



Taking Cisco to space



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A space vision from a networking company

**One day, each and every manned
and unmanned spacecraft, high
altitude platform, unmanned
aerial vehicle, airframe...
will be a node on the network.**

Terrestrial and space communications
will be indistinguishable.

(We talk about
merged space-ground architectures.)

Steps in taking Cisco into space

- Extending the Internet into space.
how IP was first used in orbit.
- CLEO Cisco router in Low Earth Orbit.
launched in 2003, and still working over five years later.
- The Interplanetary Internet
testing the Delay-Tolerant Networking Bundle Protocol.
- IRIS router for geostationary orbit.
to be launched on Intelsat-14 in 2009.

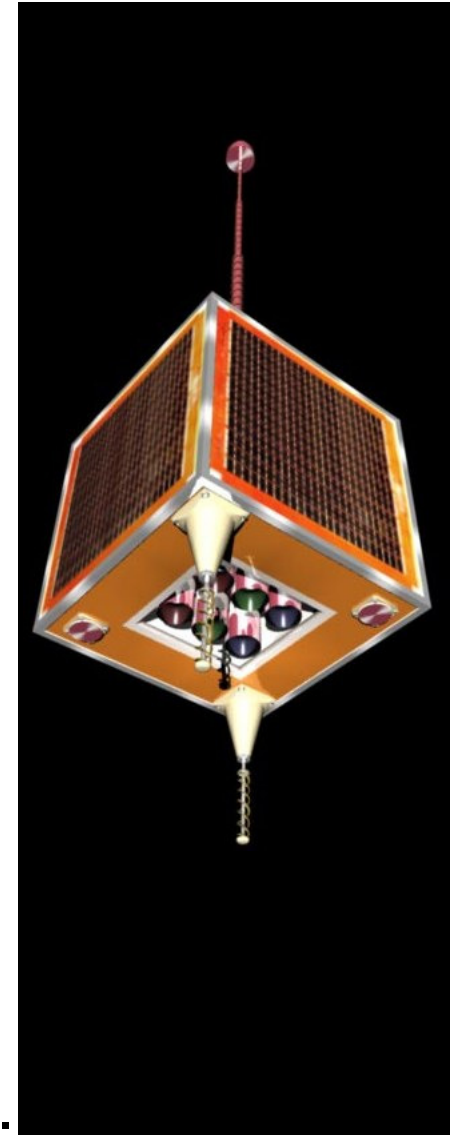
Images shared by other organisations are used with thanks.

Extending the Internet into space

- NASA JPL gives DERA's STRV-1b an IP address (1996).
- NASA Goddard flies IP stack on Surrey Satellite Technology Ltd's UoSAT-12 (2000). This encourages SSTL to adopt IP.
- Cabletron router on Russian module of International Space Station. NASA uses IP onboard shuttles, e.g. VoIP with Cisco SoftPhone tested from *Atlantis* (Feb 2001). Experiments included CANDOS, tested onboard *Columbia* (Jan 2003).
- NASA gets SpaceDev to launch CHIPSat (Jan 2003).
- **SSTL adopts IP with Disaster Monitoring Constellation (DMC)**
AISAT-1 launched in Nov 2002, UK-DMC *et al.* Sep 2003, Beijing-1 Oct 2005. Cisco and SSTL fit CLEO mobile access router on UK-DMC satellite, alongside imaging payloads.
- **New DMC satellites to be launched this year.**

CLEO – Cisco router in Low Earth Orbit

- UK-DMC satellite, with Cisco router onboard, launched with other satellites into low Earth orbit, September 2003.
- UK-DMC and sister satellites built by Surrey Satellite Technology Ltd are based around use of Internet Protocol (IP). IP works for satellite and payload communication and control.
- IP internetworking of satellite and router tested and validated by international collaboration and demonstration at Vandenberg Air Force Base, June 2004. Worked closely with NASA Glenn.
- IPv6 and IPsec tested in orbit, March 2007.
- Cisco router works well in orbit.
- Has introduced Cisco to the aerospace industry.



Disaster Monitoring Constellation (DMC)

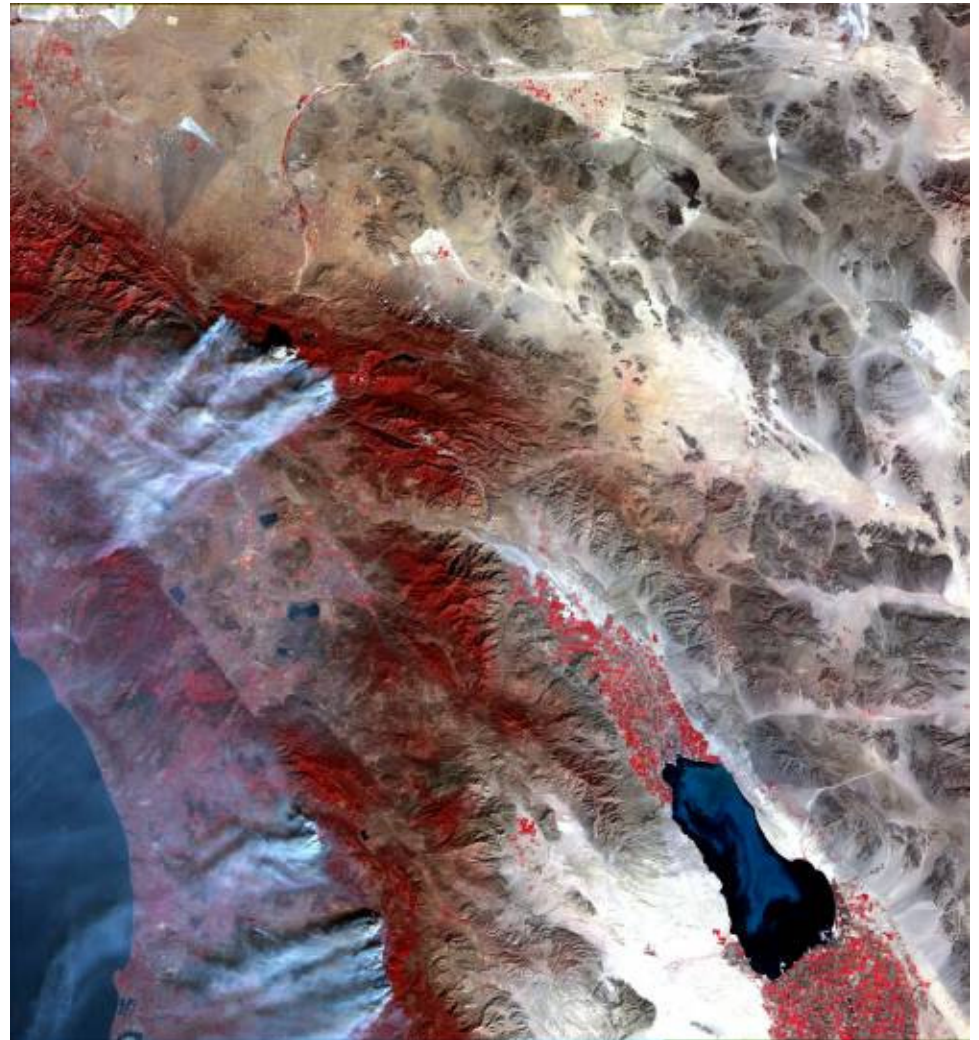
www.dmcii.com

Surrey Satellite Technology Ltd (SSTL) build and help operate an international constellation of small sensor satellites.

These IP-based satellites share a sun-synchronous orbital plane for rapid daily large-area imaging (640km swath width with 32m resolution). Can observe effects of natural disasters.

Government co-operation:
Algeria, Nigeria, United Kingdom, Turkey and China.

Each government finances a ground station in its country and a satellite. Ground stations are networked together. Further satellites planned.



fires in California, 28 October 2003 (UK-DMC)

DMC in use: after Hurricane Katrina, 2005



In this false-color image, dry land is red. Flooded and damaged land is shown as brown.

Small part of an image taken by the Nigerian DMC satellite on Friday 2 September, for the US Geological Survey.

DMC is working as part of the United Nations International Charter for Space and Major Disasters.

Imagery delivered by using Internet Protocol.

www.dmci.com

What is the CLEO router?

A Cisco 3251 Mobile Access Router (MAR).

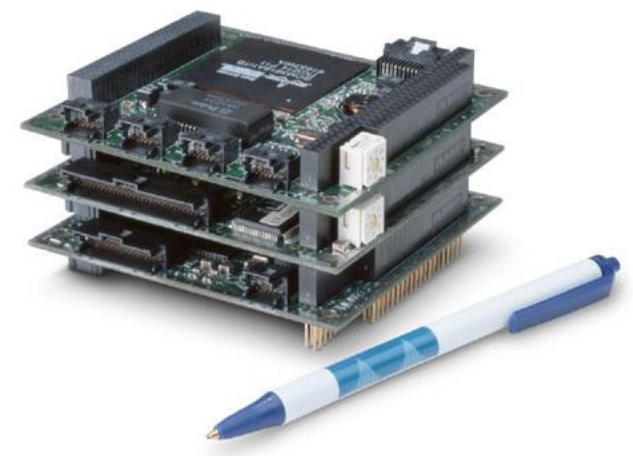
The MAR is a commercial off-the-shelf (COTS) product family – 3251 and 3220 series. Runs Cisco's IOS (Internetwork Operating System) router code – version 12.2(11)YQ.

The 3251 MAR featured:

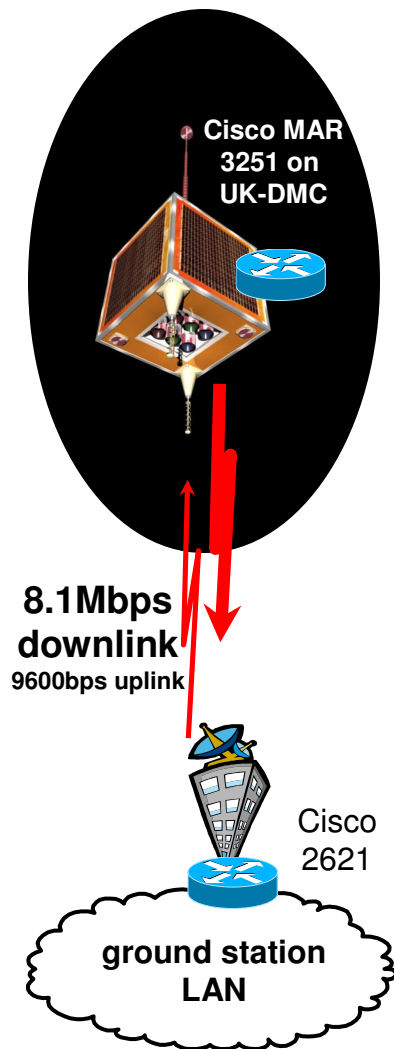
- 210MHz Motorola processor.
- Built-in 100Mbps Ethernet.
- PC/104-Plus interfaces and form factor.
- Additional stackable 90mm x 96mm cards (serial, Ethernet, power supply, WiFi, etc.)

The CLEO MAR is an experimental secondary payload on the UK-DMC satellite.

Local environment and high-speed downlink used by UK-DMC satellite dictate use of serial interface card to connect with existing 8.1Mbps serial links used onboard.



Existing network environment for the DMC



Satellite: each DMC satellite has multiple onboard computers. For housekeeping (the On Board Computer, OBC), for image capture and packetised transmission (the Solid State Data Recorders, SSDRs), for redundancy and survival. Interconnected by IP over 8.1Mbps serial links for data and slower CANbus for backup control; really a custom-built LAN.

CLEO: Cisco router was able to fit into UK-DMC satellite's onboard network by connecting to OBC and SSDRs using common serial interfaces.

Ground: SSTL's design for its ground station LANs uses IP. Satellites communicate with PCs on LAN via S-band radio space-ground link. IP over 8.1 Mbps serial stream from downlink commercial modem goes into a rack-mounted Cisco 2621 router, which forwards IP packets onto the LAN. SSTL's ground station LAN is connected to and an integral part of SSTL's corporate IP network.

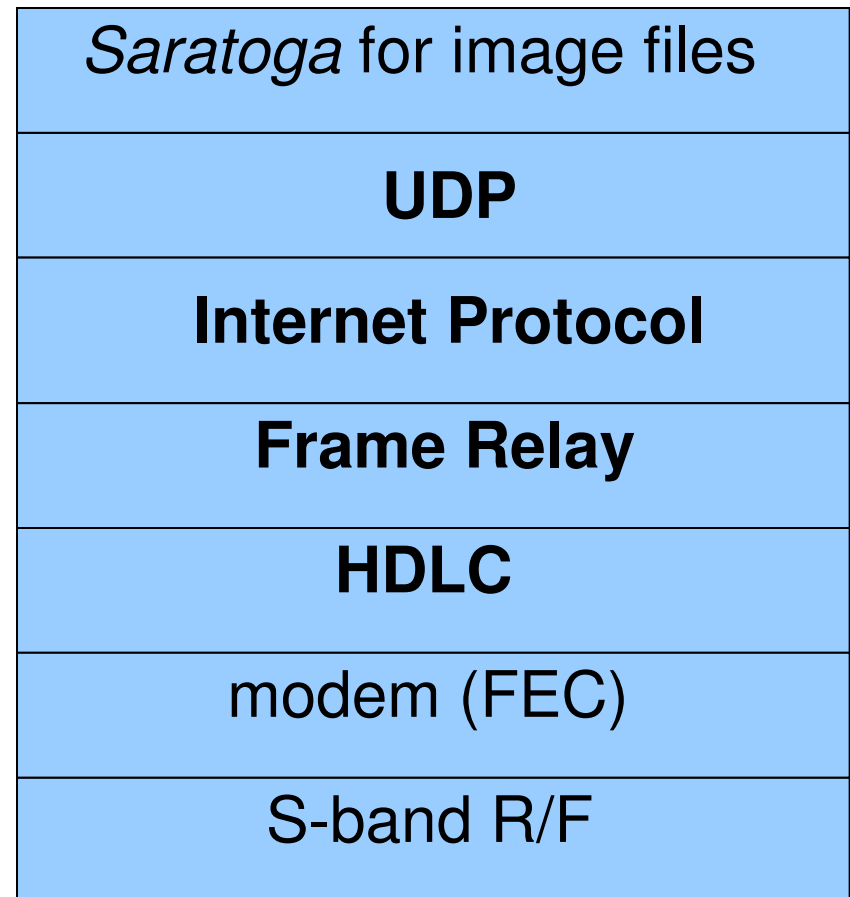
The networking stack used by DMCs

The only custom protocol in this stack is *Saratoga*, developed for rapid file transfer across dedicated private links.

(It's like the ultimate *tftp*.)

We've since described *Saratoga* to the IETF in internet-drafts.

Not at all like CCSDS custom protocol stacks for space agencies.



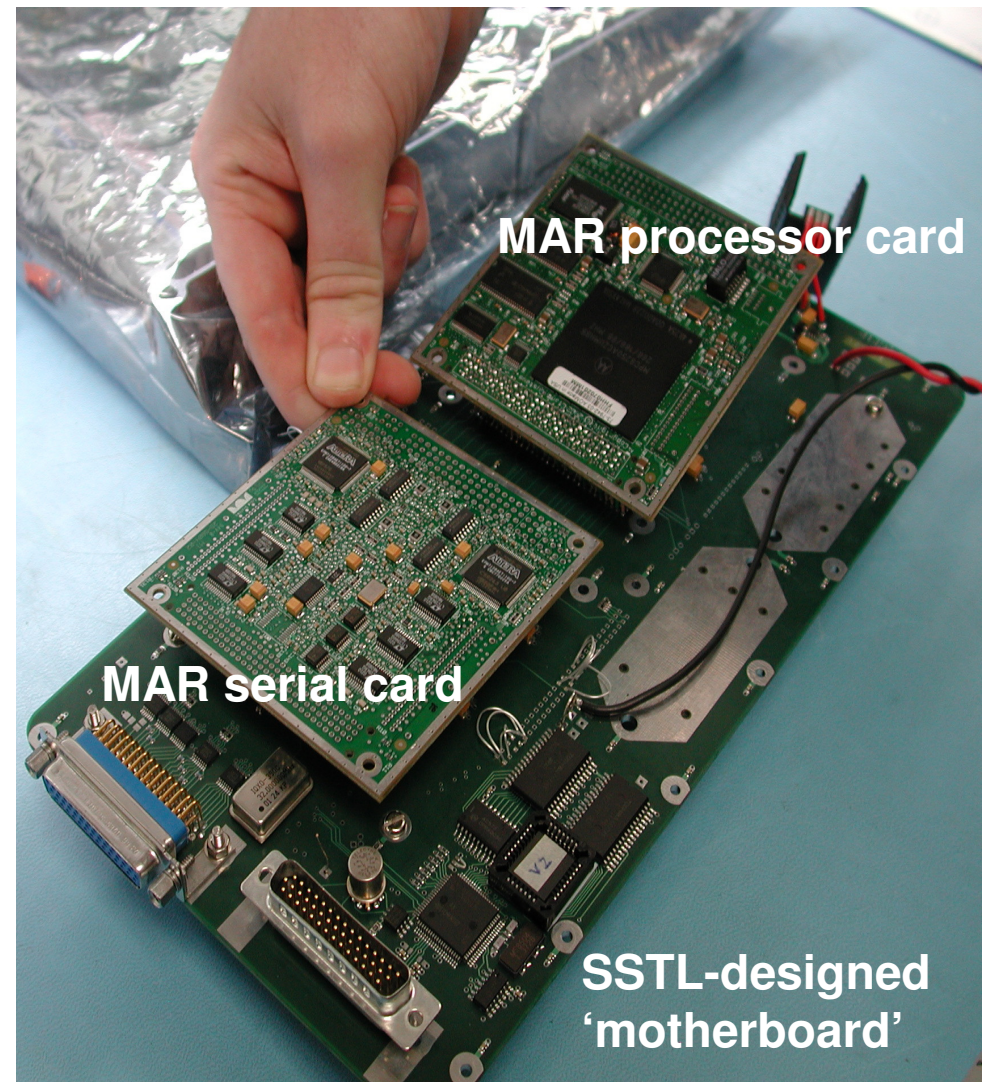
Alterations to CLEO for launch and space

No radiation hardening; low orbit environment is relatively benign.

No unique hardware design or software work done by Cisco.

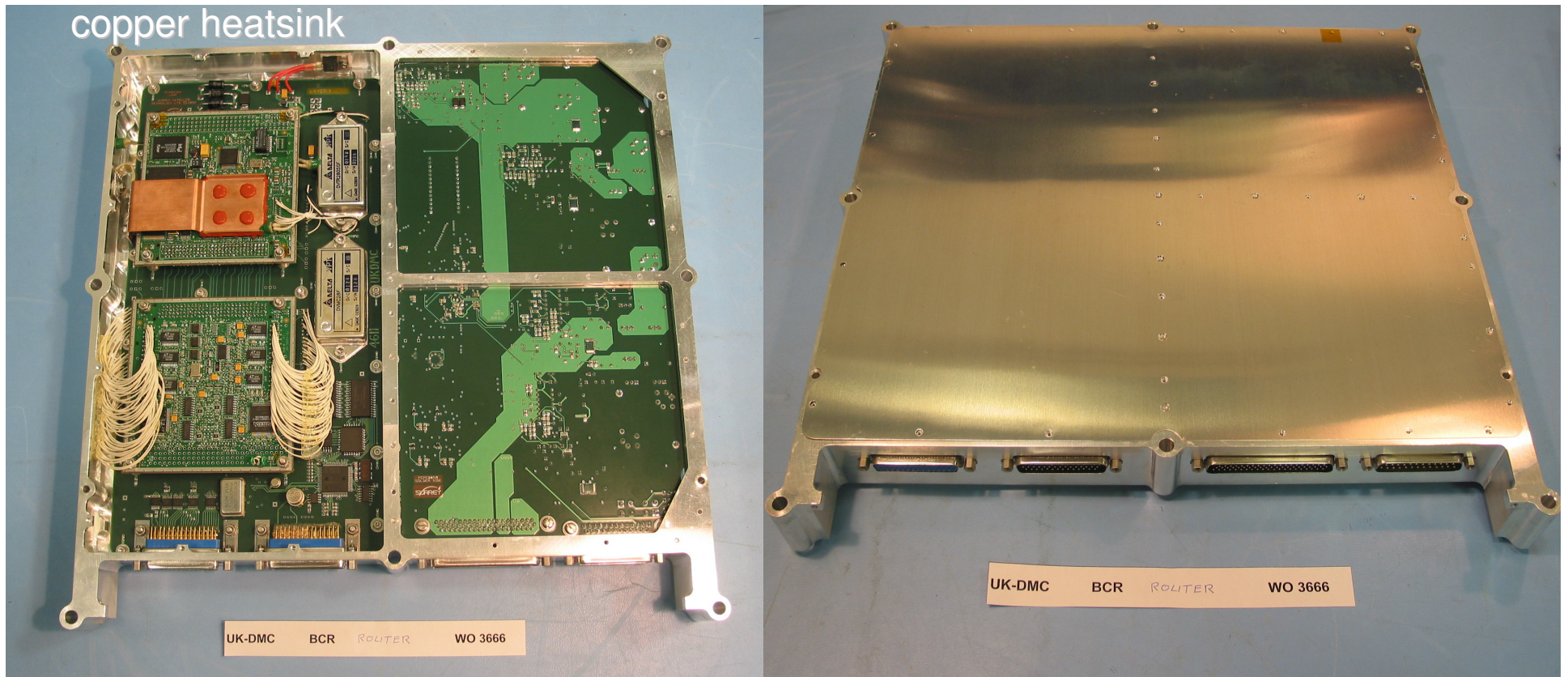
Minor physical modifications made to router and serial card.

- Flow-soldered with lead-based solder to avoid ‘tin whiskers’.
- Flat heatsink added to main processor to take heat to chassis.
- To avoid leakage in vacuum, wet electrolytic capacitors with pressure vents replaced with dry.
- Unused components removed, including plastic sockets and clock battery. Time set with NTP. Directly soldered wires are more robust for vibration/thermal cycling.



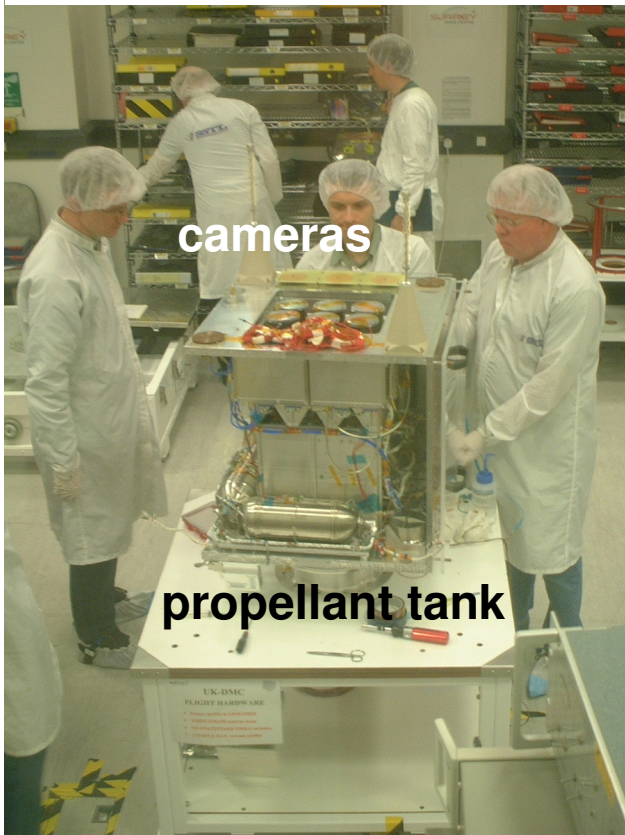
CLEO integration 2 – the payload tray

SSTL's satellites are modular stacks of identical aluminium trays, screwed together. Aluminium provides grounding, heat conduction, and structural rigidity. Satellites are built rapidly, using COTS parts, in under 18 months. Router card assembly takes up half of stackable tray.



CLEO integration 3 – testing before launch

Satellite assembly, subsystems and router operated in partial vacuum of less than 1×10^{-5} torr (1×10^{-3} Pa), temperature range of -35°C up to $+60^{\circ}\text{C}$.
Also vibration tested.



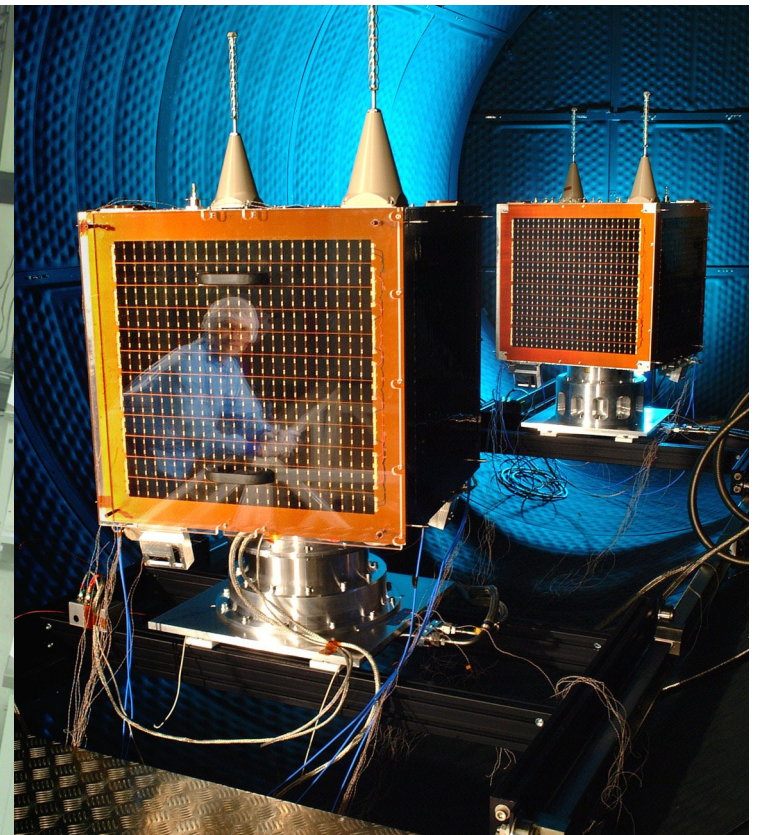
cameras

propellant tank

satellite assembly



in-house testing






vacuum chamber testing

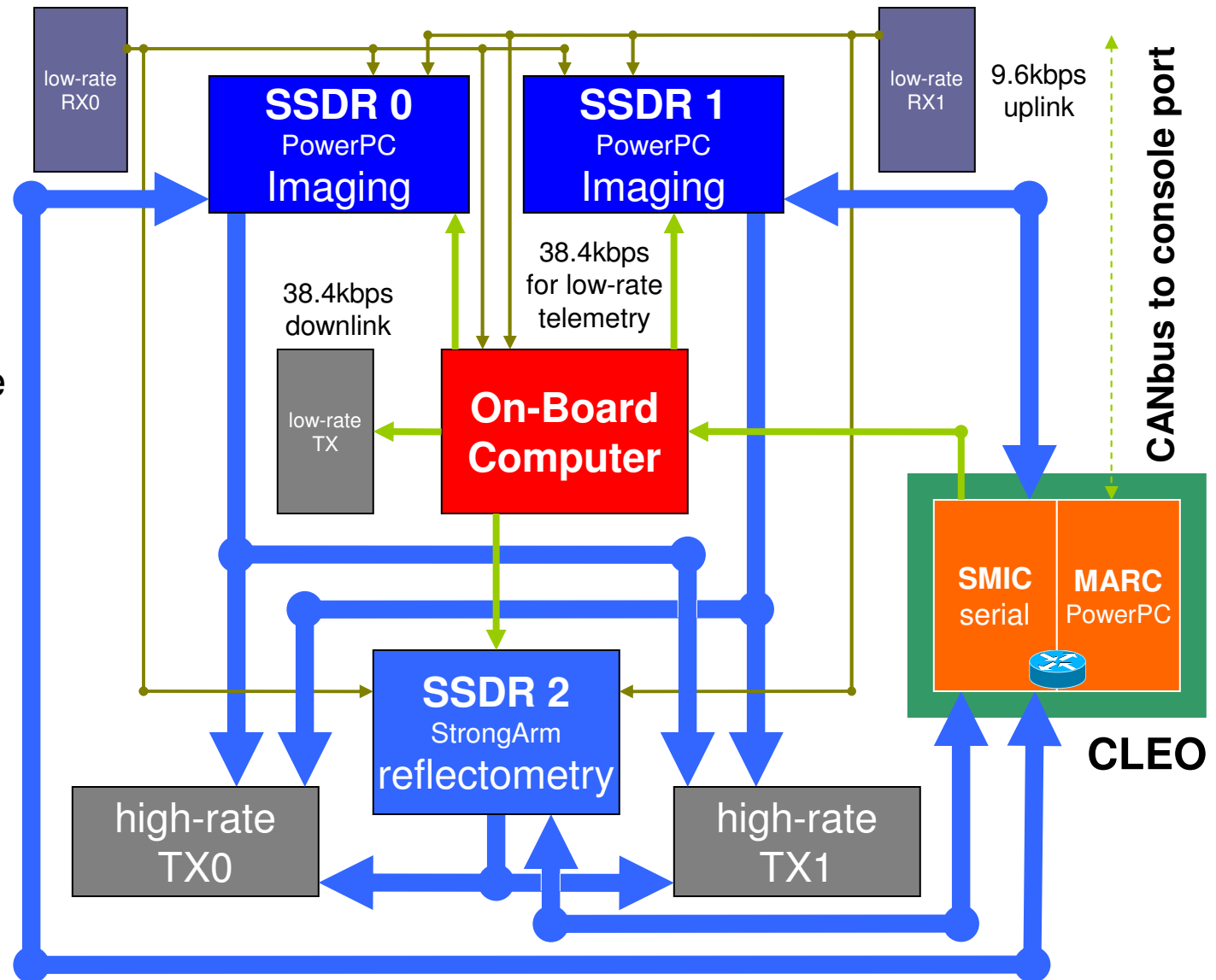
UK-DMC payloads... connected to CLEO

Redundancy in dual transmitters, dual receivers, and dual imaging computers.

CLEO uses available 'spare' connections to form a high-speed onboard network.

CANbus mesh not shown.

-  8.1Mbps
-  38400bps
-  9600bps



CLEO tested from Vandenberg Air Force Base

May-June 2004, image request and access to onboard CLEO router were tested by commercial/civil/military partners 'in the field' in tent and Humvee at Vandenberg Air Force Base in California.

Tested:

- requesting sensor data (imagery) from the UK-DMC satellite.
- use of IP for field operations.
- tasking a satellite payload (the CLEO router, accessed using mobile networking).
- failover between operations centers.

Testing and demonstration were successful. Cisco's CLEO router in orbit shown to work by third parties while testing a larger integrated 'system of systems'.



Limits to use of CLEO

CLEO is an experimental payload, normally turned OFF.

CLEO is only active when being tested during passes over ground stations, or when being used to transfer data onboard.

CLEO is a commercial product, not a space instrument.

CLEO does not contain any special instrumentation for the space environment. CLEO does not measure cumulative radiation dosage. SSTL does have some additional thermal and power draw instrumentation around the CLEO assembly motherboard.

Power is a constraint.

CLEO is powered up for around ten minutes at a time during a daytime sunlit pass to communicate with ground station using high-speed 8.1Mbps downlink. CLEO needs ~10W. High-speed downlink needs ~10W. UK-DMC power budget is only ~30W.

Can't upgrade IOS – no plans to *ever* upload 6MB router IOS software over multiple passes via 9600bps uplink.

IPv6 and IPsec testing with CLEO

IPv6 and IPsec have now been tested onboard CLEO. First to test IPv6 on a satellite, 29 March 2007.

IPv6 – CLEO, ground Cisco routers and PIX firewalls are IPv6-capable, although SSTL and UK-DMC payloads rely only on IPv4.

IPsec – CLEO and ground station routers can use this to secure unencrypted ground-space link by tunnelling IP traffic through the router.

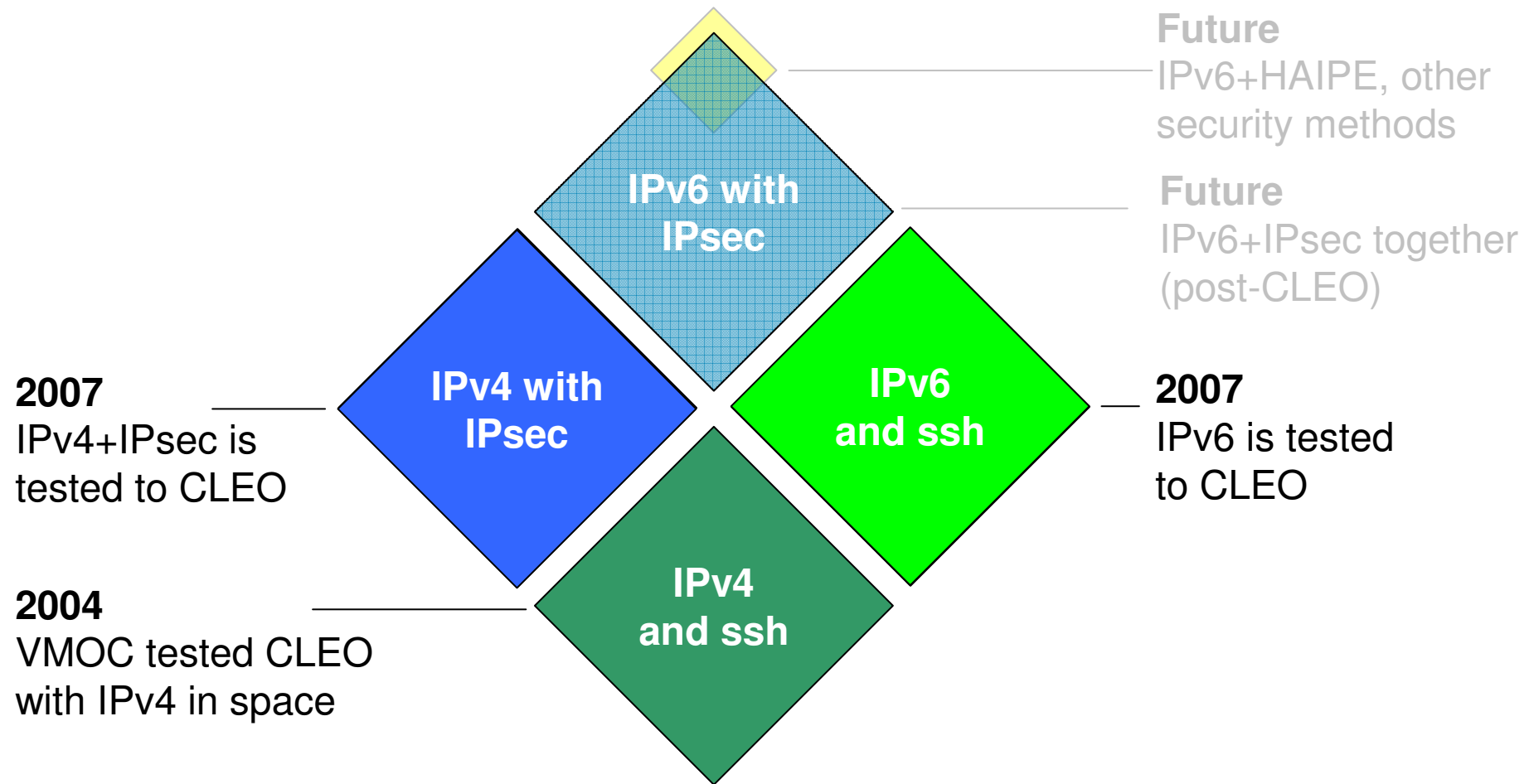
Separate frame-relay/HDLC subinterfaces are used to the satellite:

- unencrypted IPv4 and IPv6.
- IPv4 with IPv4 IPsec, able to carry IPv6 in a 6-to-4 tunnel.

(IPv6 IPsec was introduced in more recent code releases, and not flown.)

CLEO shows roadmap for IPv6 and IPsec

IPv6 and IPsec are now working in orbit



CLEO, the Cisco router in Low Earth Orbit, is able to show three of these steps.

Status of CLEO

CLEO remains operational.

CLEO was first to show IPv6 and IPsec from space.

As a secondary experimental payload, use of CLEO is on a best-effort basis, balanced against the other demands on the UK-DMC satellite. When not being tested, CLEO is simply switched off to save power.

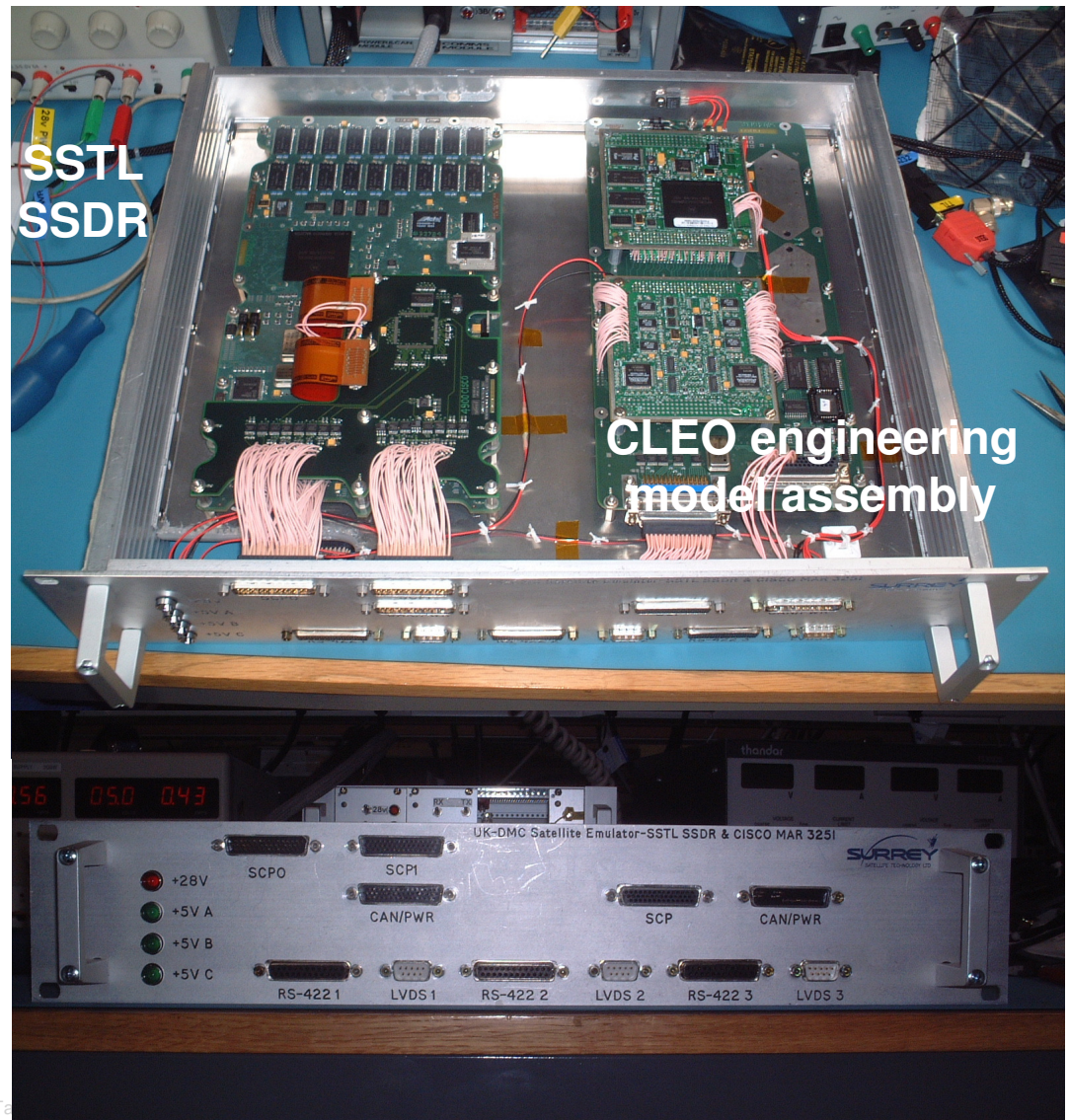
CLEO has now been in orbit for over five years.

CLEO and UK-DMC have both exceeded the planned satellite design lifetime.

CLEO has been powered up for use on more than one hundred occasions.

Ground testbed enables new development

- Ground-based testbed loaned to NASA Glenn was key to success of testing CLEO to deadline.
- IPv6 configs prepared and tested by NASA Glenn, before being copied to CLEO on orbit.
- Testbed now being used for software development on SSTL computers.
- Delay-Tolerant Networking Research Group's 'Bundle Protocol' being tested.



Delay-tolerant networking (DTN)

- DTN began intended for deep-space connectivity, now also used for opportunistic ad-hoc networks.
- Data is moved like store-and-forward email messages in 'bundles' between nodes when limited connectivity becomes available and links are up.
- DTN research group investigating this in IRTF.
- NASA Glenn has ported DTN bundling code to SSTL's onboard computers, using CLEO testbed.
- Many 'convergence' (transport) layers for DTN – SSTL's custom *Saratoga* UDP transfer is a simple, high-performing choice that runs over IP.
- **First tests of the Bundle Protocol in space, prototyping the 'Interplanetary Internet.'**



150MB image transferred from UK-DMC satellite using Bundle Protocol over *Saratoga* with proactive fragmentation, 25 August 2008. **First sensor data in bundles from space.**

TIME Magazine best inventions of the year **#9 Orbital Internet**, 10 November 2008 issue.



Beyond the success of CLEO

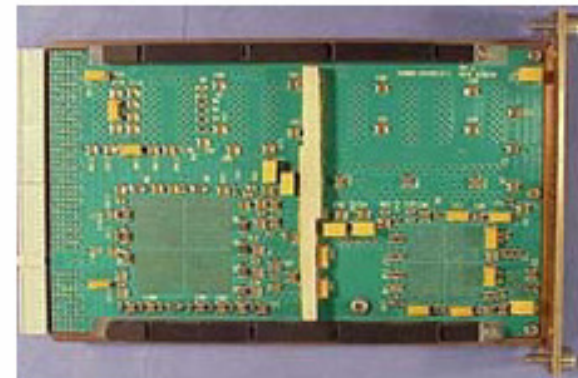
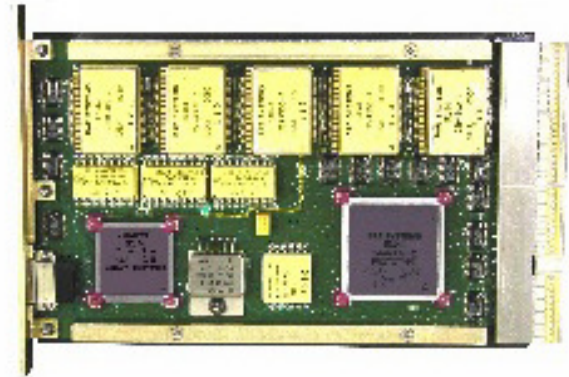
The outcome of the CLEO project and testing has encouraged Cisco Systems to prototype and evaluate IOS software running on radiation-hardened PowerPC processors and hardware *very* different from this first demonstration.

Cisco Systems is interested in working with others to take IP and routing functionality to new places... including high altitude and with *IRIS*, (IP Routing in Space) to geostationary orbit.

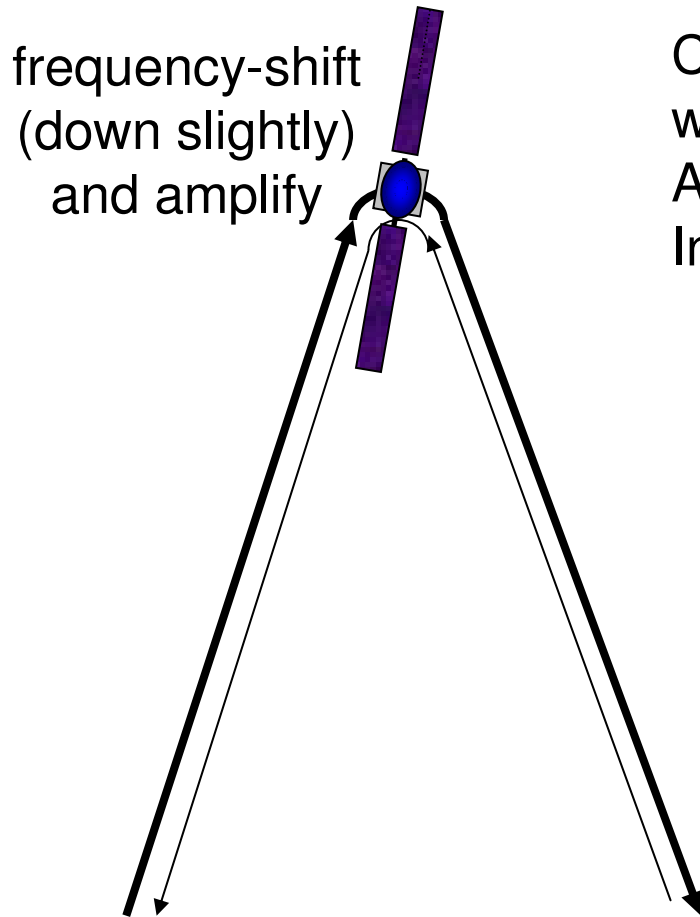
Geostationary orbit is a harsh environment – must deal with effects of radiation.

Port of IOS to a rad-hard processor

- **Aqueduct** project in cooperation with NASA Goddard, intended as proof of concept for future embedded space systems.
- Demonstrated IOS in an embedded application, using software derived from 12.3(11.4)T.
- Main processor is 133MHz PowerPC-based RAD750 from BAE Systems.

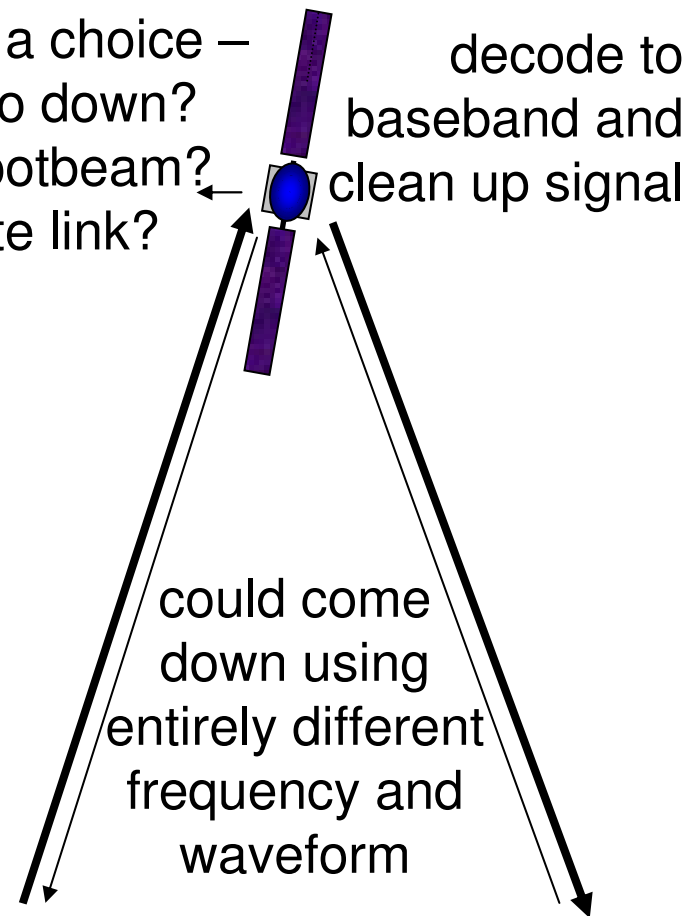


Changing geostationary satellites



traditional 'bent-pipe'
switching on ground
can lead to 'double hops'

Can make a choice –
where to go down?
Another spotbeam?
Intersatellite link?



newer 'onboard processing'
gaining some acceptance
with different tradeoffs.

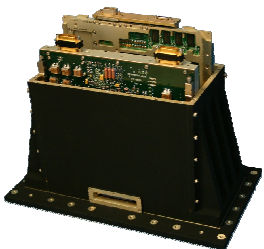
IRIS – IP Routing In Space

- Place a **custom-designed** Cisco router as a hosted payload on a commercial geostationary satellite: **Intelsat IS-14**.
- Commercial effort to support a US Army Joint Capabilities Technology Demonstration (JCTD).
- Based around a PowerPC G4 processor with custom modems.

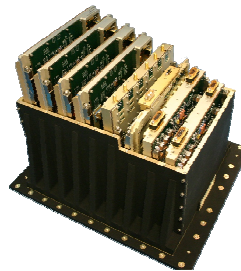


IRIS router now on Intelsat IS-14

- bolted onto the satellite for final testing, January 2009.
- launch planned for July 2009.
- first 90 days of testing for US JCTD programme.
- Then can be opened for commercial customers to evaluate.



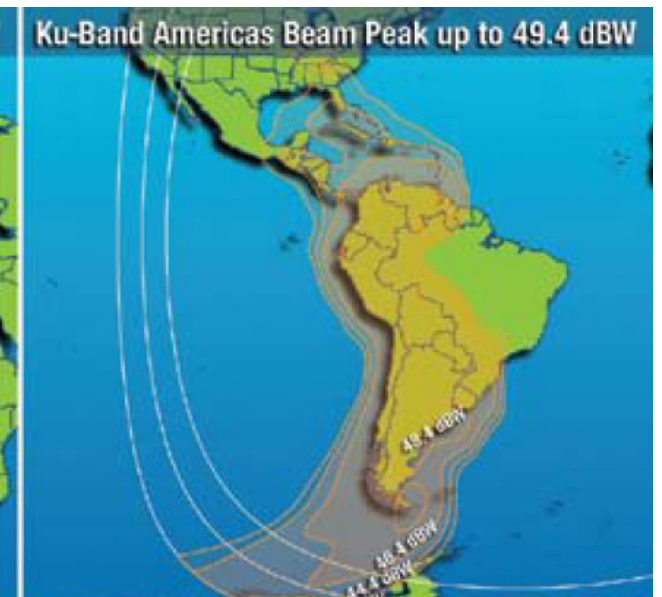
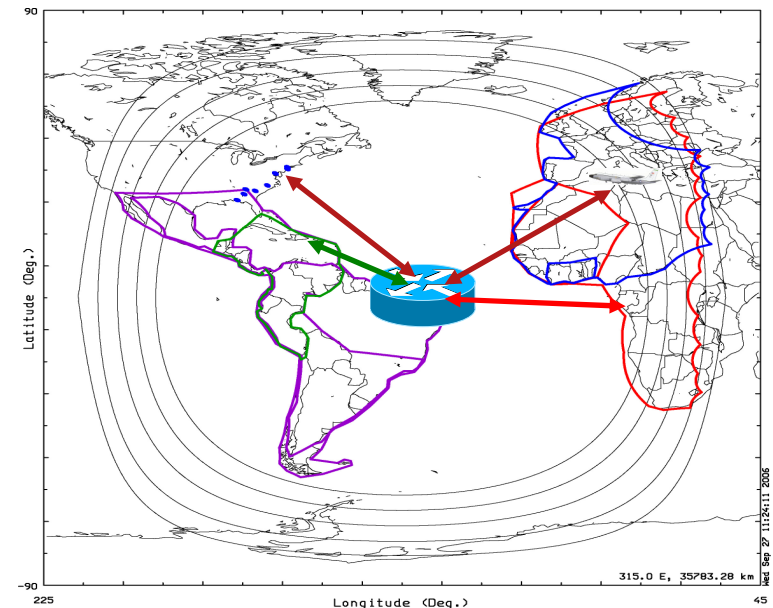
IRIS payload



IRIS expected coverage on Intelsat-14

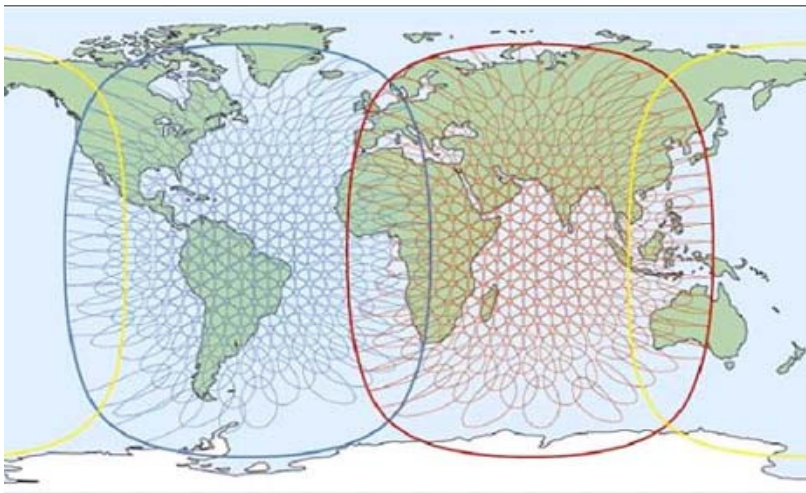
IRIS connects three of IS-14's spotbeams (one C-band, two Ku-band).

IRIS supports a number of different waveforms. Come up using one frequency and one waveform, go down using another.

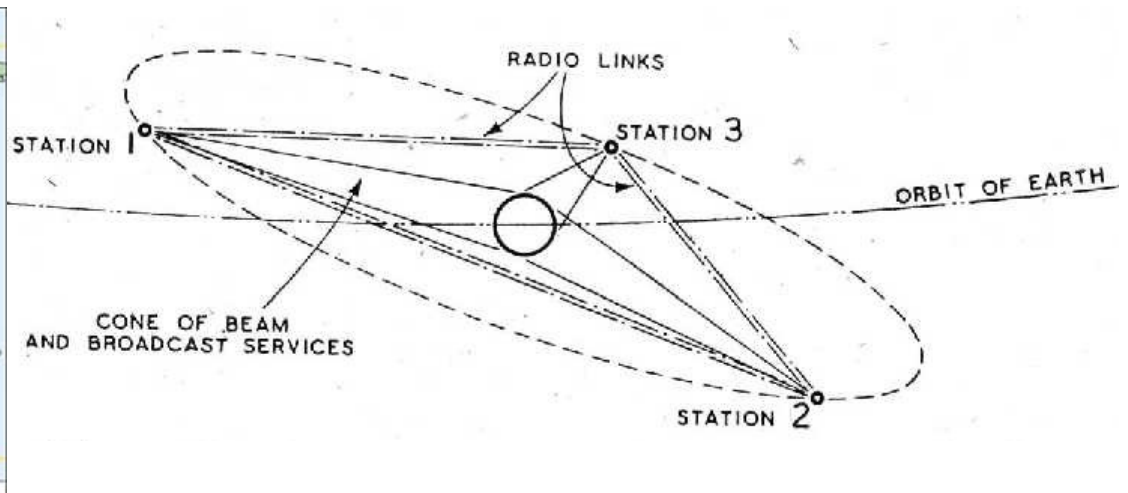


Further developments beyond IRIS

- Routers switch between multiple ports – the more interfaces, the more need for routing functionality between those interfaces.
- Many spotbeams and intersatellite links, e.g. *Iridium*, demand supporting routing functionality. Intersatellite links at GEO proposed 60 years ago!



Inmarsat BGAN spotbeams



Extra-Terrestrial Relays, Arthur C. Clarke, *Wireless World*, 1945.

Conclusions

- Cisco now has taken its first steps into the space environment in demonstrations
- First to Low Earth Orbit, and soon, entering Geostationary Orbit, to affect commercial and military users of satellite communication.
- Improving how civil space probes communicate and how the Interplanetary Internet will be built is also of interest.
- IRIS and Intelsat-14 are scheduled for launch later this year. Interesting times!

further information:

<http://www.cisco.com/go/space>

<http://www.cisco.com/go/iris>

or just google “cleo router”

Questions?

thankyou



CISCO