Space Internet
What's Missing?

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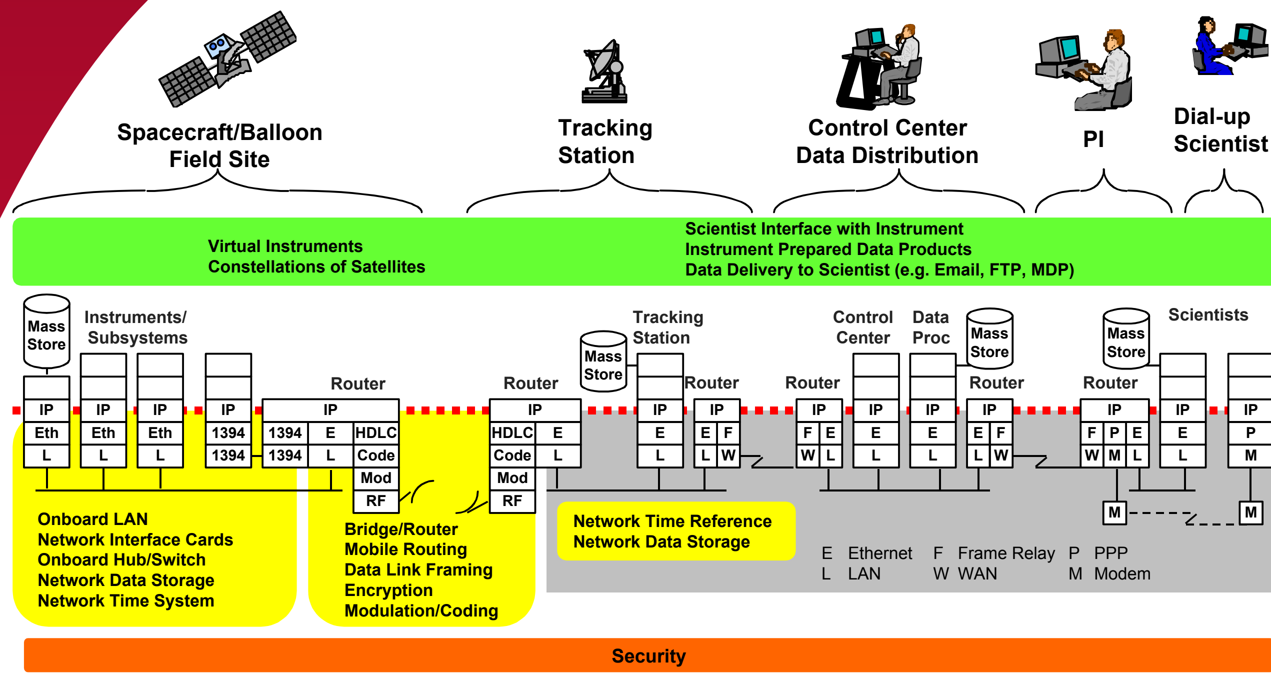


Overview

- What is Space Internet
- Onboard Components
- Ground Components
- End-to-End Protocols & Applications
- Summary

What is Space Internet

- **End-to-end network connectivity using Internet technologies from spacecraft instruments and subsystems to ground systems, scientists, and other spacecraft**

- **Communication systems based on layered protocol models used in the Internet**
  - Break end-to-end communication into component areas the can be designed and built independent of other components
  - Allow upgrading or replacing individual components without disturbing the rest of the communication system

- **Mission design, development, testing and operation using standard distributed network concepts**

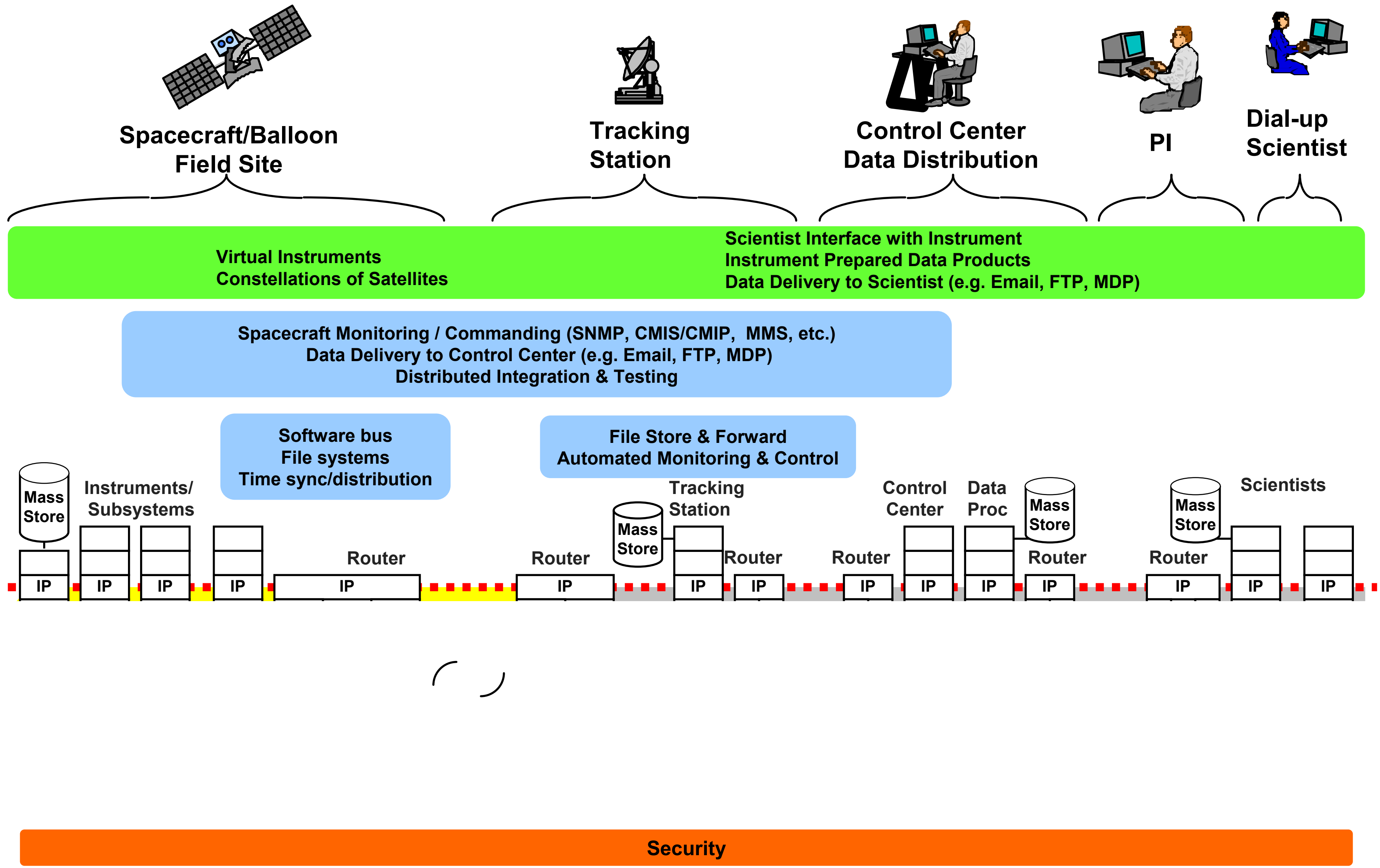
Why Space Networking ?

- **Design**
  - Simpler/faster design using widely used, well known protocols
  - Simpler ICDs since basic protocol design details already done
  - Less risk using technologies that have been around for years and used by millions
  - New types of operations concepts enabled with Internet communication technology
- **Development**
  - Cheaper to use standard technology than design custom
  - Internet community pays for most design and development costs
  - Protocols and applications supported by vendors in operating systems
  - High-rate communication equipment readily available from vendors
- **Integration & Test**
  - Many hardware and software diagnostic tools available for standard network environments
  - Simpler subsystem interfaces using standard network technologies
  - Much earlier integration and testing, find problems while they can be corrected easily
  - Virtual spacecraft testing while subsystems are still under development across the country and around the world
  - Reduced risk and better management visibility into ongoing development and test activities

Why Space Networking ?

- **Operation**
  – Automated operations using standard distributed processing concepts
  – Protocols support spacecraft intercommunication if links are available
  – Distributed processing across spacecraft
  – Standard cross-support and interoperations among ground stations
  – Long-term interoperability (current systems will work with future ones because the Internet needs that sort of interoperability)
- **Maintenance**
  – Easier equipment maint & upgrade using standard technologies
  – Network equipment vendors do most maint& upgrades and users only pay a minimal annual fee, users don't need large maintenance groups
  – Fixes are better analyzed and tested in the Internet world due to the millions of users
- **Security**
  – Leverage huge investment in security being done for Internet community
  – Continual upgrades in security protocols and mechanisms from Internet
  – Extensive testing of security mechanisms on Internet

End-to-End Network Architecture



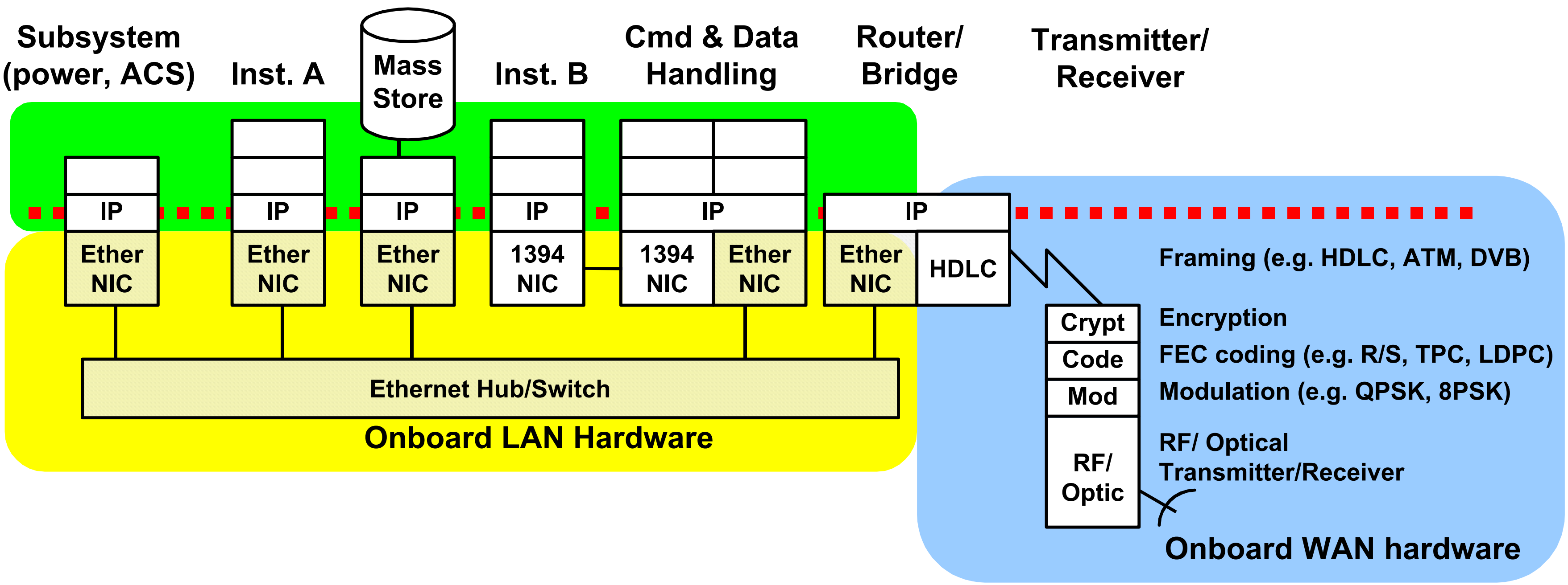
Space Components

- **Primary challenge is developing standard network components for the challenging space environment**

radiation	- some radiation hardening needed in LEO orbits, higher and polar orbits need more
power	- spacecraft/remote systems operating with solar or battery power have limited power
cooling	- devices may require redesign for conduction cooling, relates to low-power
thermal	- devices must operate over extended thermal ranges and temperature cycling
vibration	- range/space equipment must survive launch and operational vibration
weight	- launching or flying more weight costs more money
size	- larger size results in more weight and associated launch issues
reliability	- devices must be highly reliable, replacement or repair is often impossible

Space System Architecture

- Onboard LANs among systems (e.g. Ethernet, ATM, 1394)
- Onboard WAN interface for passing data to RF/Optical link
- Upper layer protocols & applications onboard and end-to-end



Onboard LAN Component Status

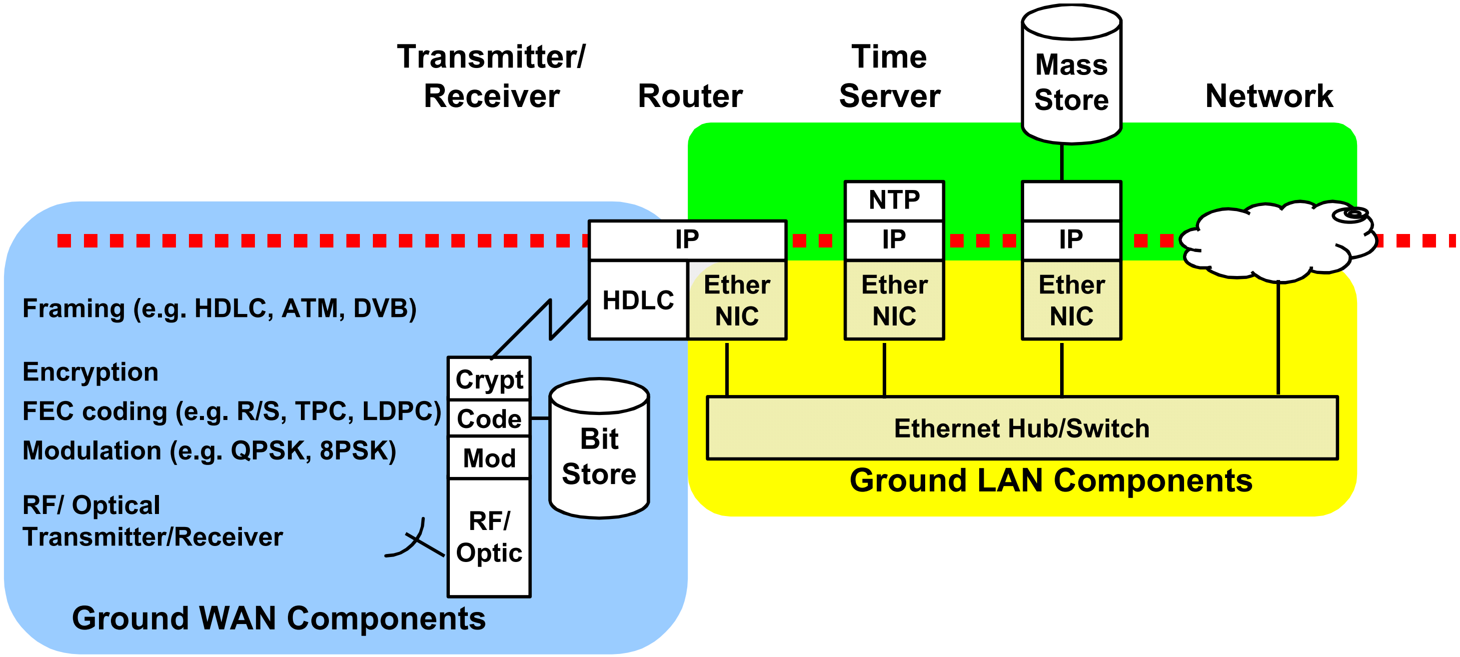
Component	Status
Space qualified Ethernet, Firewire, ATM connectors	Rugged Ethernet connectors for factory floor
Radiation-hard Ethernet 10/100/1000 network interface cards (NICs)	Spectrum Astro working on 10/100 Ethernet using rad-hard and qualified COTS cmponents NASA/GSFC building rad-hard FPGA Ethernet
Rad hard Firewire (IEEE 1394) NICs	Being developed for NPOESS mission
Rad hard ATM NICs	Northrop Grumman (TRW) Astrolink design
Rad-hard Ethernet, ATM hubs, switches,	NASA/GSFC working on Ethernet switch
Device drivers for NICs in standard OSÕs	Should be similar to standard NICs
Fault tolerant LAN equipment and failure recovery strategies	Factory automation and process control community working on components/concepts
High-speed, network attached random access mass storage for file systems	Possible application of SAN and iSCSI network storage concepts
High stability, radiation-hard, time systems (clocks, network time servers)	Work needed on low-cost stable clocks

Onboard WAN Component Status

Component	Status
Link level encryption/decryption hardware	Some military components available
Radiation-hard, forward-error-correction hardware (e.g. Reed/Solomon, Low Density Parity Check, Turbo Product Code)	Reed/Solomon encoders available for space Work underway on TPC and LDPC
Radiation -hard framing hardware (e.g HDLC, ATM, EIA IS-787, DVB)	COTS HDLC chips used on LEO spacecraft for over 20 years. Simple to implement in rad-hard FPGAs.
High-rate versions of coding, encryption, and framing hardware	Possible solutions coming from DoD Transformational Communication project
Rad-hard Etherner, ATM bridges to transmitter/ receiver	GPM mission working on Ethernet/serial bridge
Rad-hard routers with Ethernet, Firewire, ATM, serial interfaces	General Dynamics (Motorola) and Cisco working on prototype ITT adding routing features to LPT
Basic mobile routing protocols	Mobile IP available and flown on CANDOS More mobility solutions coming in IPv6
Mobile Routing to hide mobility details from onboard systems	Cisco Mobile Routing being prepared for test flight on SSTL DMC spacecraft in 2003

Ground System Architecture

- Main issues are to identify modulation, FEC coding, encryption, and framing mechanisms that are widely available, efficient, and feasible for remote systems
- Network time and file servers may support network time access and data storage/rate-buffering
- Standard network technologies to the rest of the world



Ground Component Status

Component	Status
High-rate, forward-error-correction hardware (e.g. Reed/Solomon, Low Density Parity Check, Turbo Product Code)	Reed/Solomon and Turbo Code available LDPC becoming popular Gbps rate support still needed for all
High-rate framing compatible with remote system framing (e.g. HDLC, DVB, ATM,etc.)	HDLC framing available up to 100 Mbps DVB framing available up to 240 Mbps Need space hardware at these and higher rates
High-rate mass storage systems	Large storage area network (SAN) systems available with increasing capacity and speed
Network timing systems for use by S/C	Standard NTP time servers are available but may need special features for higher precision timing and to accommodate RF/optical links
Standard high-rate ground networking technologies	Available at rates of 10 Gbps, constantly growing
Mobile routing protocol support	Mobile IP protocol readily available (flown 1/03) Mobile routing technologies being deployed (flying in 2003 IPv6 evolving in test environments (e.g. 6Bone)
End-to-end IP addressing concepts	Work needed on scalable system addressing schemes and operational security mechanisms
Security approaches	Commercial security options available but scalable addressing and security schemes need to be developed for range and space applications

Upper Layer Protocols & Applications

- **IP provides an end-to-end datagram delivery service that supports upper layer “unreliable” and “reliable” data delivery**
- **User Datagram Protocol (UDP) provides “unreliable” transport identical to legacy mechanisms like TDM and CCSDS framing**
  - Works over both one-way and two-way links
  - Can be used to support all possible communication needs of a mission
  - All missions must use UDP for worst case error modes
- **Transport Control Protocol (TCP) provides “reliable” byte stream transport but has problems with some space communication links**
  - one-way links don’t work (e.g. blind commanding or TDRSS return-only links)
  - high link bandwidth asymmetry (TCP can’t go much beyond 50:1 asymetry)
  - high link error rate (TCP will keep trying until it gets all data through, may not be possible)
  - long propagation delays (TCP feedback loop limits throughput with long delays)
- **Many UDP applications work well in space (e.g. MDP, NTP, CFDP)**
- **TCP applications can be used under proper conditions**

E2E Protocols & Applications

Component	Status
Security algorithm accelerator chips for supporting network and application level security	Ground based components available but rad-hard ones needed
Application level data encryption and key management	Many standard commercial solutions available but best solutions for range and space use need to be identified
Standard time stamping mechanisms (e.g. time stamped PING, RTP,) for IP packets	Options exist but may be different than legacy mechanisms. New concepts built on Internet standards are needed.
Time synchronization and clock management mechanisms (e.g. NTP)	NTP being used on so me spacecraft but more work needed on higher timing precision.
Standard messaging protocols	GMSEC task at GSFC working on messaging protocols to provide end-to-end software bus
UDP based highly reliable protocols for one-way links (e.g. FEC, MDP, NORM, Digital Fountain)	MDP successfully tested on CANDOS shuttle mission. Digital Fountain is an interesting option for highly reliable file distribution over one-way links. Work needed on memory efficient versions
UDP based reliable protocols for asymmetric, intermittent links (MDP, NORM, CFPD)	MDP being used for various unicast, mulitcast, and one-way link applications NORM being developed as IETF s tandard with modular building blocks for FEC CFDP being used on AISAT-1 spacecraft

Summary

- End-to-end IP space networking is doable today and missions are currently using it (e.g. AlSat-1, CHIPSat, CANDOS)
- Future missions are designing and building some of the missing pieces for space networking (e.g. GPM)
- DoD Transformational Communication project is pushing development and deployment of future space networking
- Vendors are developing additional components for space networking
- The benefits of end-to-end networking with standard Internet technologies are being realized and will continue to drive further development

http://ipinspace.gsfc.nasa.gov/