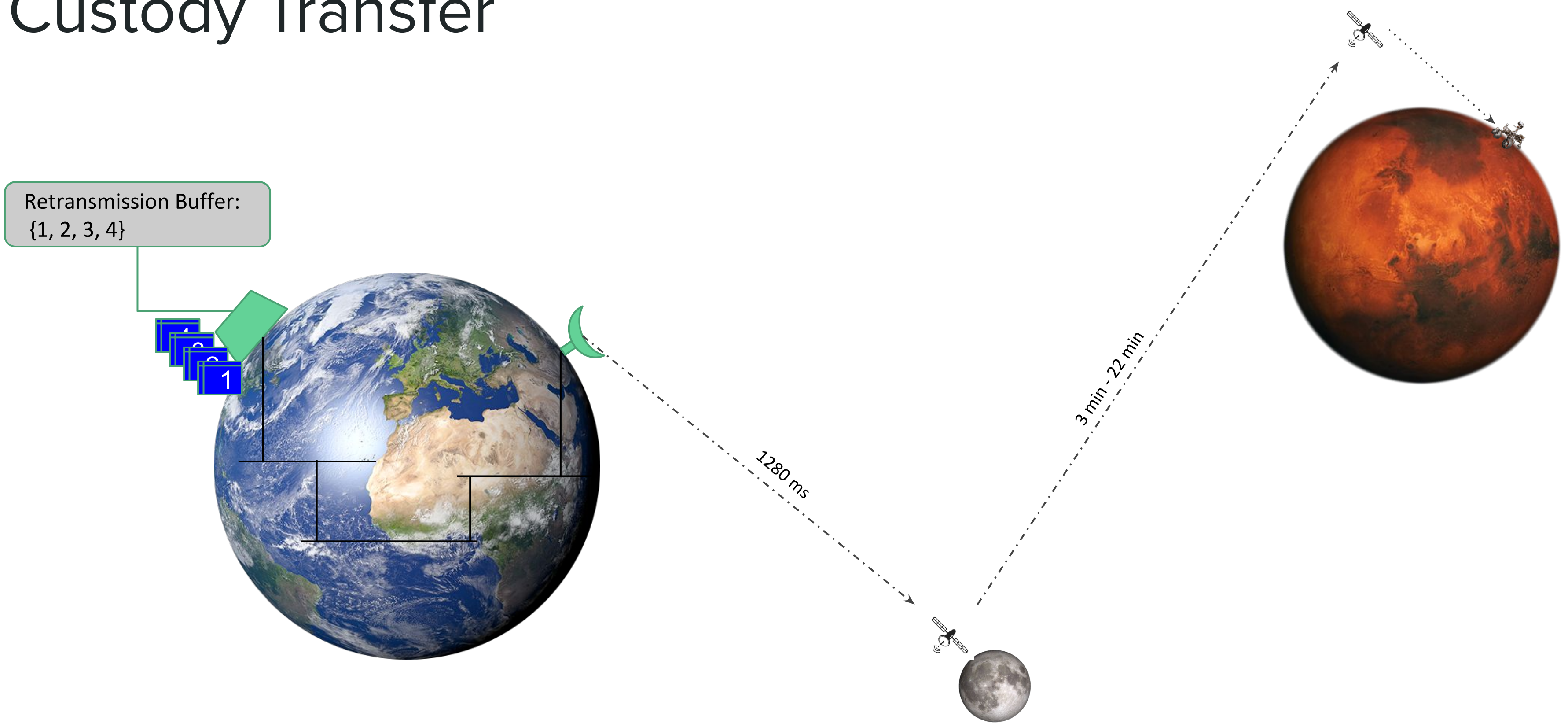
- Custody-based retransmission
  - Tiered ARQ
- Ability to cope with intermittent connectivity
- Ability to take advantage of scheduled, predicted, and opportunistic connectivity (in addition to continuous connectivity)
- Late binding of overlay network endpoint identifiers to constituent internet addresses

source: "RFC 5050 - Bundle Protocol Specification"

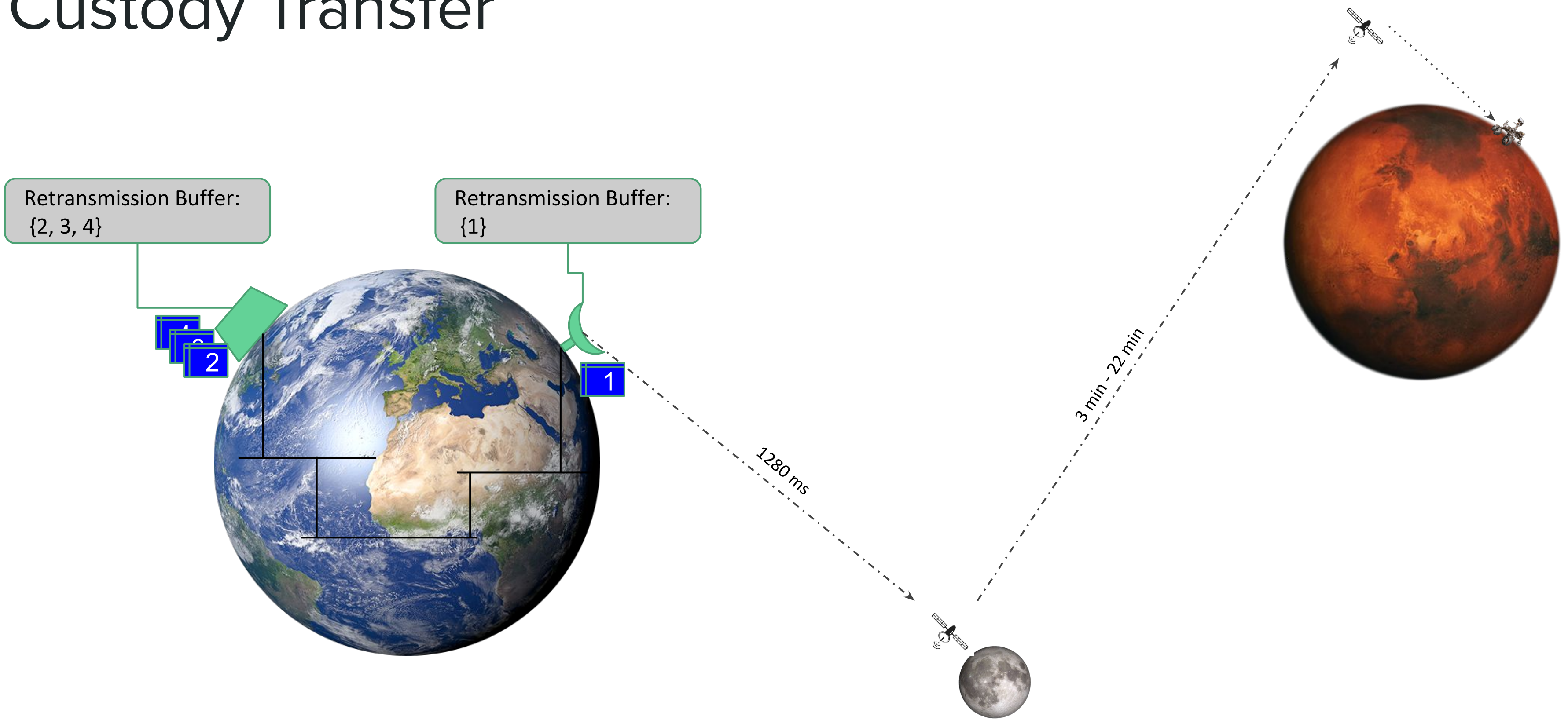


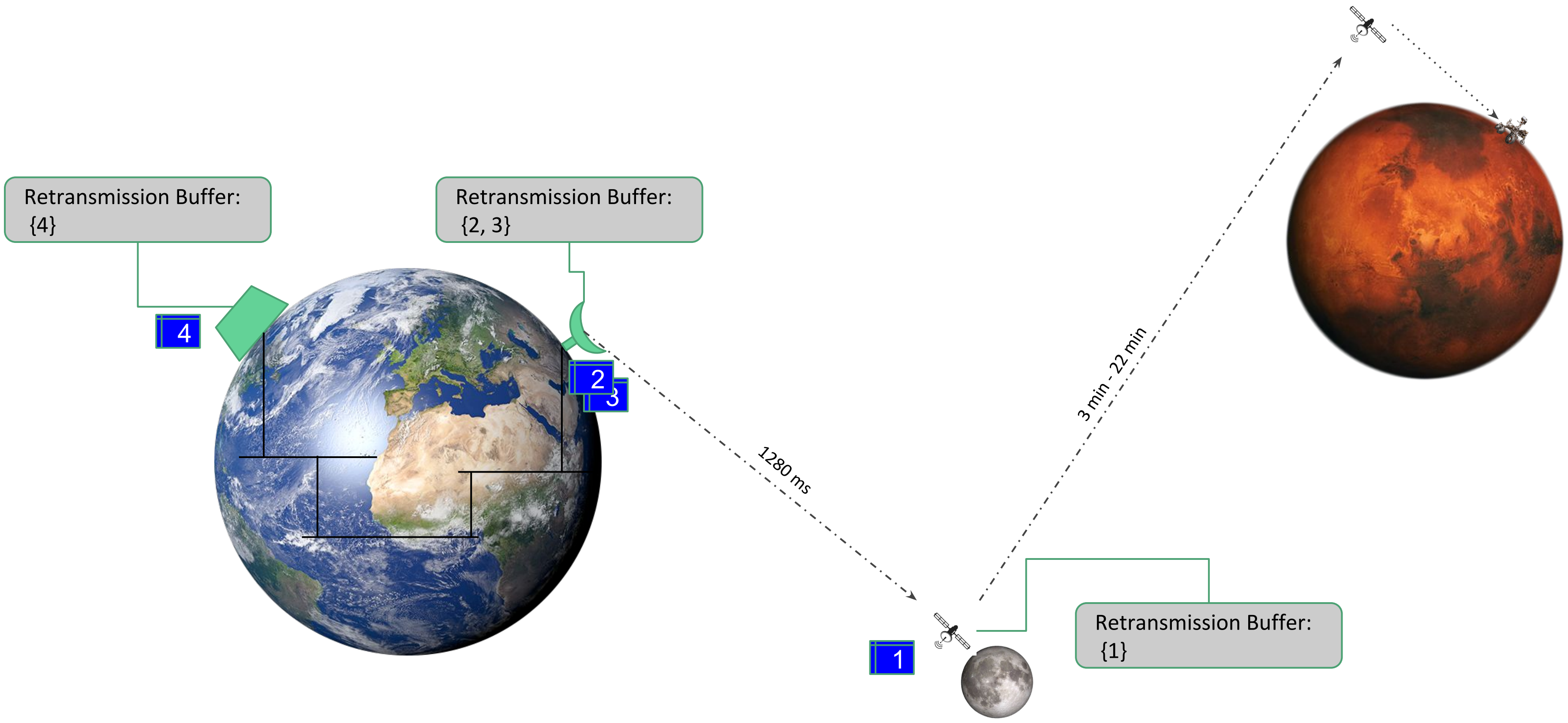
source: IEEE Communications Magazine - 0163-6804

Custody Transfer

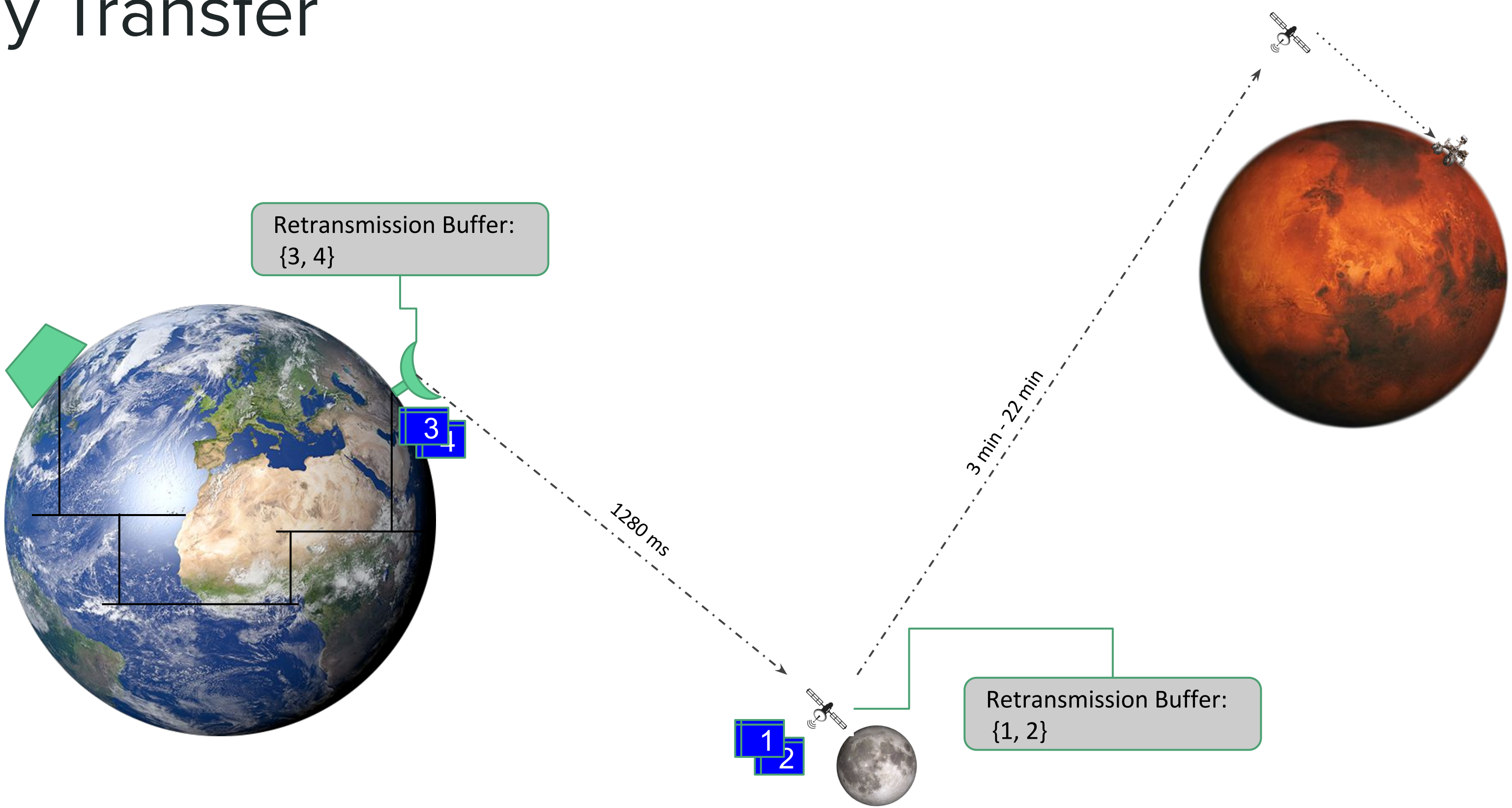


Custody Transfer




Retransmission Buffer:
{4}
4
Retransmission Buffer:
{2, 3}
2
3
1280 ms
3 min - 22 min
1
Retransmission Buffer:
{1}

Custody Transfer



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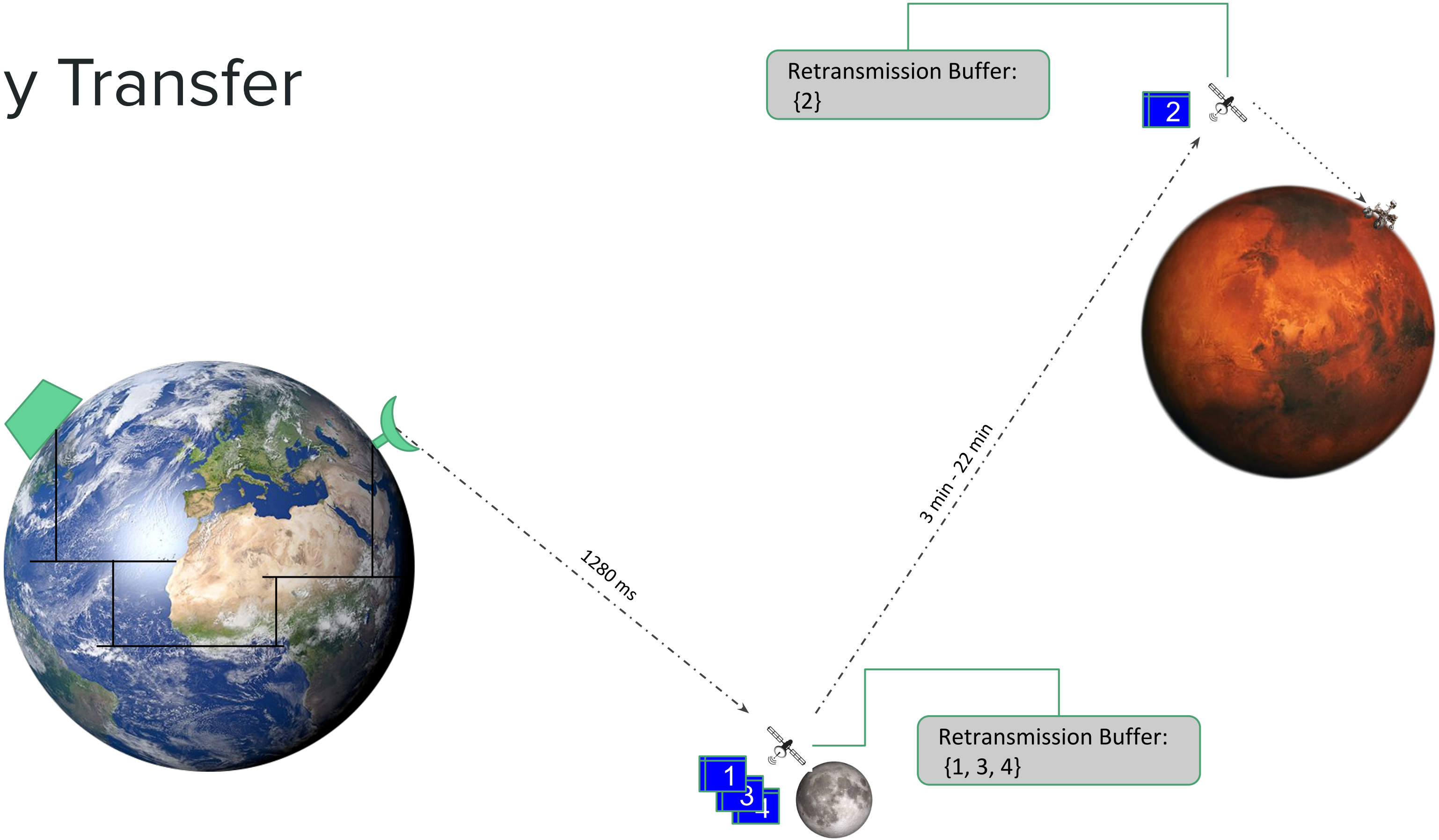

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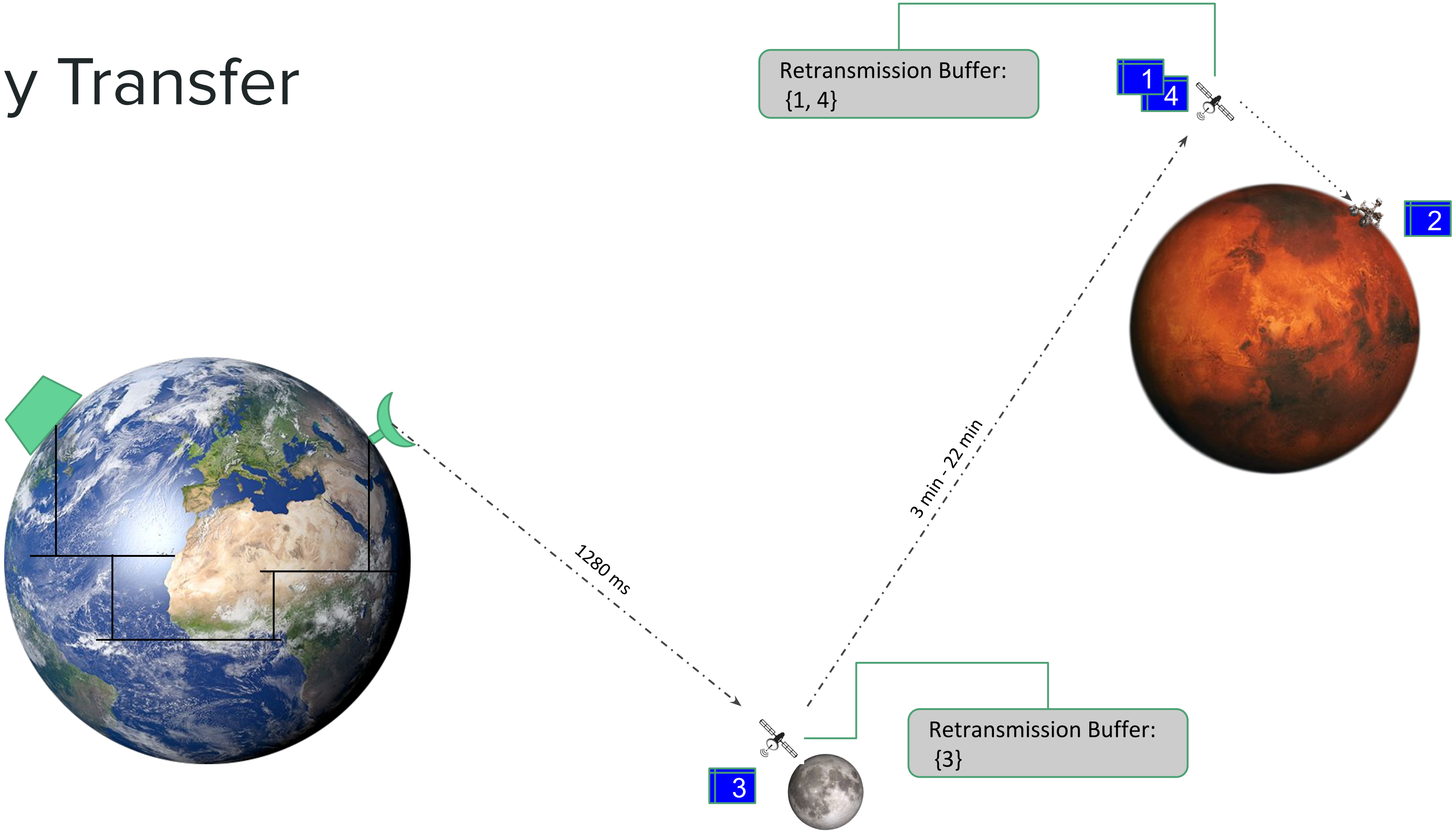

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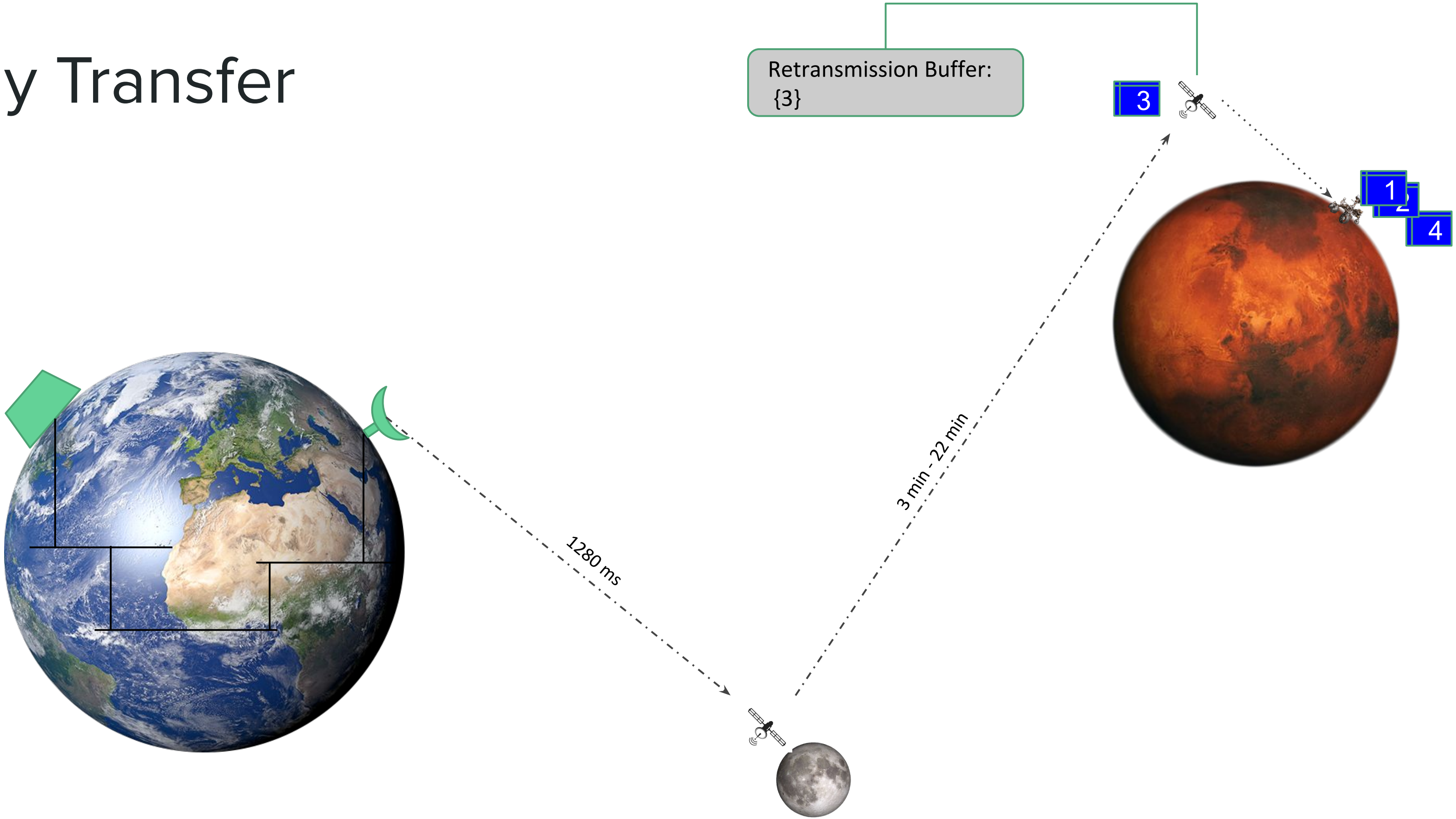

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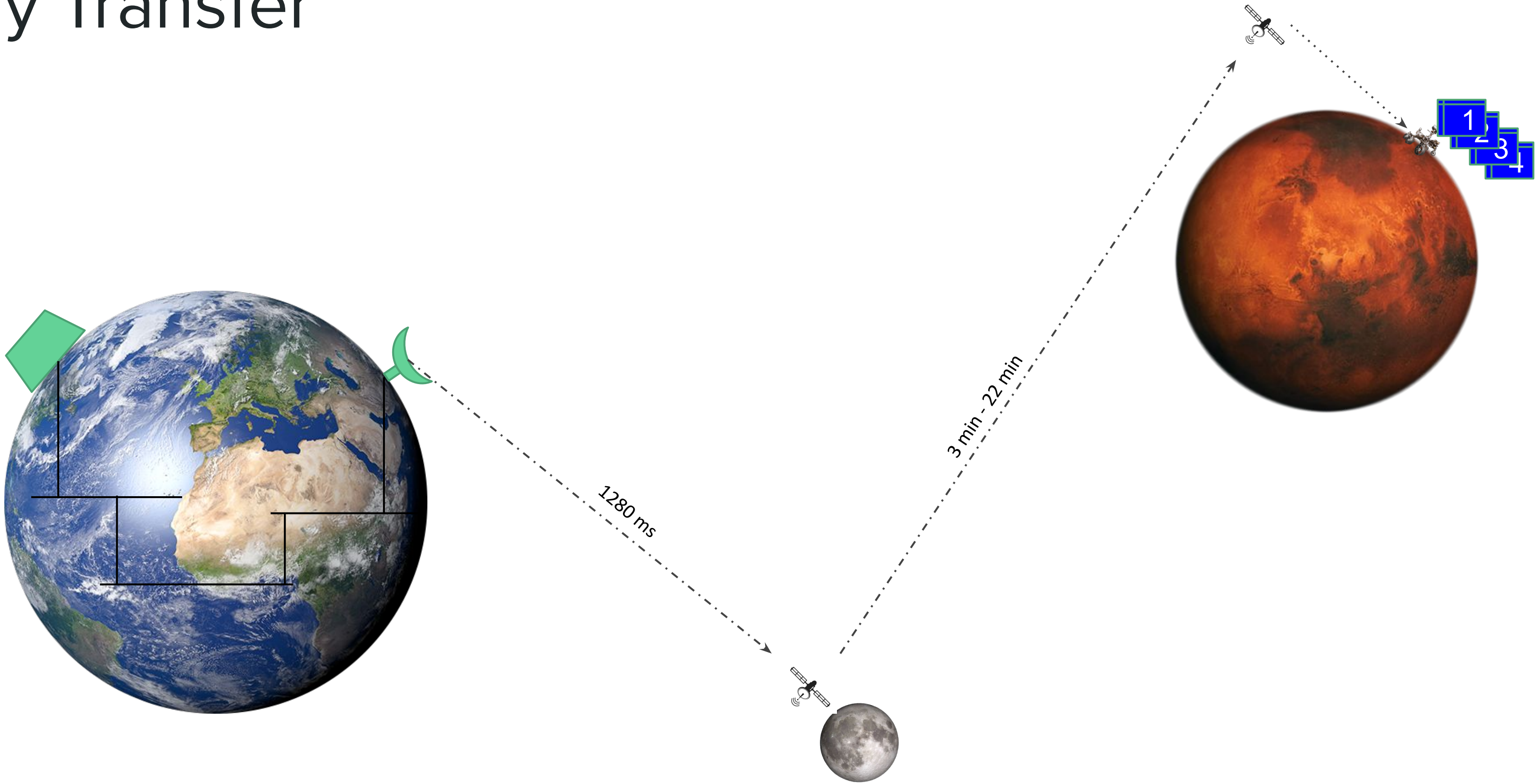


CCSDS File Delivery Protocol (CFDP)

File transfer (application layer) protocol for file delivery and file management services

Need driven by increased storage capacities on board spacecrafts and shift towards file systems

- Manual data downlink/uplink becoming unwieldy

Formalized implementation in NASA GSFC’s core Flight System flight software

“Acknowledged Mode” retransmission scheme → Licklider Transmission Protocol (later restandardized by CCSDS 734.1-B-1)

Licklider Transmission Protocol (LTP)

Delay/Disruption-tolerant point-to-point convergence layer (CL) protocol

- Application/Transport or Network/Link (as in CCSDS 734.1-B-1)

Provides retransmission-based reliable service using report segments

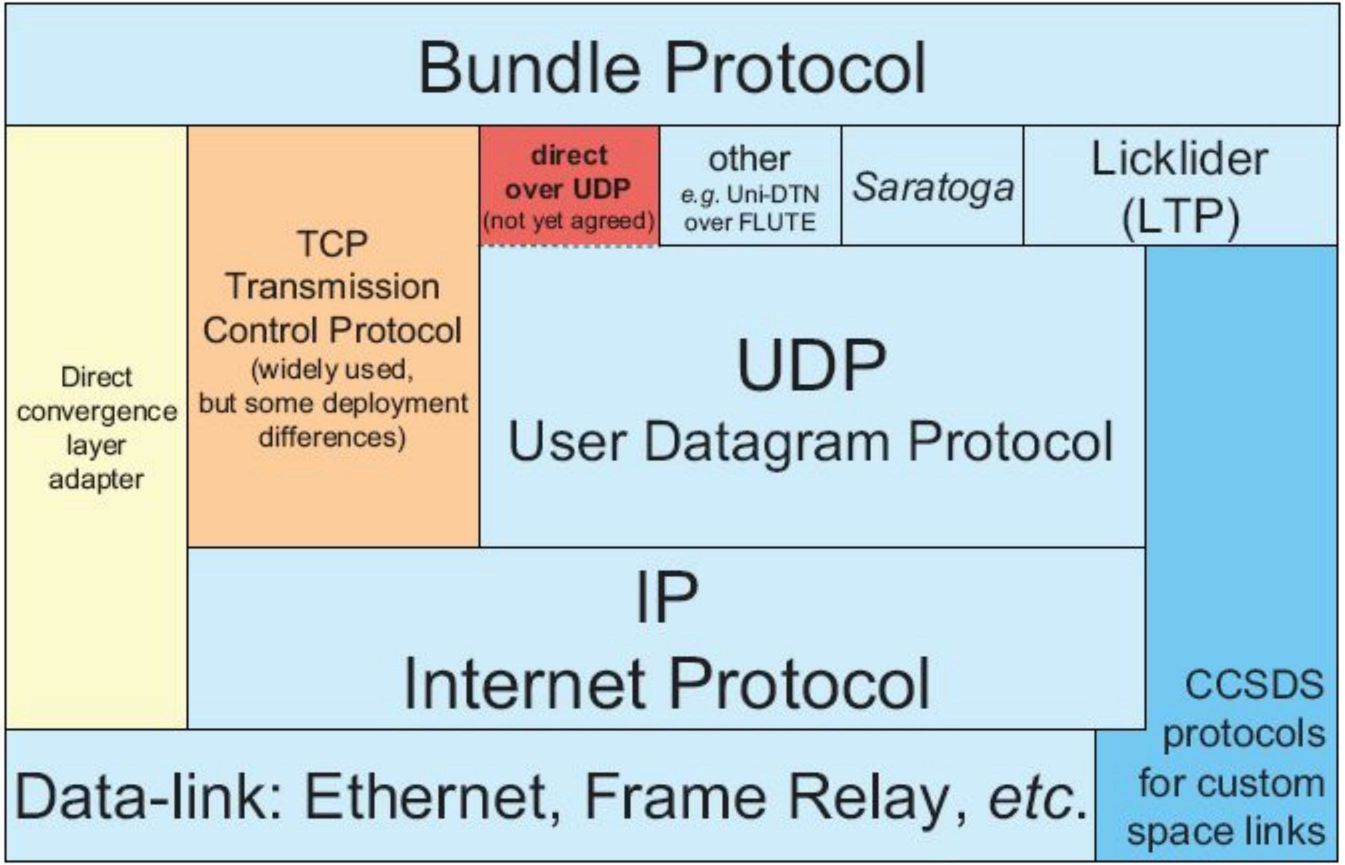
Can provide partial reliability with red (reliable) and green (unreliable) blocks

- Either can have length zero, so long as one is non-zero

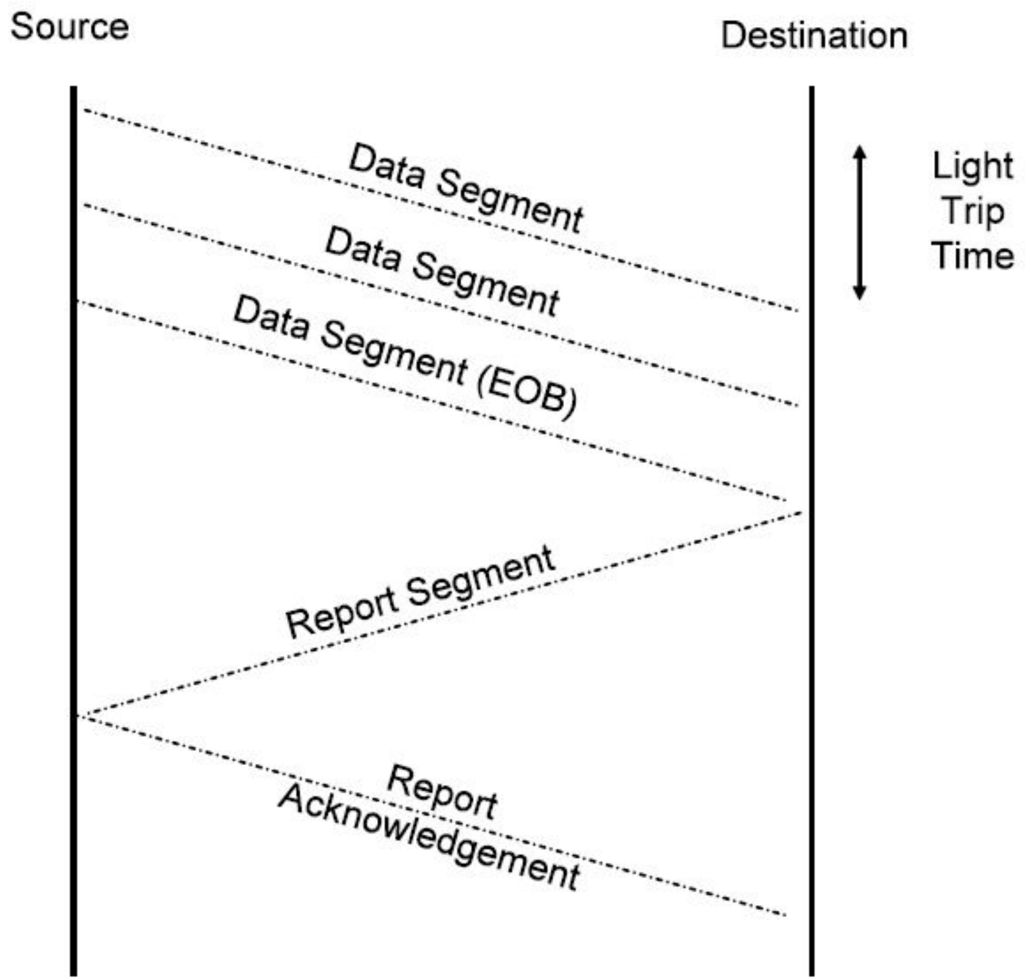
Tolerates disconnections through timer management

- Takes cues from DTN node and underlying link layer to suspend/resume timers

Cancels segment transfer after too many timeouts (RLEXC)



source: Tomlinson, P., et al. (2009)



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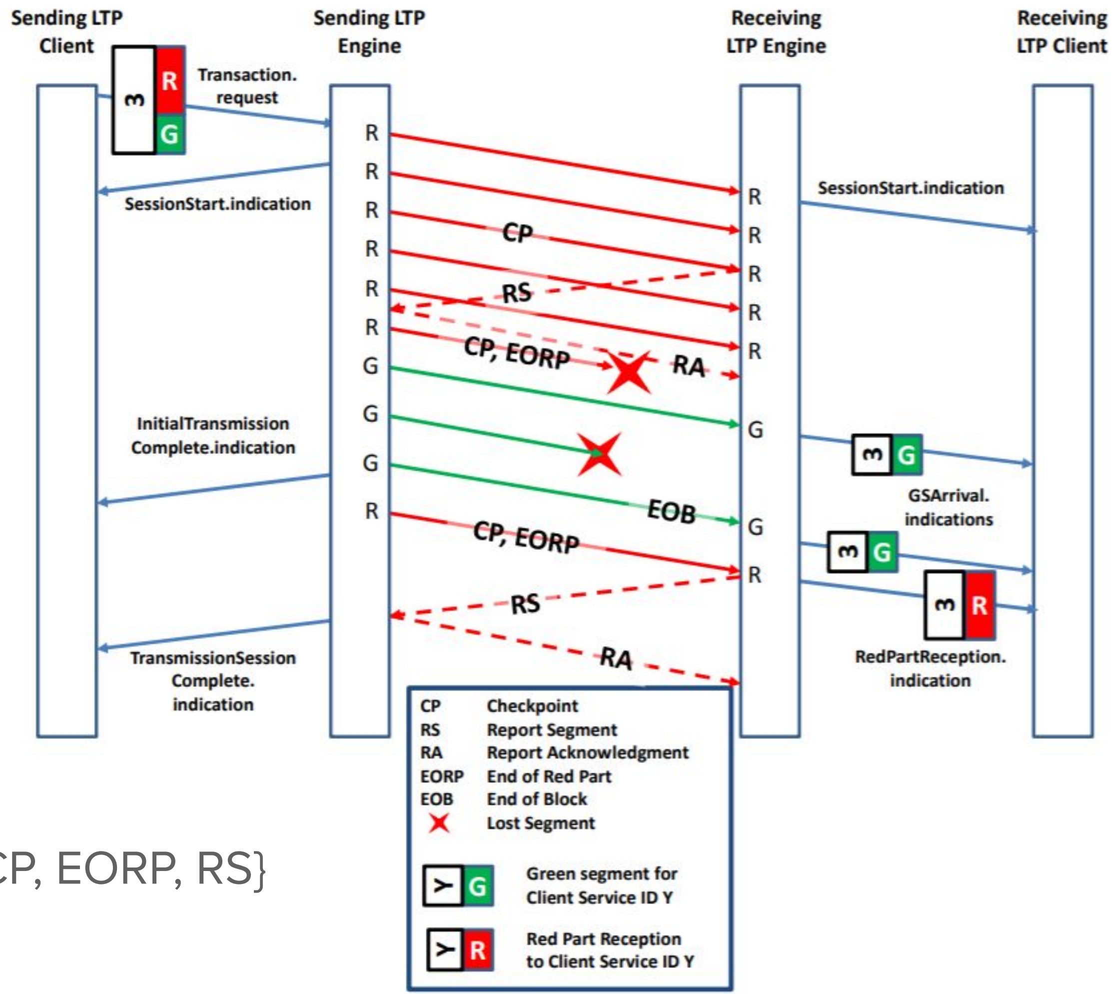
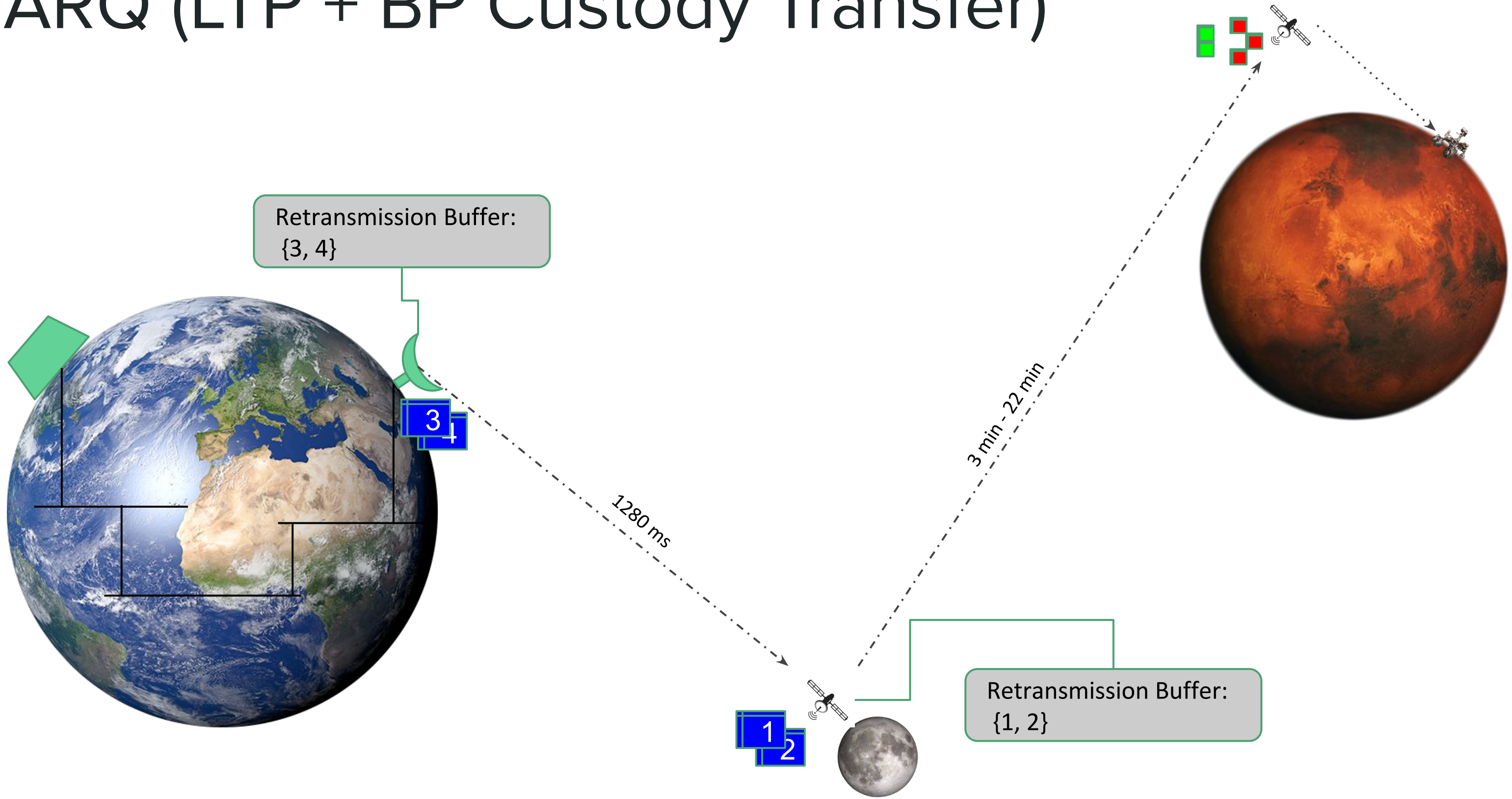


Timers only for {CP, EORP, RS}

source: CCSDS 734.1-B-1

Tiered ARQ (LTP + BP Custody Transfer)



Interplanetary Overlay Network (ION)

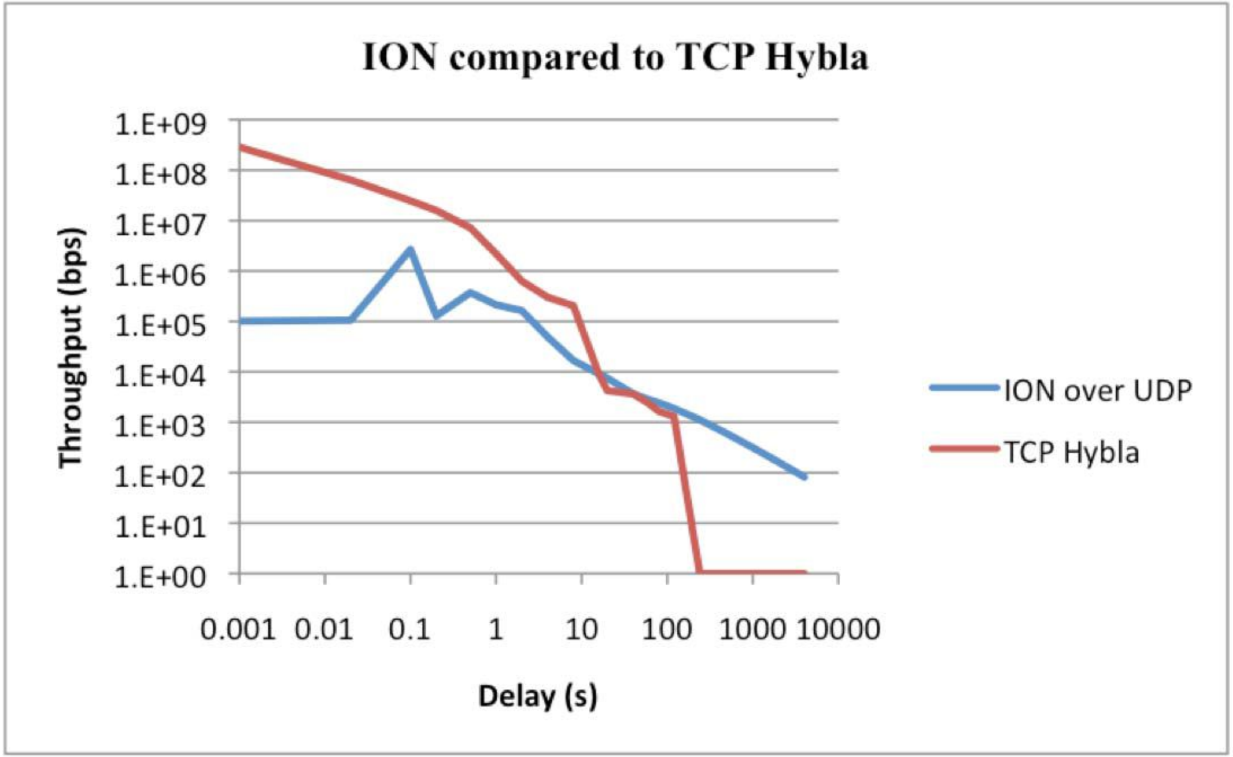
Implementation of the Delay-Tolerant Networking (DTN) architecture, as described in Internet RFC 4838

Developed by NASA/JPL, maintained (actively) at Caltech

Intended for use in embedded spacecraft environments

Demo

Performance Results



source: Tomlinson, P., et al. (2009)

Future Work

- LTP Dynamic Retransmission Aggregation
  - Based on link properties (propagation delay, bandwidth, connection opportunity), retransmit in smaller or larger chunks (batch up LTP sessions)
  - Supported today with LTP Service Data Aggregation (SDA) [CCSDS 734.1-B-1], but only via preconfigured settings
- Optimizing LTP for multi-hop links
  - How to account for heterogeneous space data links? micro transfers? LTP-T*ransport*
- Tiered Congestion Control for space links
  - Admission-controlled ➔ On-demand
- Use ION bpdriver/bpcounter/bpecho to evaluate various configurations in GCP

Challenges / Lessons-Learned

- Got lost in reading, ideas changed
  - 16 specs, 4 papers, 8 articles
- Formulating the historical timeline makes research easier
- Learning entirely new network protocols left little time for implementation
- ION implementation is sizeable
- This is an area ripe for continued research

Thank You

Backup Slides

Primary Bundle Block

```
+----------------+----------------+----------------+----------------+
| Version | Proc. Flags (*) |
+----------------+----------------+----------------+----------------+
| Block length (*) |
+----------------+----------------+---------------------------------+
| Destination scheme offset (*) | Destination SSP offset (*) |
+----------------+----------------+----------------+----------------+
| Source scheme offset (*) | Source SSP offset (*) |
+----------------+----------------+----------------+----------------+
| Report-to scheme offset (*) | Report-to SSP offset (*) |
+----------------+----------------+----------------+----------------+
| Custodian scheme offset (*) | Custodian SSP offset (*) |
+----------------+----------------+----------------+----------------+
| Creation Timestamp time (*) |
+---------------------------------+---------------------------------+
| Creation Timestamp sequence number (*) |
+---------------------------------+---------------------------------+
| Lifetime (*) |
+----------------+----------------+----------------+----------------+
| Dictionary length (*) |
+----------------+----------------+----------------+----------------+
| Dictionary byte array (variable) |
+----------------+----------------+---------------------------------+
```

Bundle Payload Block

```
+----------------+----------------+----------------+----------------+
| Block type | Proc. Flags (*)| Block length(*) |
+----------------+----------------+----------------+----------------+
/ Bundle Payload (variable) /
+-------------------------------------------------------------------+
```

Figure 5: Bundle Block Formats

```
+-----------+-----------+-----------+-----------+
|Block type | Block processing ctrl flags (SDNV)|
+-----------+-----------+-----------+-----------+
| Block length (SDNV) |
+-----------+-----------+-----------+-----------+
/ Block body data (variable) /
+-----------+-----------+-----------+-----------+
```

Figure 6: Block Layout without EID Reference List

```
+-----------+-----------+-----------+-----------+
|Block Type | Block processing ctrl flags (SDNV)|
+-----------+-----------+-----------+-----------+
| EID Reference Count (SDNV) |
+-----------+-----------+-----------+-----------+
| Ref_scheme_1 (SDNV) | Ref_ssp_1 (SDNV) |
+-----------+-----------+-----------+-----------+
| Ref_scheme_2 (SDNV) | Ref_ssp_2 (SDNV) |
+-----------+-----------+-----------+-----------+
| Block length (SDNV) |
+-----------+-----------+-----------+-----------+
/ Block body data (variable) /
+-----------+-----------+-----------+-----------+
```

Figure 7: Block Layout Showing Two EID References

Table C-2: Remote Engine Configuration Information

Item	Comment
Remote engine ID	The remote LTP engine ID.
UCP address	UCP address to use when transmitting to this engine during this contact.
Maximum segment length	The maximum segment length that the remote implementation supports, in octets.
One-way light time (outbound)	One-way light time TO the remote engine from the local one; for use in computing timer intervals.
One-way light time (inbound)	One-way light time FROM the remote engine to the local one; for use in computing timer intervals.
Remote queuing and processing delay	Allowance for queuing and processing delay at remote engine; for use in computing timer intervals.
Remote operating schedule	Schedule indicating when the remote engine is expected to be communicating with the local one. This information may or may not be provided by the MIB but is listed here for clarity; there may be other ways for the engine to determine the remote operating schedule.
Security: use authentication when sending	Whether the local LTP engine uses the LTP security authentication mechanism when communicating with this remote entity.
Security: allowable authentication ciphersuites	The authentication ciphersuites the local engine can use when communicating with the remote engine.
Security: sending authentication keys	The authentication material (key) that should be used for each ciphersuite the local LTP engine uses when communicating with the given remote engine. NOTE – Implementations may wish to use a single key per ciphersuite for all peers.
Security: require authentication on incoming sessions	Whether authentication is required on incoming sessions; if true, then at least the initial segments received in sessions from this remote engine must carry LTP authentication extensions.
Security: receiving authentication keys	The authentication material that should be used to authenticate incoming LTP segments containing LTP authentication extensions for each ciphersuite that may be used to communicate from the remote LTP node to the local one.

Table C-1: Local Engine Configuration Information

Item	Comment
Local Engine ID	The LTP engine ID of the local (i.e., this) LTP engine.
Checkpoint retransmission limit	As described in section 6.7 of RFC 5326.
Report segment retransmission limit	As described in section 6.8 of RFC 5326.
Reception problem limit	As described in section 6.11 of RFC 5326.
Cancellation segment retransmission limit	As described in section 6.16 of RFC 5326.
Retransmission cycle limit	As described in section 6.22 of RFC 5326.
Local queuing and processing delay	Allowance for queuing and processing delay at local engine; for use in computing timer intervals.
Local operating schedule	Schedule of times that the local LTP engine expects to be operating (able to communicate with remote engines).
SDA Aggregation Size	The maximum amount of data (bytes) that will be aggregated by the SDA service before an LTP block is transmitted (7.2.3.4.1.2).
SDA Aggregation Time	The amount of time that service data units will be aggregated by the SDA service before an LTP block is transmitted (7.2.3.4.1.3).
Implements green part data	True if this LTP engine supports transmission/reception of green-part (unreliable) data, otherwise false.

source: CCSDS 734.1-B-1

7.3.3 EVENT DIAGRAM FOR CLASS 2