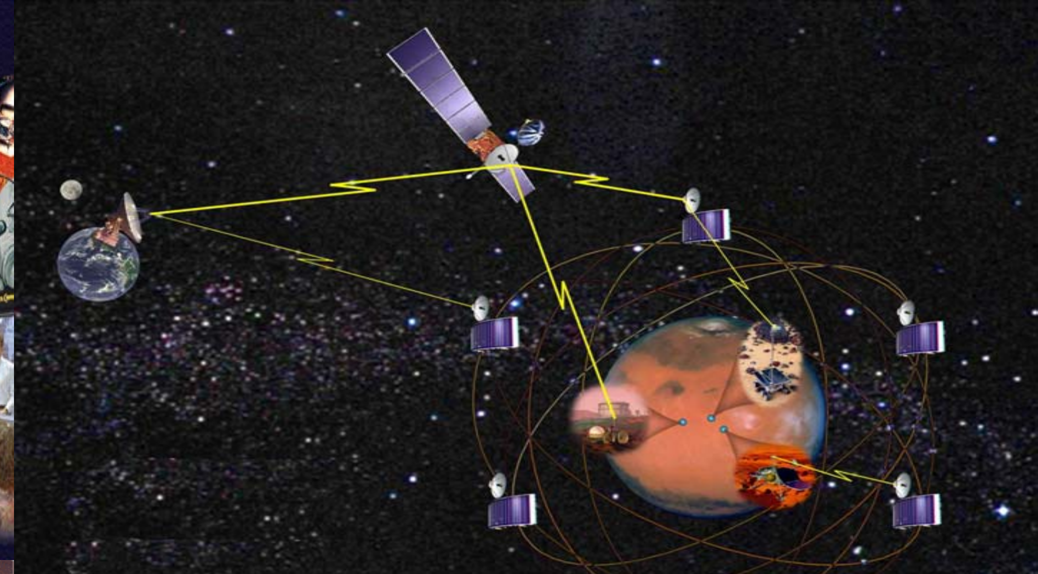


InterPlaNetary Internet

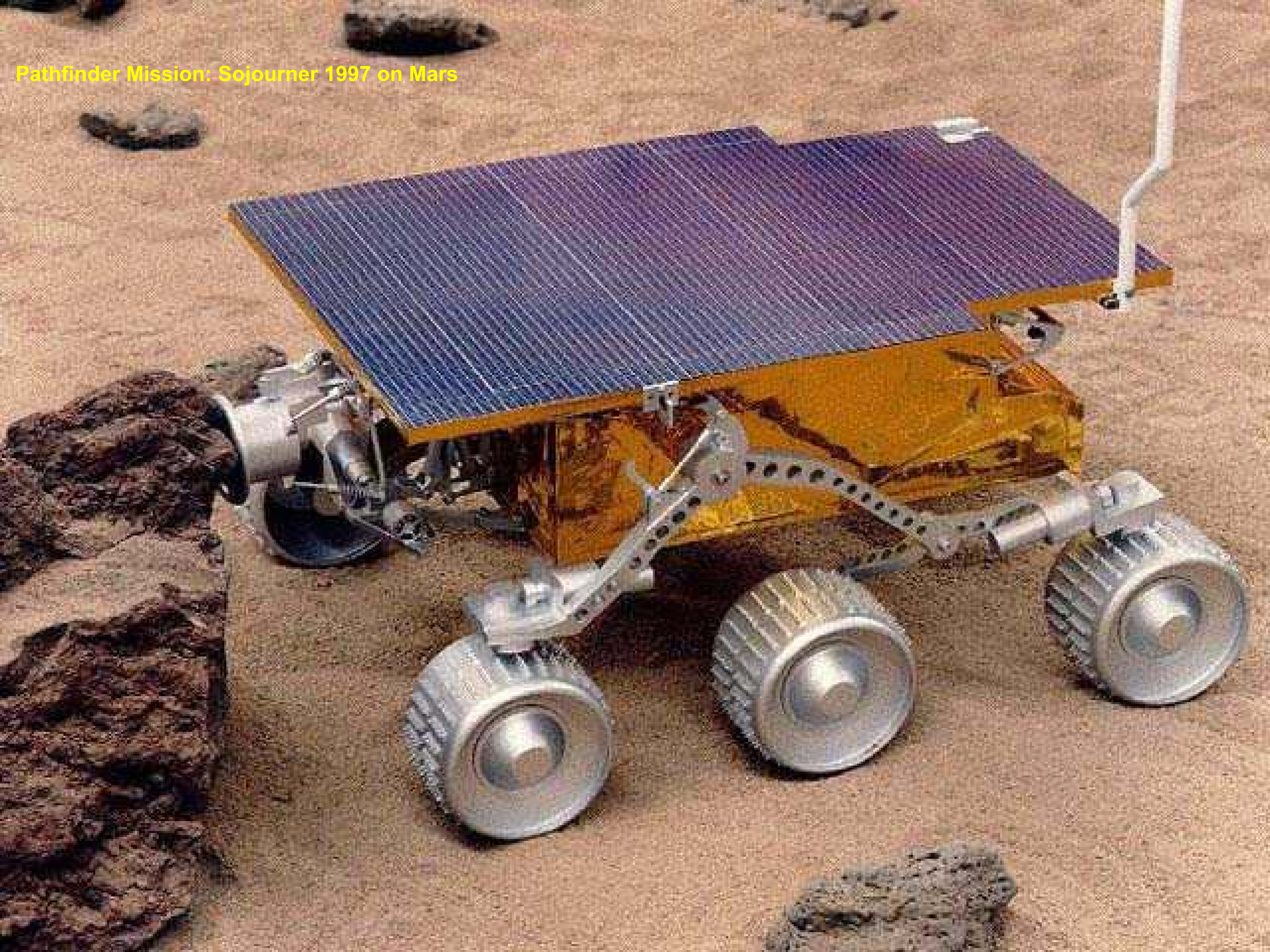
Vint Cerf

DARPA Proposer's Day
21 January 2004

Acknowledgments

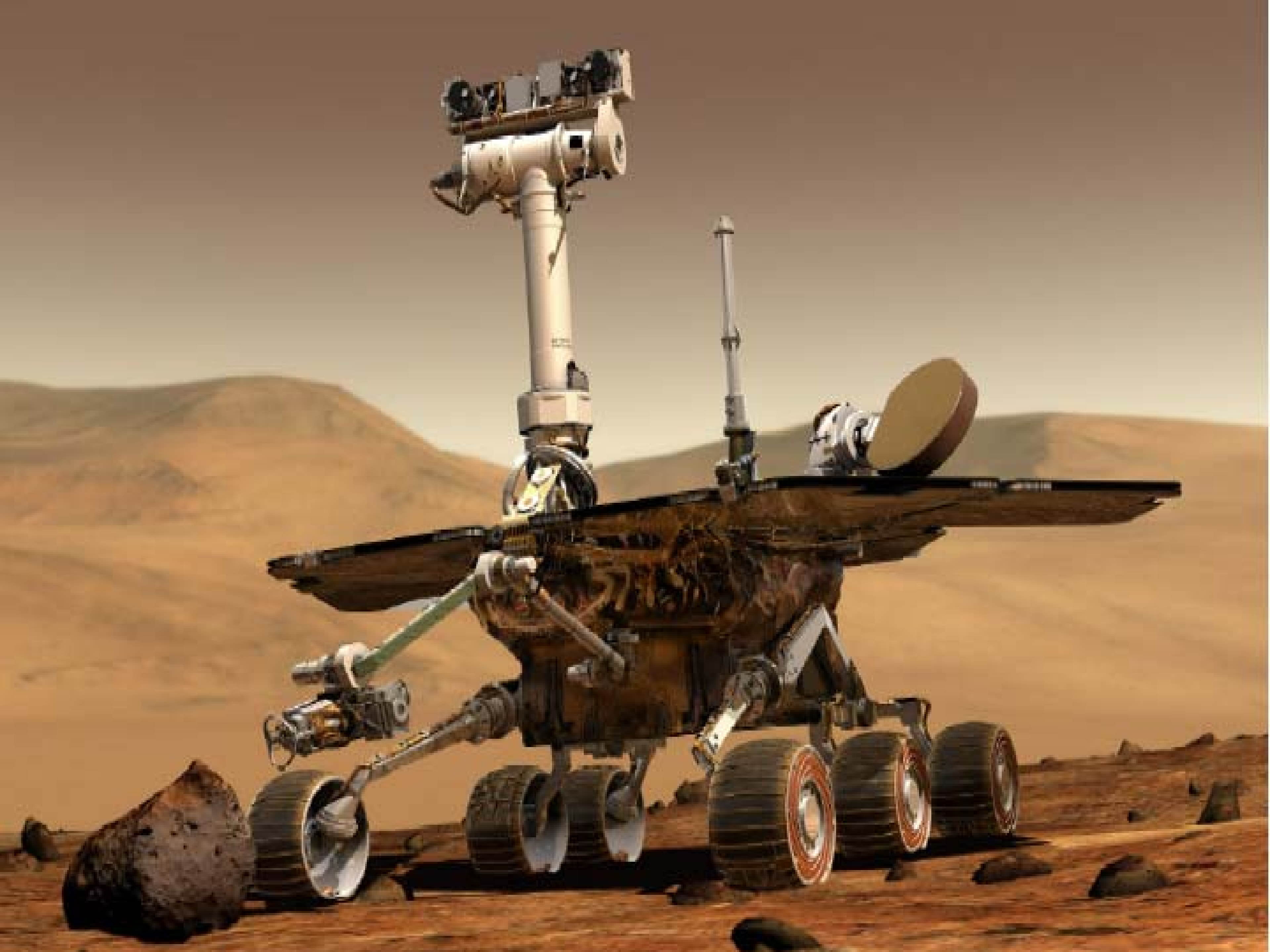
- The IPN Team:

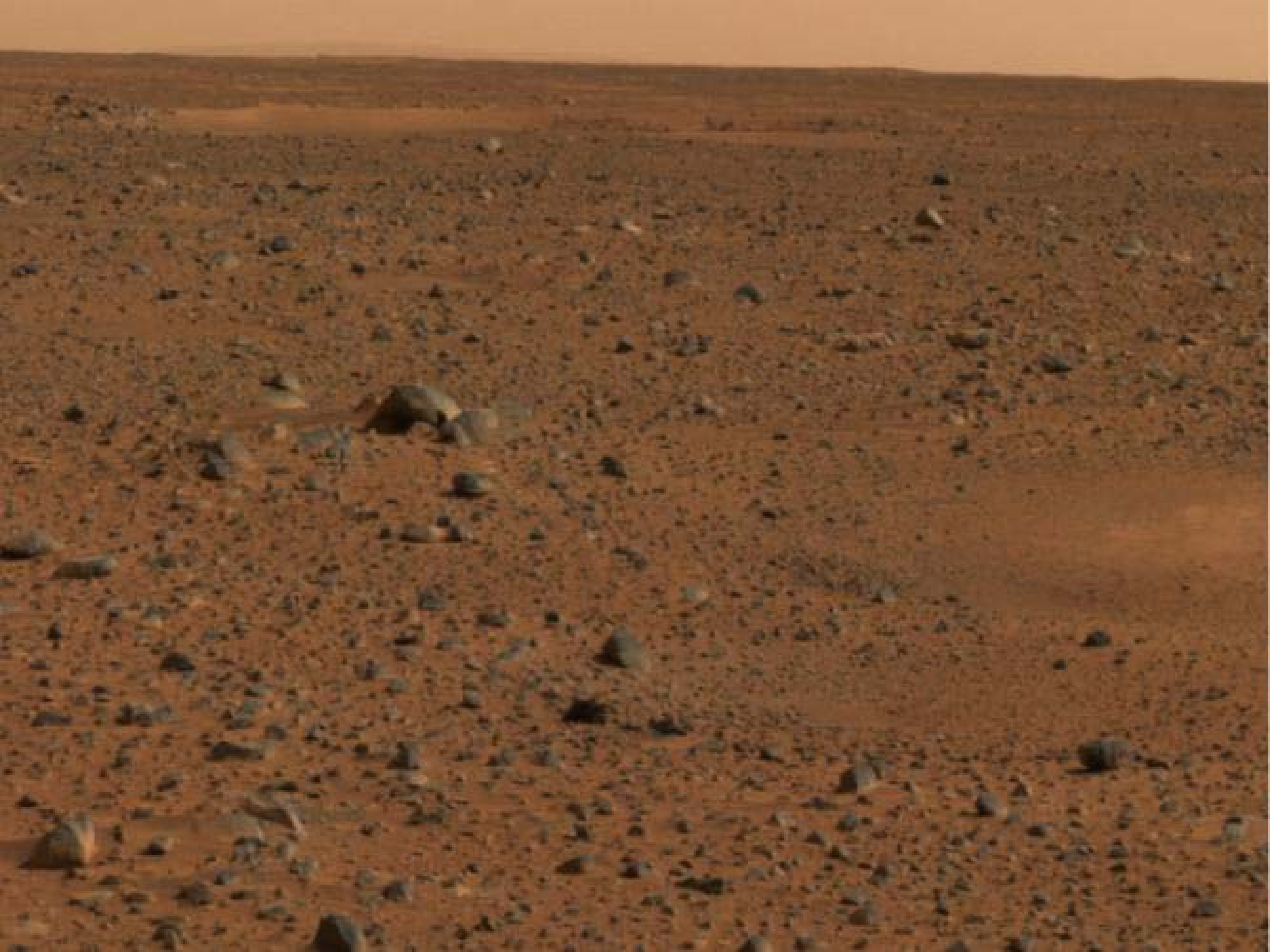
- Juan Alonso - SICS
- Adrian Hooke, Scott Burleigh, Leigh Torgerson – JPL
- Eric Travis – GST
- Bob Durst, Keith Scott – MITRE
- Howard Weiss – SPARTA
- Kevin Fall – Intel/UC Berkeley
- Vint Cerf - MCI


Pathfinder Mission: Sojourner 1997 on Mars

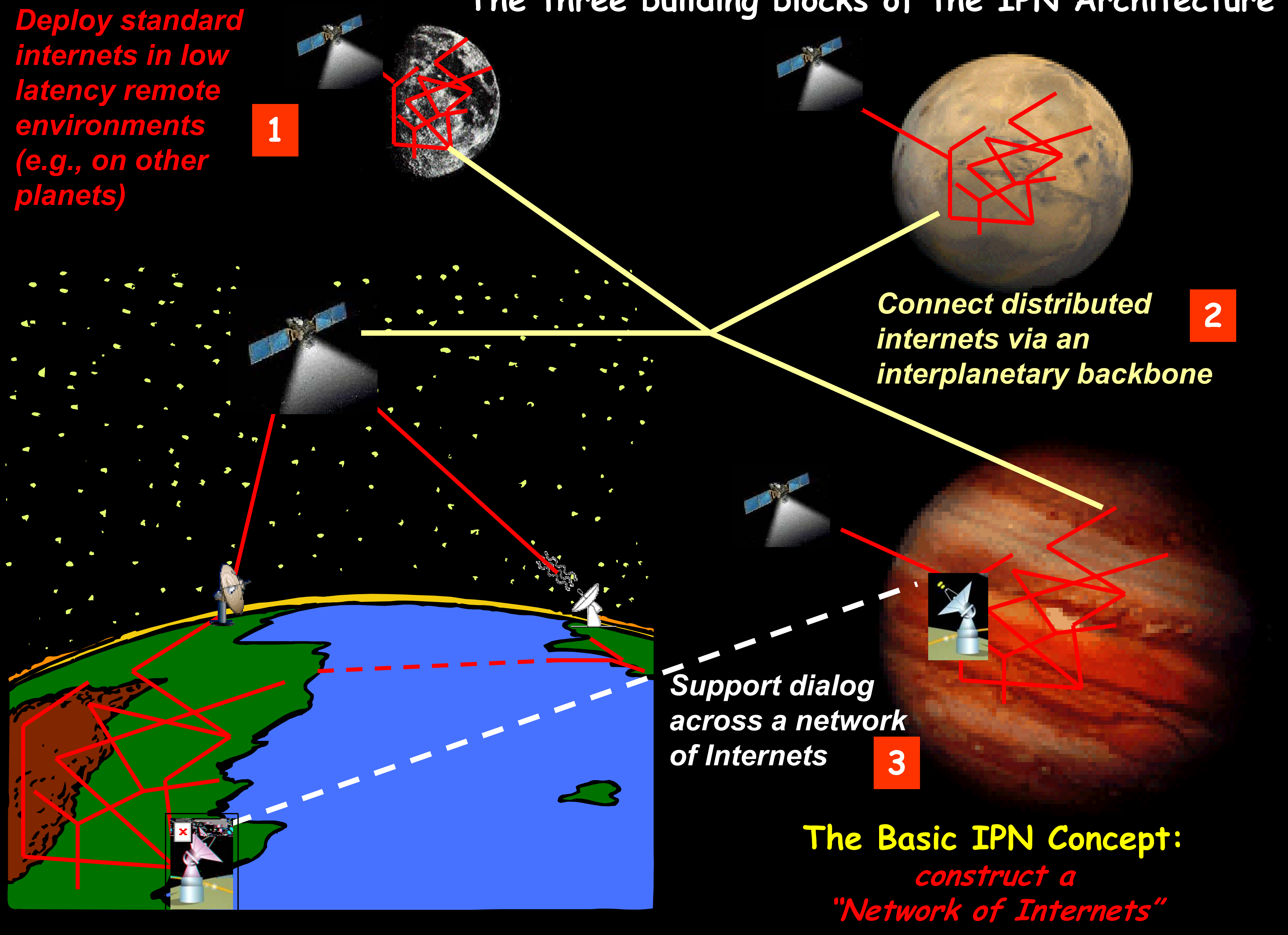
2003-2004 Missions to Mars

- Spirit
  - launched 6/10/2003 1:58 PM EDT
  - arrives Jan 4, 2004
  - Gusev Crater in Gusev Plain
- Opportunity
  - Launched 7/7/2003
  - arrives Jan 25, 2004 about 9:05 pm PST
  - Meridiani Planum

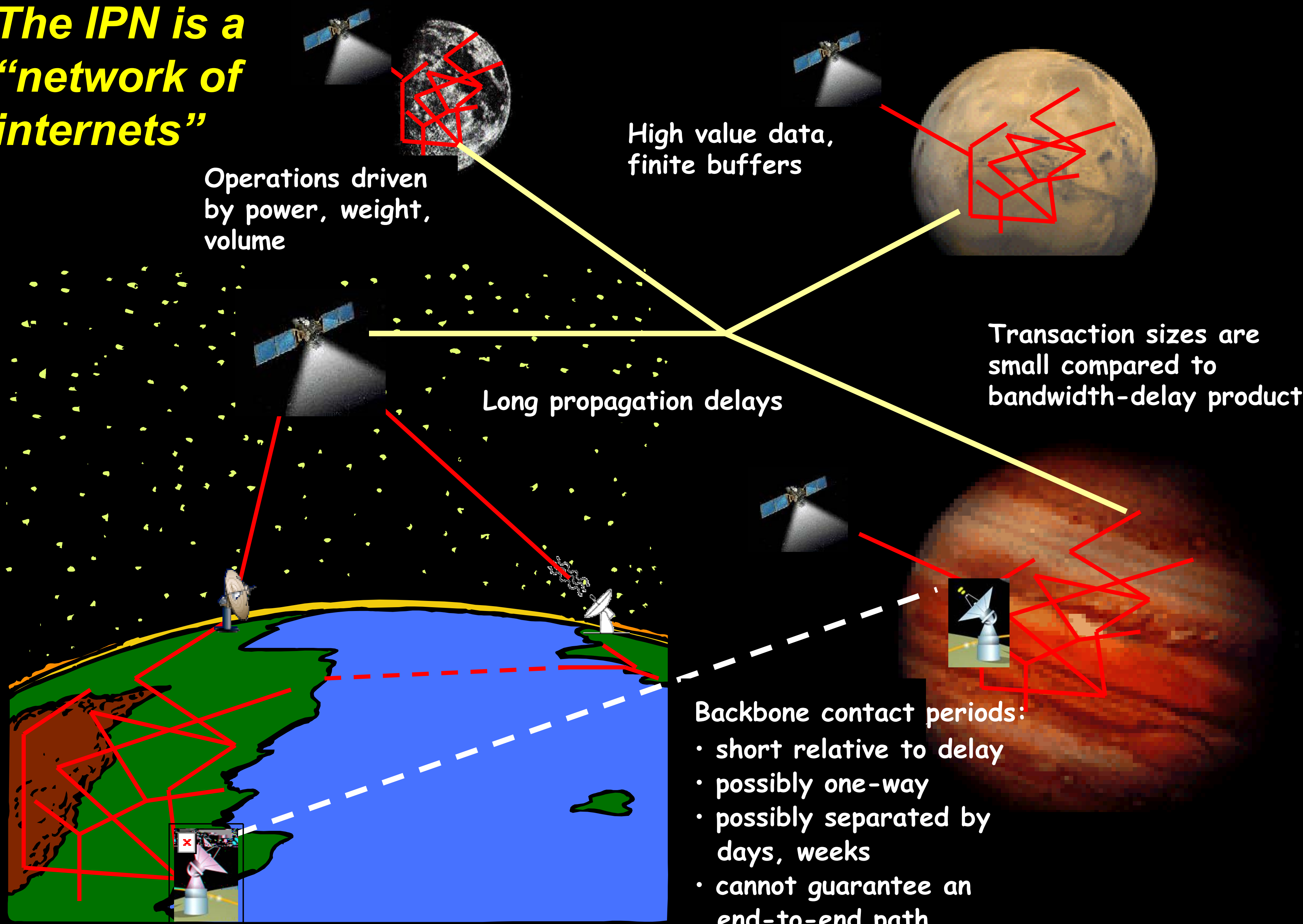




The three building blocks of the IPN Architecture

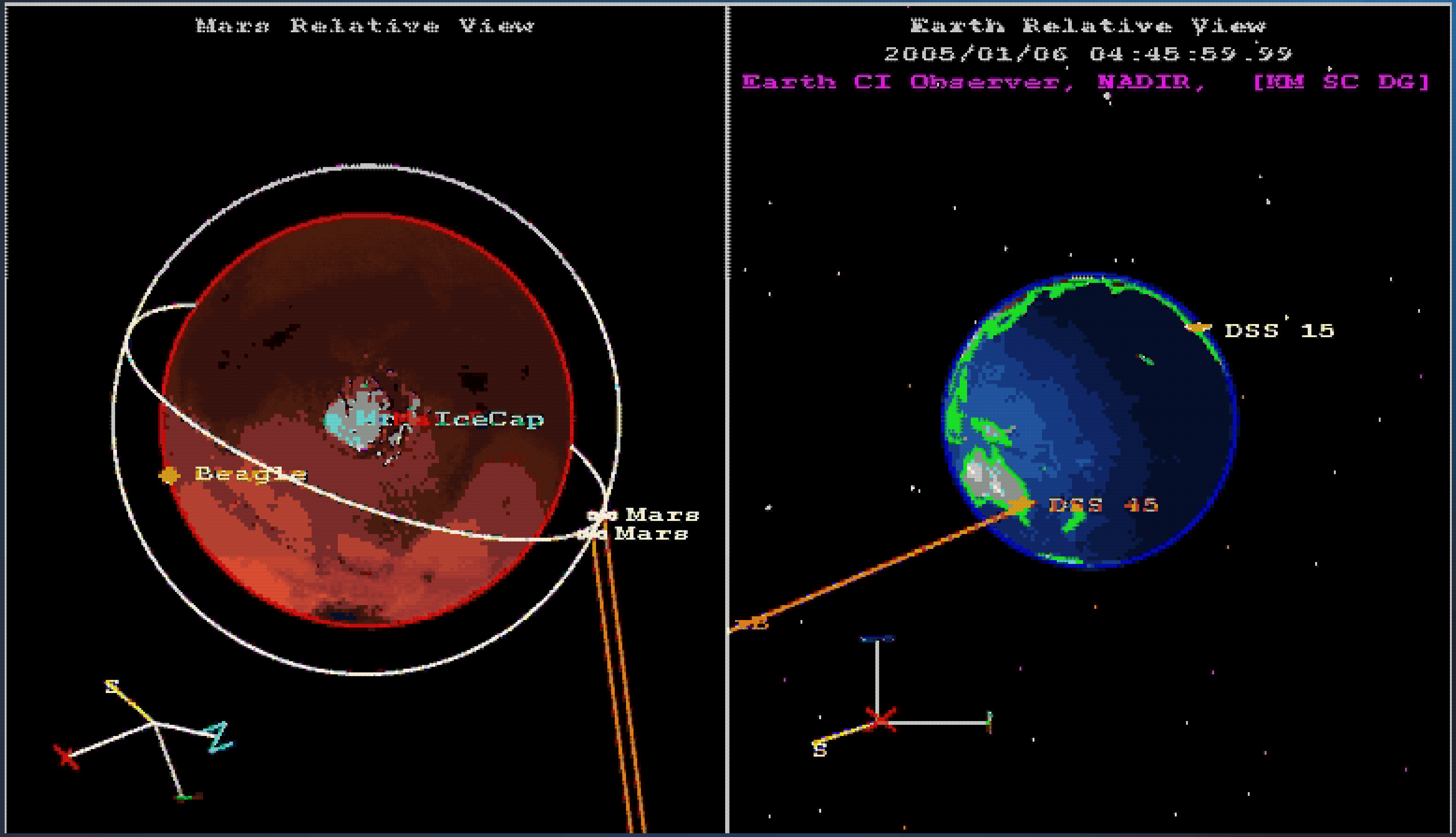


The IPN is a "network of internets"



The Internet is a connected, chatty 'network of networks' based on a wired backbone with negligible delay and errors (with untethered "edges" emerging)

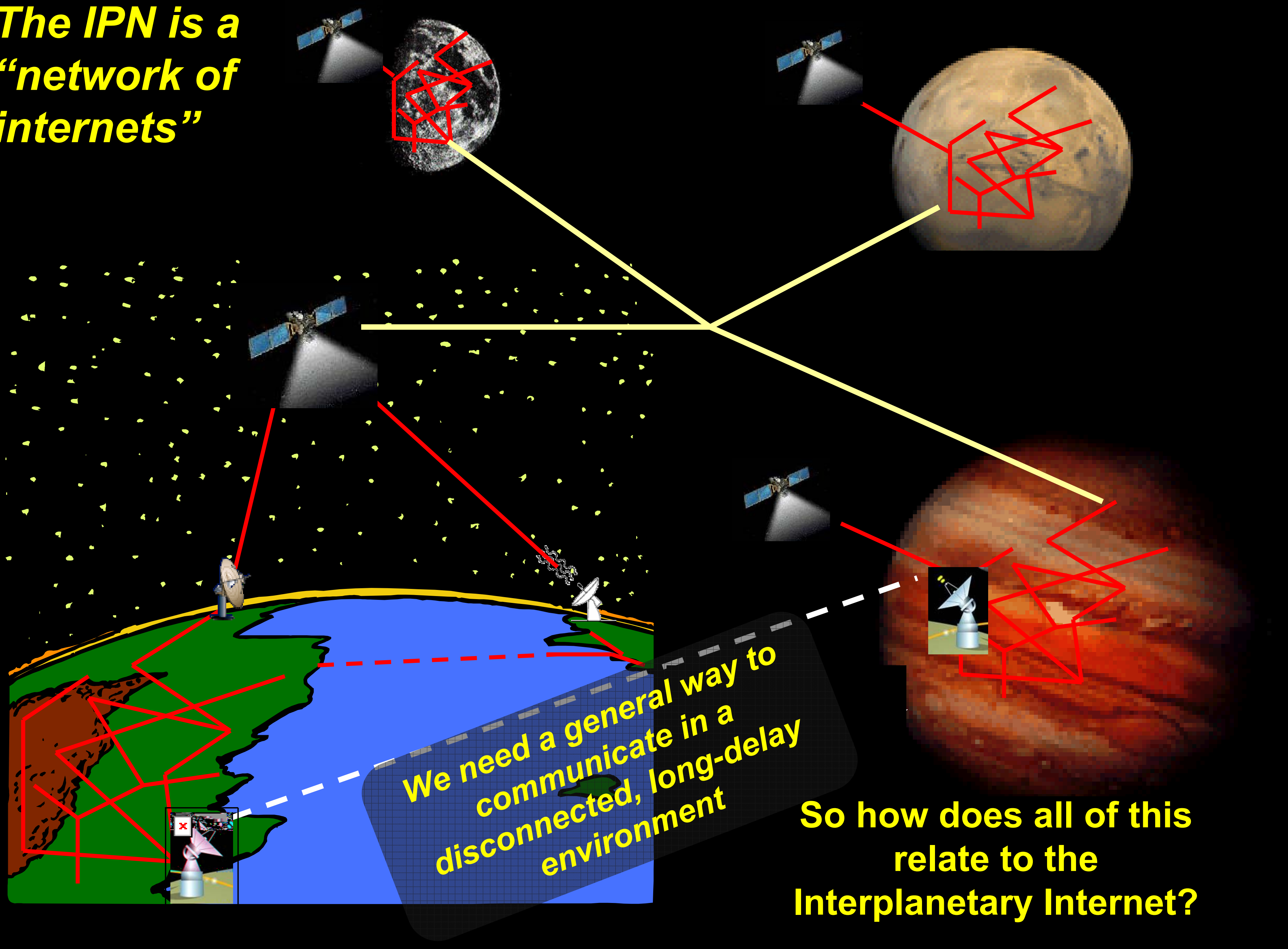
The InterPlaNetary Internet is a disconnected, store-and forward 'network of Internets' based on a wireless backbone with huge delays and error prone links



Some of the Hard Problems

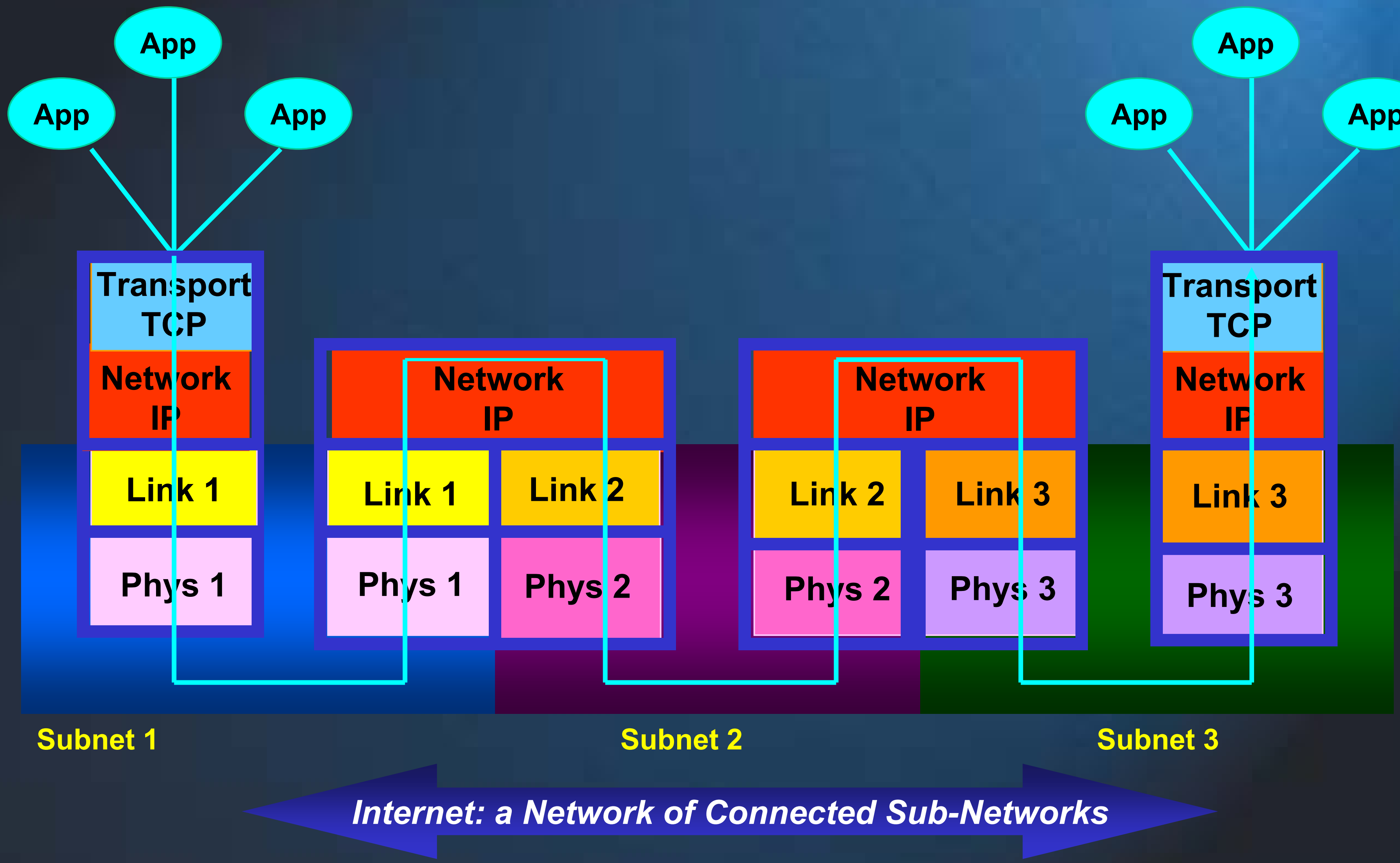
- Time synchronization/scheduling
- Antenna pointing(note optical)
- Routing
- Flow Control
- Error handling, retransmission, reassembly
- Persistent communication over operation system reboots
- Mobile robot control in high delay/uncertainty cases
- Naming conventions (DNS doesn’t work: tuples!)
- Mobile spacecraft with multiple “named” processes

The IPN is a “network of internets”



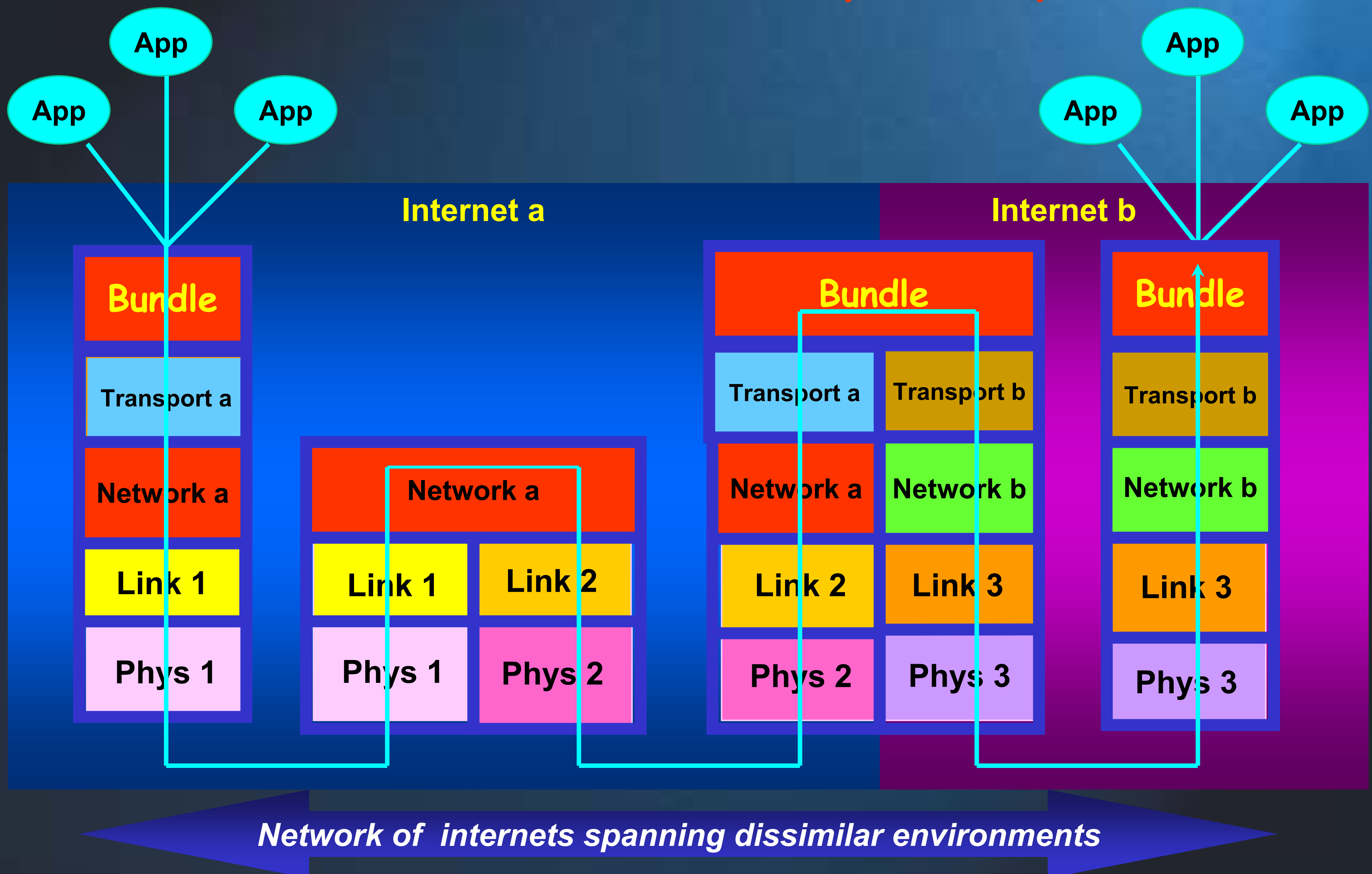
So how does all of this relate to the Interplanetary Internet?

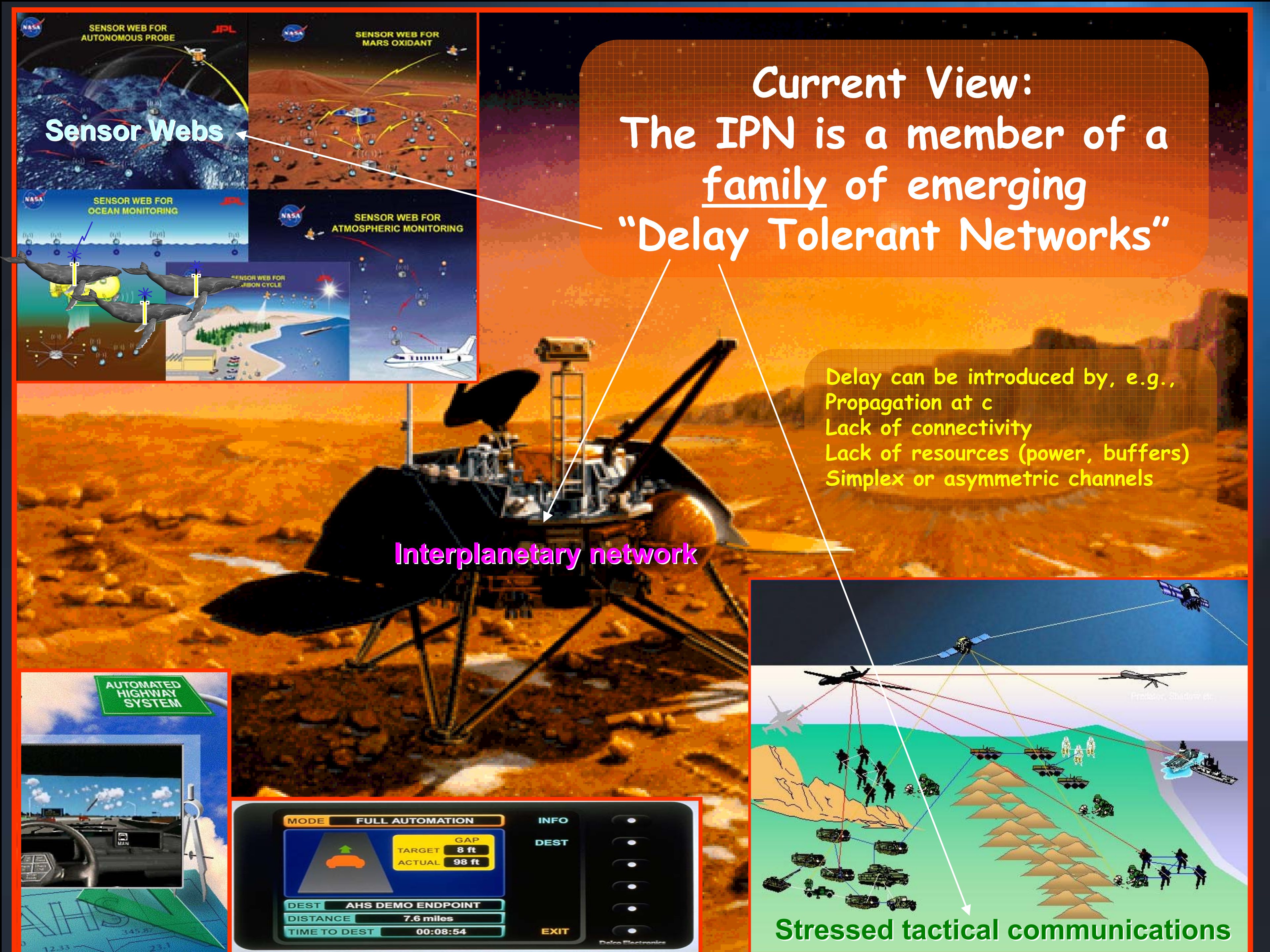
IP:
the "Thin Waist" of the Earth's Internet



Bundles: A Store and Forward Overlay

The "Thin Waist" of the Interplanetary Internet




Current View:
The IPN is a member of a family of emerging "Delay Tolerant Networks"
Sensor Webs
SENSOR WEB FOR AUTONOMOUS PROBE
JPL
SENSOR WEB FOR MARS OXIDANT
SENSOR WEB FOR OCEAN MONITORING
JPL
SENSOR WEB FOR ATMOSPHERIC MONITORING
Delay can be introduced by, e.g.,
Propagation at c
Lack of connectivity
Lack of resources (power, buffers)
Simplex or asymmetric channels
Interplanetary network
AUTOMATED HIGHWAY SYSTEM
MODE
FULL AUTOMATION
INFO
GAP
TARGET 8 ft
ACTUAL 98 ft
DEST
DEST AHS DEMO ENDPOINT
DISTANCE 7.6 miles
TIME TO DEST 00:08:54
EXIT
Stressed tactical communications

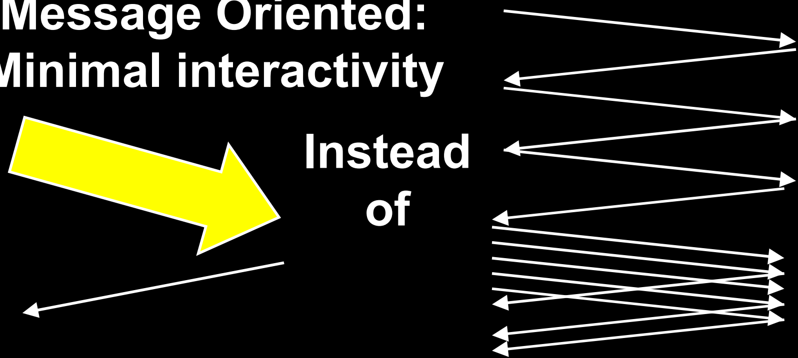
Delay/Disruption Tolerant Networking ("DTN")

The Problem

- Mobile communication systems are adopting and depending upon Internet technologies to enable combined voice/data communications
- Commercial Internet technologies generally rely on a benign communications environment, assuming:
  - An end-to-end path exists and the nodes are always on.
  - Power, bandwidth, storage, network access are readily available.
  - Dialogue is always possible, interactivity is “free.”
- Untethered edges of the internet cannot rely on these assumptions, and they do not always hold for space-based systems or terrestrial systems in stressed environments.
- Some of these challenges have been met through “hacks” rather than best of breed architecture.
  - Results tend to be “brittle” and purpose-built

Key DTN Architectural Concepts

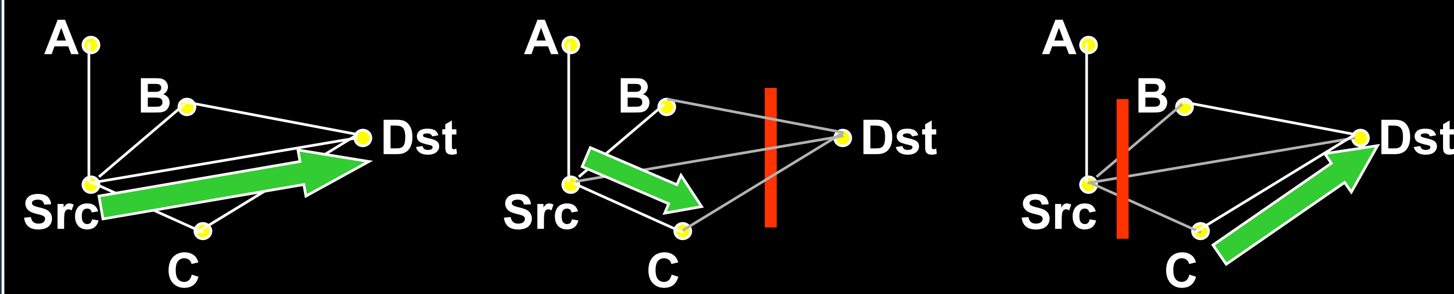
Message Oriented:
Minimal interactivity



Routing Across Network Disruption

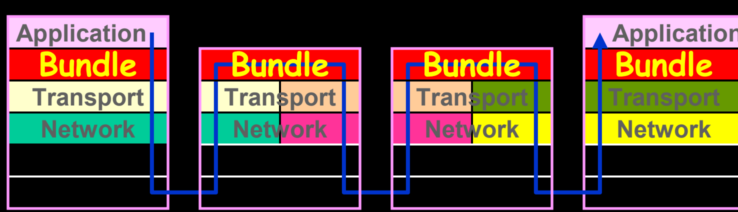
- On-demand connections
- Scheduled connections
- Predicted connections
- Opportunistic (unexpected) connections

Store-and-Forward Operation



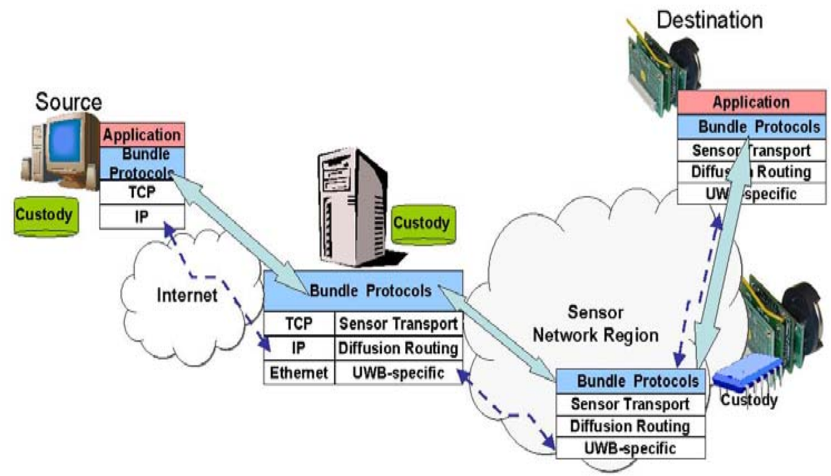
Overlay Network

- Operates above transport
- Uses available xport/net technologies

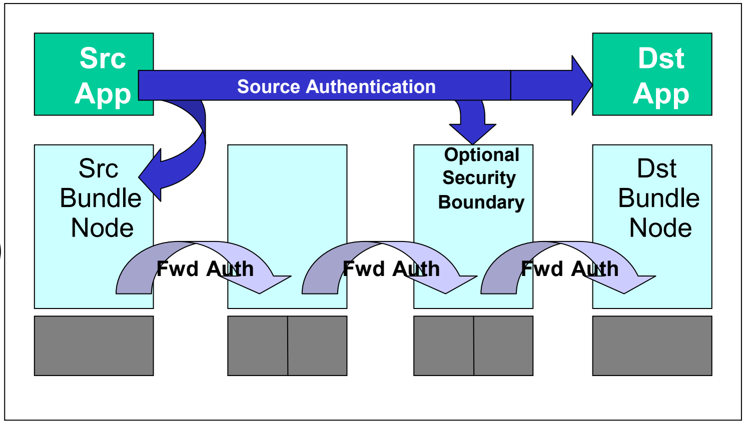


Key DTN Architectural Concepts (Continued)

- Regions aggregate nodes
  - **Aggregation based on technology, policy, proximity, etc.**
  - **Gateways between regions provide control points, store-and-forward resources, active transcoding, opportunities for protocol translation (e.g., IPv4/IPv6 and non-IP systems)**



- Infrastructure protection
  - **Authenticated application registration**
  - **Signed exchanges among routers**
  - **S/MIME-like (no Diffie-Hellman exchange)**
  - **Public keys may or may not (more likely) accompany the bundle**



Key Architectural Concepts (Continued)

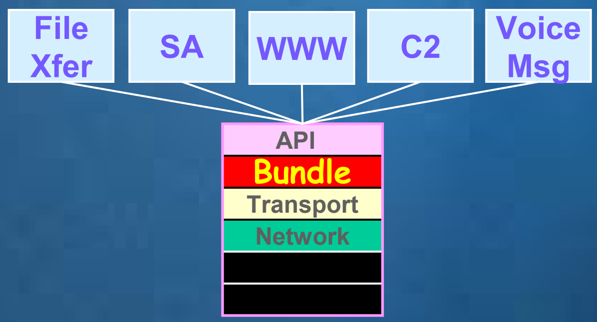
- Routing across disconnection
  - **Cognizant of path entropy**
    - Persistent links
    - Scheduled connectivity
    - Predicted contacts
    - Opportunistic contacts
  - **Selection based on path characteristics**
  - **Replication on multiple paths for robustness**
  - **Enables "fire-and-forget" networks robust against disruption**

Key Architectural Concepts (Continued)

- Late binding of names to addresses
  - Name tuple carries destination *region* and administrative *name*
  - Alleviates need for *universal* name-to-address binding database
  - Implicitly supports role-based addressing

- Class of Service similar to postal system
  - Types: Priority, regular, bulk
  - Options: send notification, keep delivery record, inform on delivery
  - Helps to optimize resource use

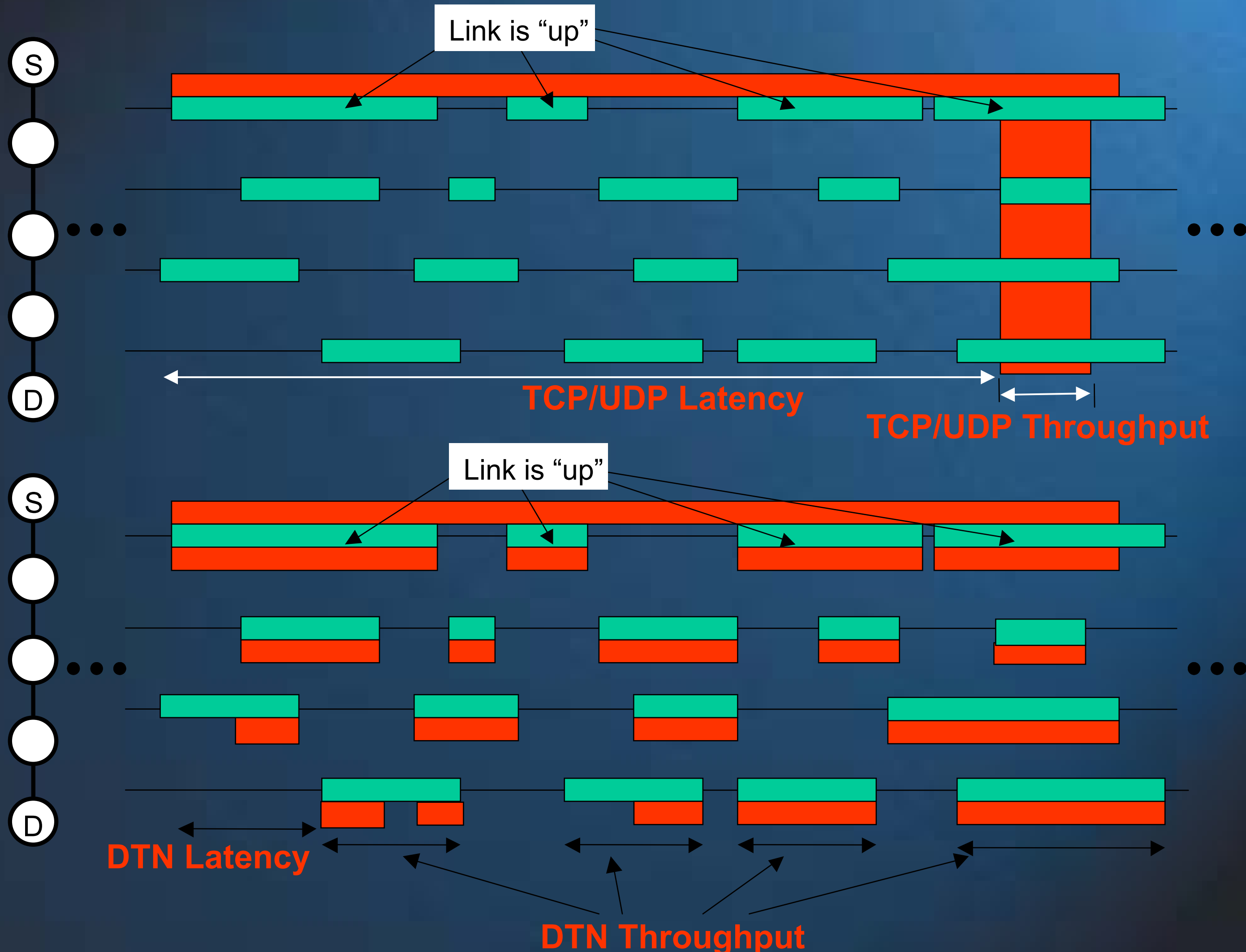
Key Architectural Concepts (Continued)



- Application multiplexing/demultiplexing
  - Demultiplexing based on administrative name, syntax defined by application
  - Provides a new general-purpose network delivery service

- Process persistence/reanimation
  - Useful in embedded systems that are resource poor (e.g. sensor nets)
  - Upon bundle arrival, application *and relevant state* are reinstantiated
  - Allows operation across (planned or unplanned) power cycles, software, OS upgrades
  - Supports process migration to alternate hosts

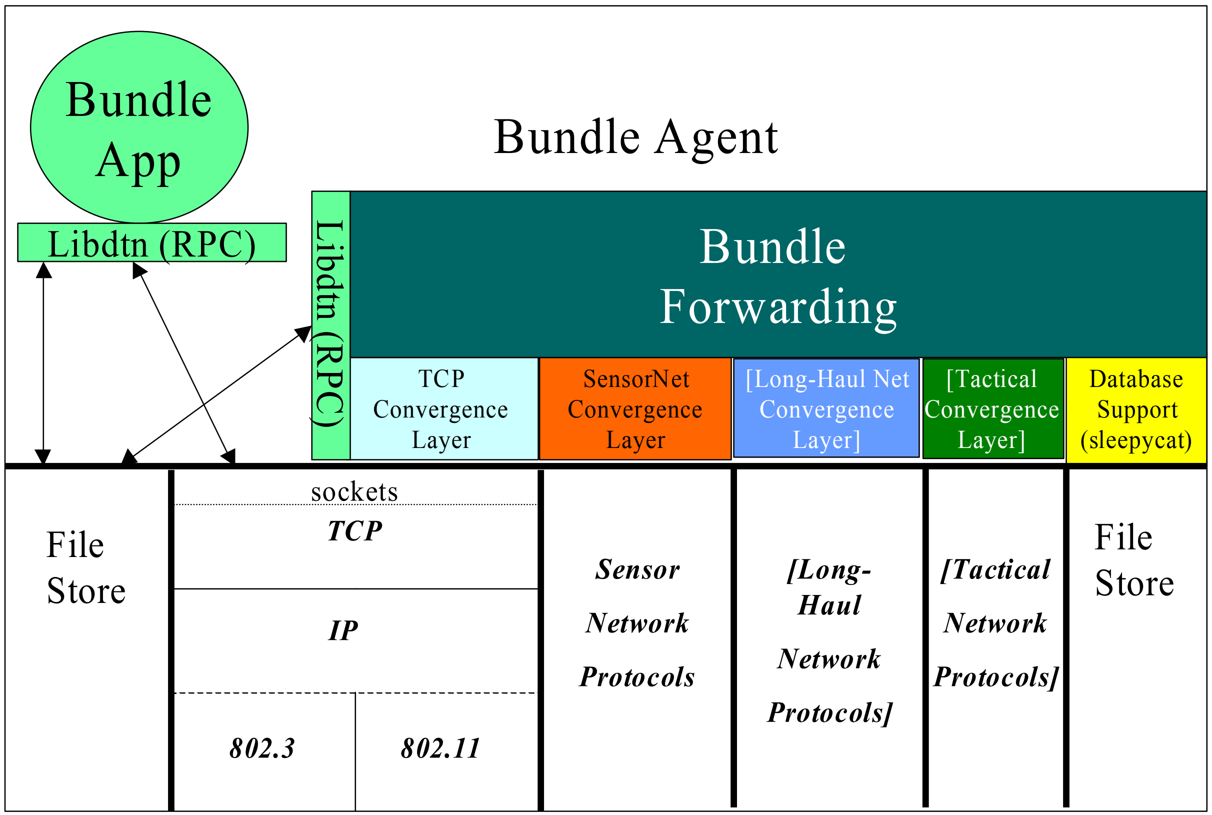
DTN vs End-to-End Internet Operation



Current development activities

- Improve robustness of current code base
  - Testing: MITRE, JPL, Intel-Research
  - Static Analysis: MITRE
  - Regression Test Development: MITRE, JPL
- Routing across intermittently-connected mobile ad hoc networks – MITRE
  - Examining alternative link availability and connectivity degree metrics
  - Alternate forwarding criteria under consideration:
    - Route on all paths that have availability > *p*
    - Route on the best paths until the sum of the metrics for those paths is > *n*
- Integrate Digital Fountain erasure coding software into DTN code base – MITRE
  - Highly efficient forward error correction coding
  - Complementary to forwarding over multiple paths, above

Prototype Implementation Structure



[…] = not yet built

Current DTN *Implementation* Limitations

- No interregion multicast support yet
  - Can depend on IP-layer multicasting within a region, but DTN does not form trees at its own layer
  - Demultiplexing to multiple destinations within a node is supported
- Erasure-coding based reliability optimized for 10KB+ transfers
  - Digital Fountain coding imposes 5% overhead for messages >= this size, larger overhead for smaller messages
- Need to develop routing strategies for different inter-regional conditions
  - DTN forwarding decisions based on current connectivity and *probability* of future connectivity (calculated based on availability history of each link)

Relevant Documents

- Internet Research Task Force Research Group (DTNRG) web site: www.dtnrg.org

- Relevant Internet Drafts:

  DTN Architecture Document: draft-irtf-dtnrg-arch-01.txt

  DTN Bundle Protocol Spec: draft-irtf-dtnrg-bundle-spec-01

For DOD:
Delays result from disconnection,
Hence "Disconnection Tolerant Networking"

Realization:
Broader applicability
Nearer term utility
Larger research community

For Further Information:

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