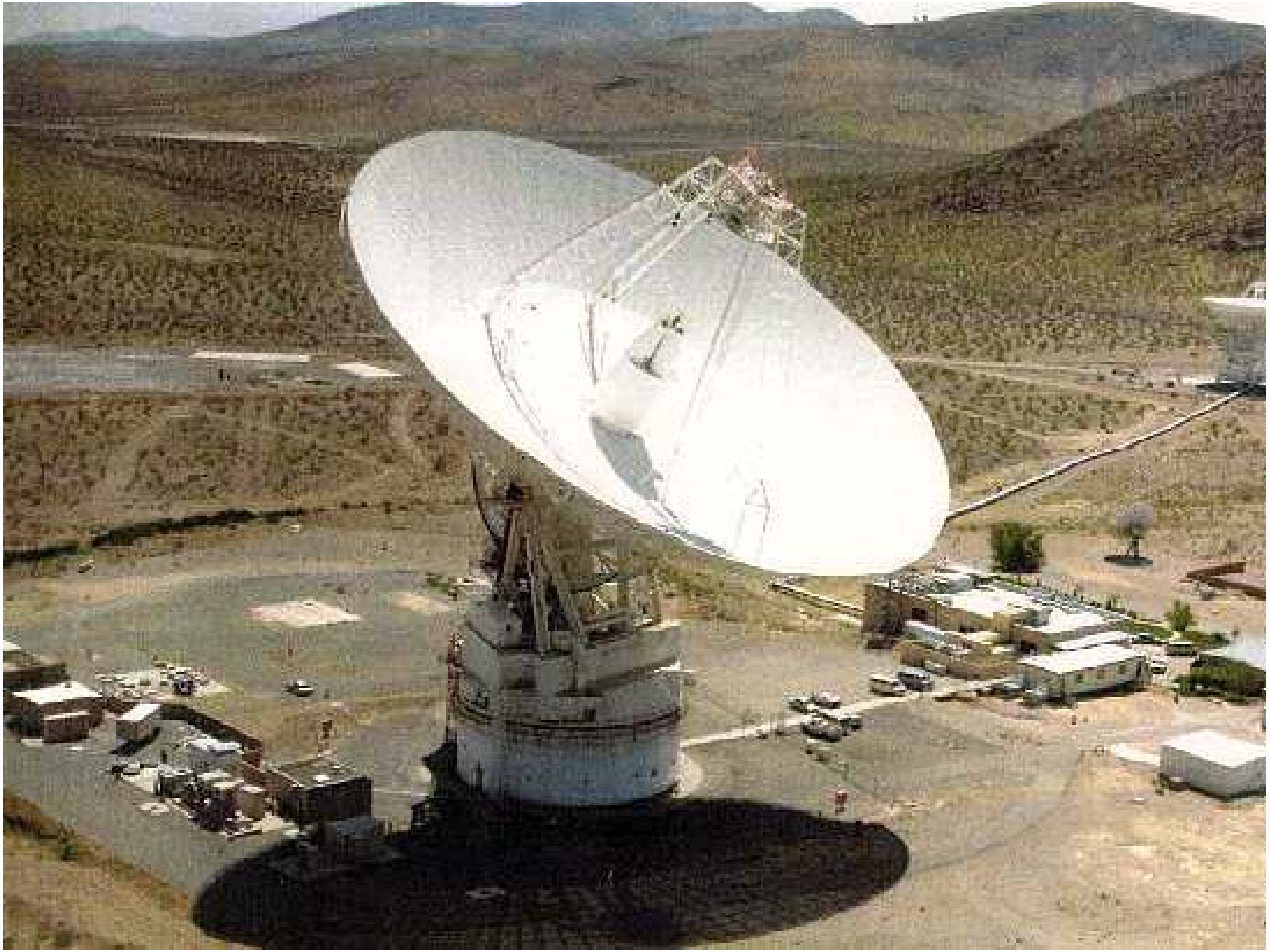
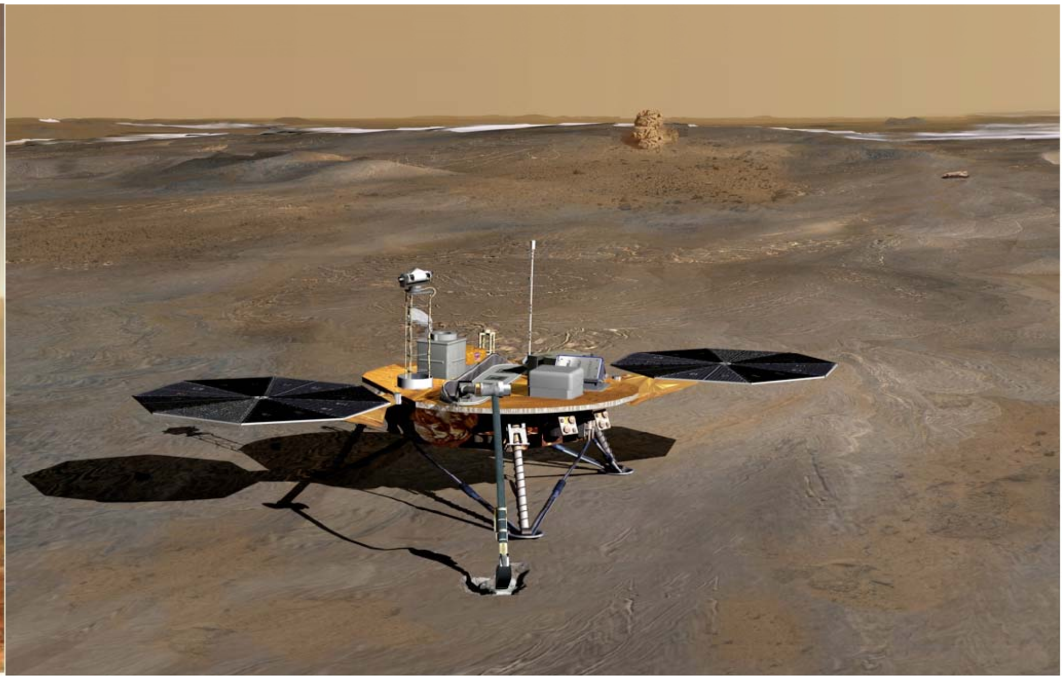
Solar System Internet

The Ultimate Collaboration



QuickTime™ and a
decompressor
are needed to see this picture.

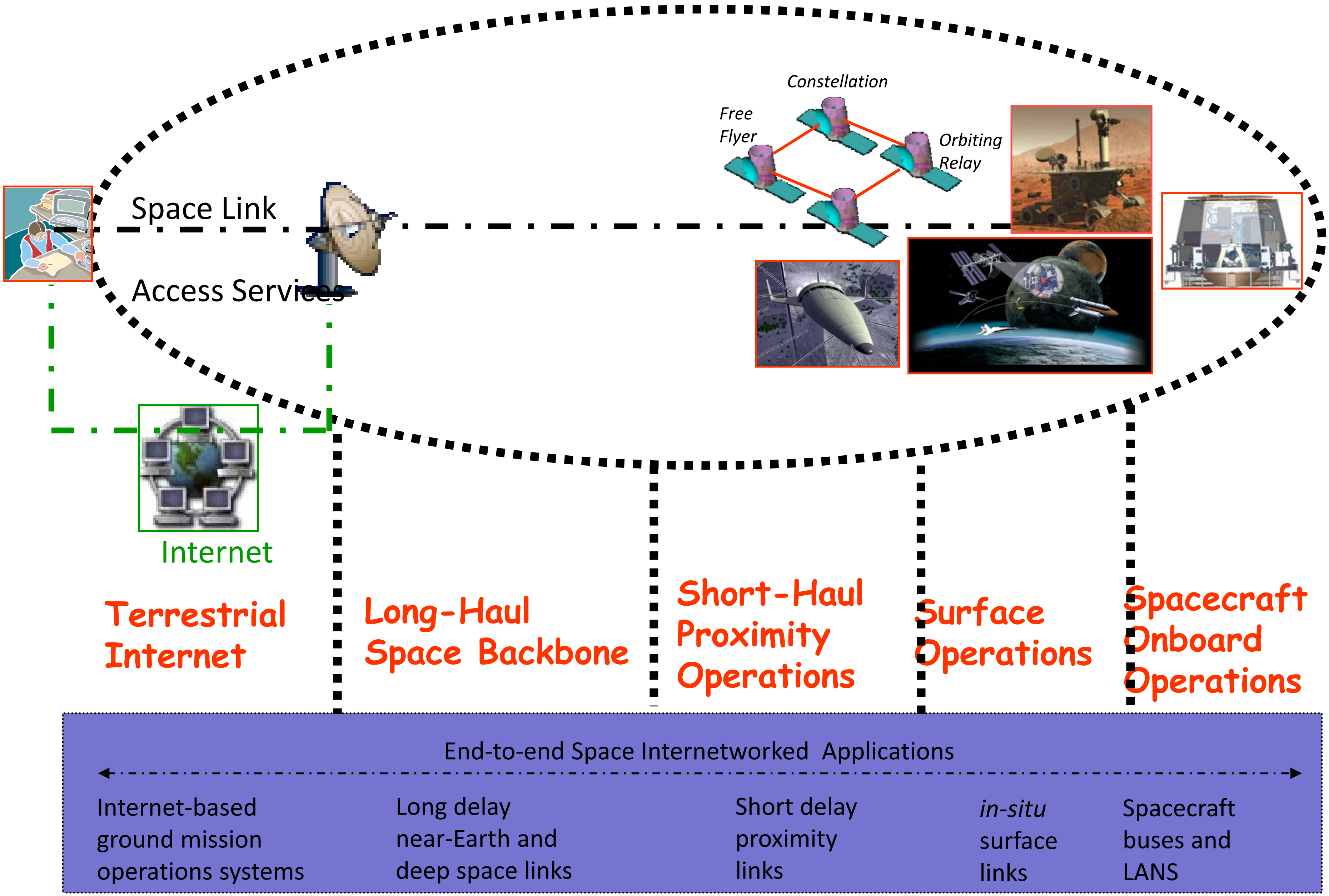
QuickTime™ and a
decompressor
are needed to see this picture.



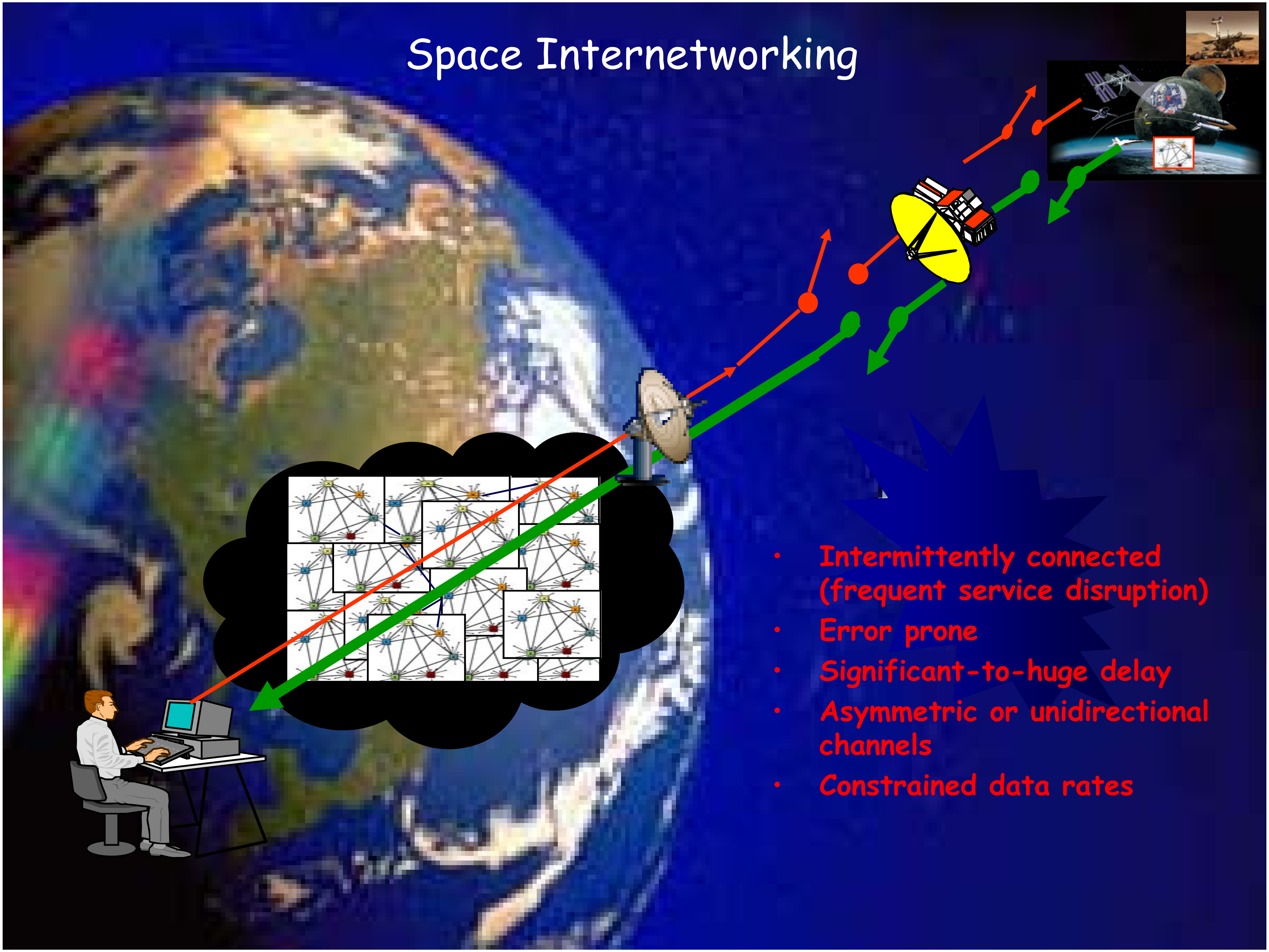
Interplanetary Networking
Nov 19, 2008

Basic Notions

- Standards for RF and Link level compatibility have been adopted by CCSDS (e.g. Prox-1, TC/TM, AOS)
- CCSDS File Delivery Protocol (CFDP)
  - End/end file transfers
- End/End Network layer architecture
  - Extends mission comm. options
  - Provides for re-use of resources (MRO, Express)
  - Provides recovery alternatives (e.g. Mars Rovers)



SPACE COMMUNICATIONS PROTOCOLS


Space Internetworking
Intermittently connected (frequent service disruption)
Error prone
Significant-to-huge delay
Asymmetric or unidirectional channels
Constrained data rates

NASA Efforts

- DTN Readiness Program
  - Multiple NASA Center participation
  - DTN Experimental Network
  - Simulation and testing facilities
  - Deep Impact Testing October/November 2008 (DINET)
  - Space Station Testing Summer 2009
  - EPOXI Testing Fall 2009

DINET Overview

- The Deep Impact Network (DINET) project was an experimental validation of “ION” (Interplanetary Overlay Network), JPL’s implementation of the Delay-Tolerant Networking protocols.
- The intent of the experiment was to raise the Technology Readiness Level of ION to 7 or 8, to enable its adoption at low risk by future flight projects.
- The ION software was uploaded to the backup flight computer of the EPOXI (formerly Deep Impact) spacecraft on 18 October 2008 and was operated continuously from that date until 13 November 2008.
  - EPOXI was in inactive cruise period while en route to encounter comet Hartley 2 (November 2010).
  - Spacecraft functioned as a DTN router in an 11-node network (see next slide).
  - 8 Deep Space Network tracking passes of 4 hours each, separated by intervals of 2 to 5 days.
  - One-way signal propagation delay was initially 81 seconds, dropped to 49 seconds by the end of the four-week exercise. (EPOXI was approaching an Earth fly-by in December.)
  - Transmission to spacecraft at 250 bytes/second.
  - Transmission from spacecraft at either 110 or 20000 bytes/second.

Results

- Moved 292 images (about 14.5 MB) through the network.
- DTN prioritization assured that all high-priority images were successfully delivered by DINET.
    - Several low-priority images were destroyed upon time-to-live expiration prior to delivery, due to insufficient contact opportunity (unplanned DSN link service outages).
- No data loss.
- No data corruption anywhere in the network.
- Operator intervention was limited to loading and booting the software (including a reboot of all EOC ground nodes necessitated by a Lab-wide power failure) and uploading corrections to the spacecraft clock.

Milestones and Conclusion

- First deep-space node on the Interplanetary Internet.
  - Automatic, contact-sensitive relay operations (store-and-forward Bundle Protocol)
  - Automatic rate control
  - Delay-tolerant retransmission (Licklider Transmission Protocol)
  - Prioritization of merged traffic flows
  - Custody transfer
- Longest digital communication network link ever.
- First use of dynamic routing over deep space links.
- First use of messaging middleware (CCSDS Asynchronous Message Service publish/subscribe) over deep space links.
- **Fully automatic** operation of a delay-tolerant network over deep space links is feasible.

Roles for Ground Assets

- Real-time mission support
  – Spacecraft control, telemetry
  – Manned communication
- Science access to data
  – Mission data capture
  – Data Archiving and Retrieval
  – Distribution of instrument data to PIs, etc.
  – Public outreach (e.g. Google Mars, Sky)

Google MARS

- Latest release March 13, 2009
- Run Demo

Thinking Differently

- High Delay and Episodic Connectivity
  - Network management isn’t real-time
  - Spacecraft Autonomy becomes critical
  - Real-time audio and video turns into email
  - State information becomes fuzzy (variably stale)
  - Increased value of contingency planning

Thinking Farther Out

- Longer term missions
  - Nuclear power sources (again)
  - Longer spacecraft lifetimes
  - Larger number of concurrent missions
  - Multi-craft missions (e.g., interferometry)
- More concurrent missions
  - Pace of national space programs
  - Increasing commercial interest
  - X-Prize stimuli

Continuously Operating Outposts

- Robotic and manned sites
- Manned orbiters controlling ground assets (local real-time potential including store/forward relay)
- In situ exploration (episodic connectivity owing to terrain, contact frequency, mobility)
- Continuous data collection and episodic connectivity (store and forward)

Resource Sharing

- Current economic climate dictates increased collaboration
- Future project ambition levels will need collaborative approaches
- Resource sharing requires standardization for interoperation and interworking (in many dimensions)

Terrestrial Infrastructure

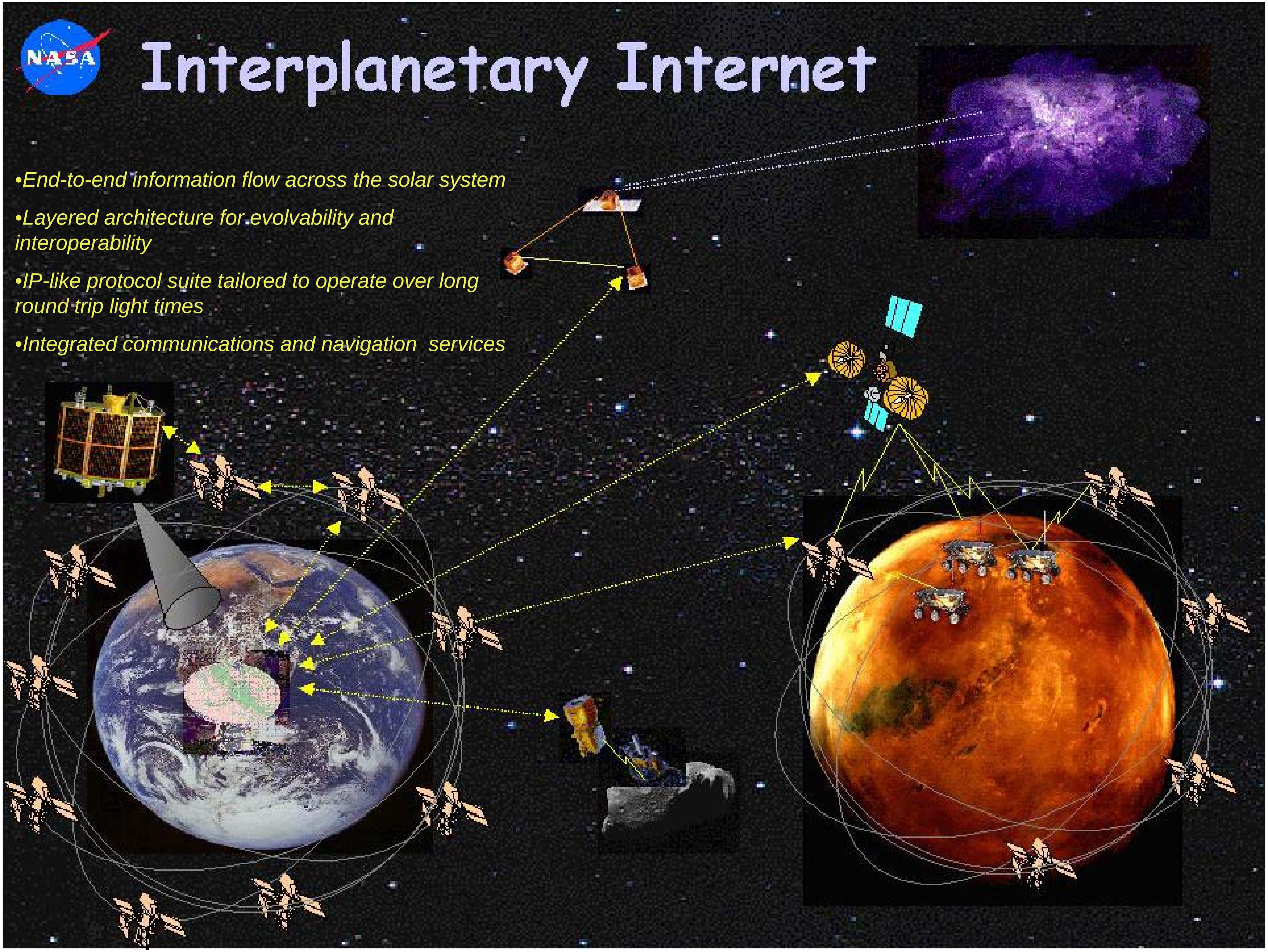
- Internet
  - ISPs share resources and provide mutual benefit to users through “peering” and “transit” relationships
  - WiFi/WiMAX access points
- Wireless Mobiles (nee “telephone”)
  - Formal “roaming” and sharing of massive ground infrastructure
  - Mobile data, 3G and LTE, etc.

Ground Systems for Space Operations

- Opportunity to develop common standards making feasible cross-system support (ie. Shared use of ground system infrastructure)
- Anecdote about origins of TCP/IP
  - – Let policy, not technology, determine whether interconnection and interoperability is possible

Solar System Internet

- Planetary internets (IP and others)
- Interplanetary Forwarders (routers)
- Interplanetary Long-Haul Architecture(RFC 4838)
    - Licklider Transport Protocol (LTP) (RFC 5326)
    - Bundle Protocol (RFC 5050)
        - Delayed Binding of Identifiers
        - Email-like behavior
- Delay and Disruption Tolerant Protocols
    - Tactical Mobile applications (DARPA)
    - Civilian Mobile applications (SameNet!)
- International Space Communication Asset Inter-operability Standards


NASA
Interplanetary Internet
•End-to-end information flow across the solar system
•Layered architecture for evolvability and interoperability
•IP-like protocol suite tailored to operate over long round trip light times
•Integrated communications and navigation services

Getting Involved

- DTN Research Group
  - www.dtnrg.org
  - Internet Research Task Force
    - www.itrf.org
  - Kevin Fall/Intel Research
  - Stephen Farrell/Trinity College Dublin
  - DTNBone (test network)
- CCSDS SIS-DTN Working Group
  - Keith Scott/The MITRE Corp.
  - http://mailman.ccsds.org/cgi-bin/mailman/listinfo/sis-dtn