



Routing in space

Cisco Systems space team

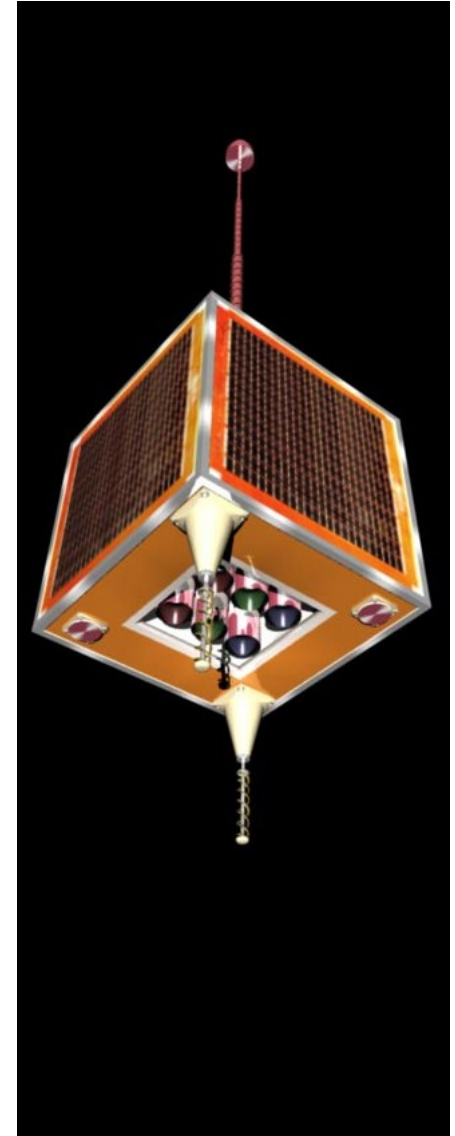


Lloyd Wood

IET seminar on military satellite communications
Savoy Place, London
12 June 2008

Executive summary

- UK-DMC satellite, with Cisco router onboard, launched with other satellites into low Earth orbit, September 2003.
- UK-DMC and sister satellites 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.
- IPv6, IPsec and DTN now being tested in orbit.
- Cisco router works well in orbit.
- Success has led to work on geostationary sats.



Overview

- Steps in extending the Internet into space.
- The Disaster Monitoring Constellation.
- CLEO – Cisco’s mobile access router.
- The existing network environment for the DMC.
- How the Cisco router was fitted to the satellite.
- Virtual Mission Operations Center demonstration.
- Latest testing using CLEO – IPv6, IPsec, DTN.
- Further developments beyond CLEO.

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 SSTL's UoSAT-12* (2000). This encourages SSTL to adopt IP.
- Cabletron router on Russian module of ISS. NASA uses IP in shuttle experiments, e.g. VoIP with Cisco SoftPhone tested from *Atlantis* (Feb 2001). These culminated in CANDOS,* tested onboard *Columbia* (Jan 2003).
- NASA gets SpaceDev to launch CHIPSat (Jan 2003).
- SSTL adopts IP with DMC (AISAT-1 launched 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.
- MidSTAR-1* and SSTL's CFESat launch (March 2007).

*Keith Hogie's team at NASA Goddard was instrumental in use of IP in these projects.

Disaster Monitoring Constellation



Disaster Monitoring Constellation (DMC)

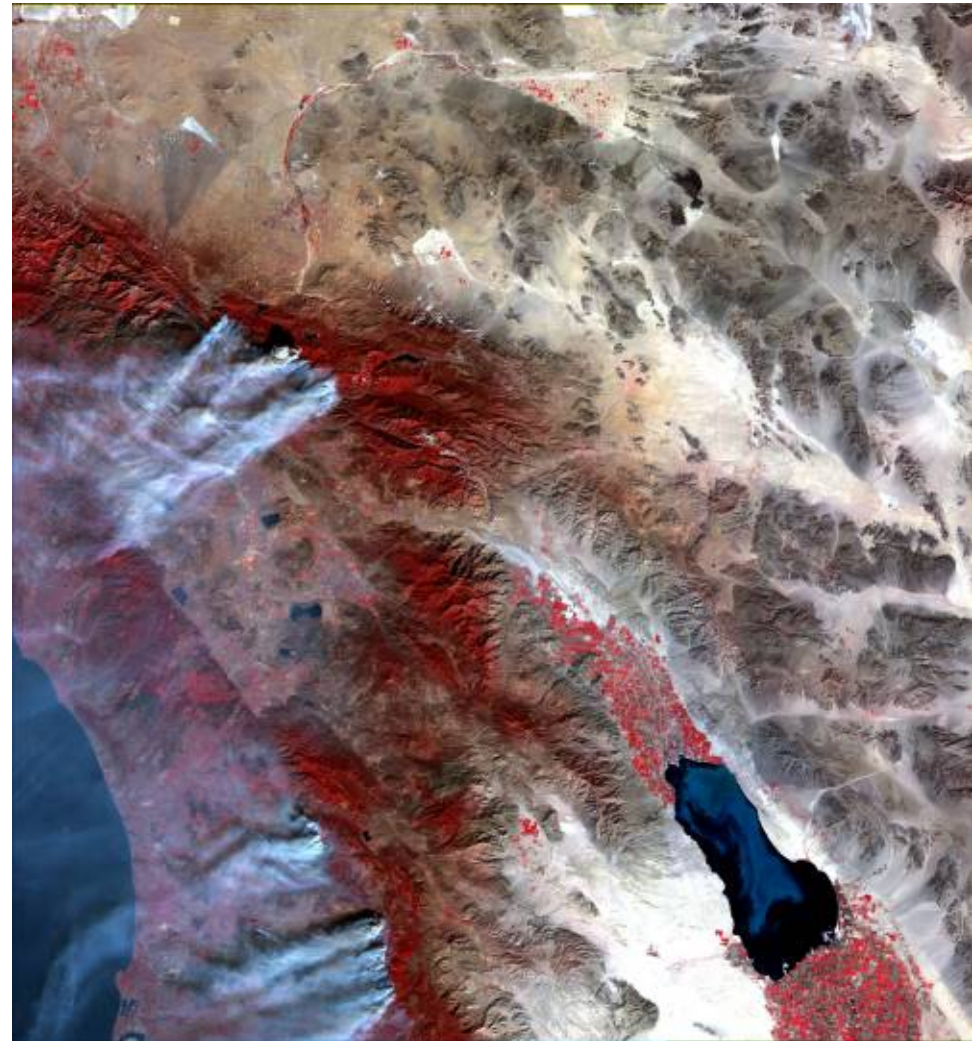
www.dmcii.com

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

The 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 satellite constellation launches

Five satellites launched so far. Similar base designs and subsystems, with custom modifications for each country.

Satellites launched from Plesetsk in Siberia on affordable shared Russian Kosmos-3M launches:

November 2002: AISAT-1 (Algeria)

September 2003: UK-DMC, NigeriaSAT-1
and BilSat (Turkey)

October 2005: Beijing-1 (China)

Satellites and ground stations in each country use Internet Protocol (IP) to communicate. Earth images delivered to ground stations via UDP-based file transfer.

SSTL migrated from AX.25, as used on previous missions. Use of IP makes a natural fit with Cisco's IP router onboard UK-DMC satellite.



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.

How the Cisco router was fitted to the satellite



What is the CLEO router?

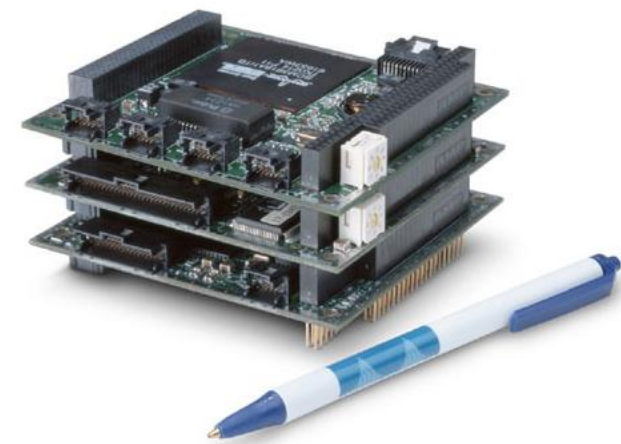
A Cisco 3251 Mobile Access Router (MAR). The MAR is a commercial off-the-shelf (COTS) product family – 3251 and 3220 series. Runs Cisco's IOS (Internetwork Operating System) router code – version 12.2(11)YQ.

The 3251 MAR features:

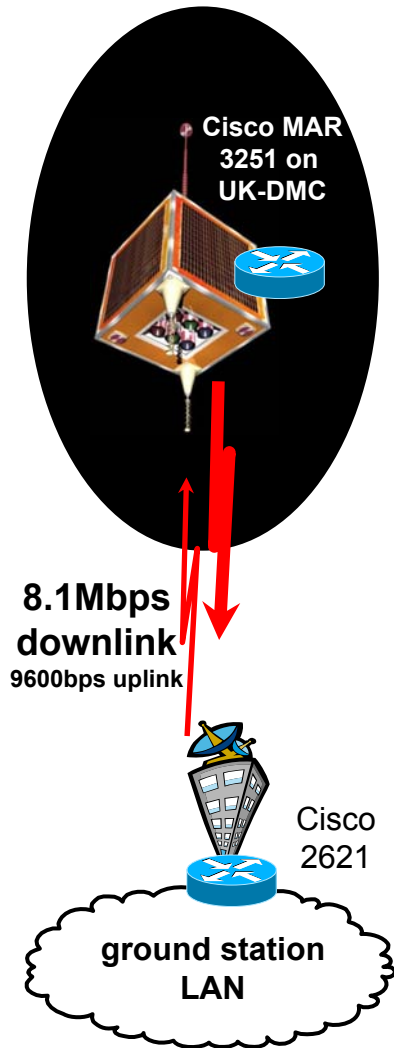
- 210MHz Motorola processor.
- Built-in 100Mbps Ethernet.
- PC/104-Plus interfaces and form factor.
- Additional stackable 90mm x 96mm cards (serial, Ethernet, power supply, WiFi, etc.)

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, SSTRs), 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 SSTRs 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.

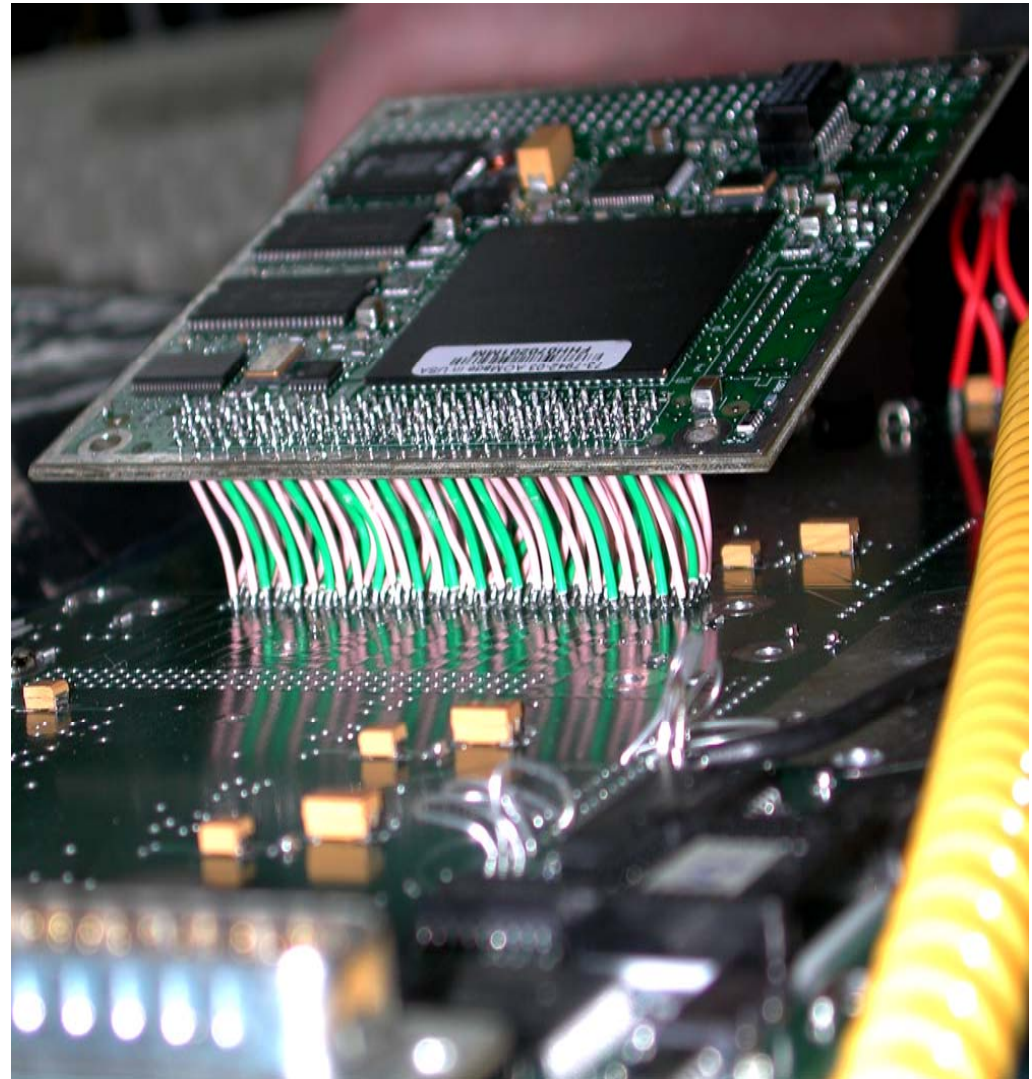
Alterations to CLEO for launch and space

No radiation hardening; low orbit environment is relatively benign.

No unique hardware design or software work done by Cisco.

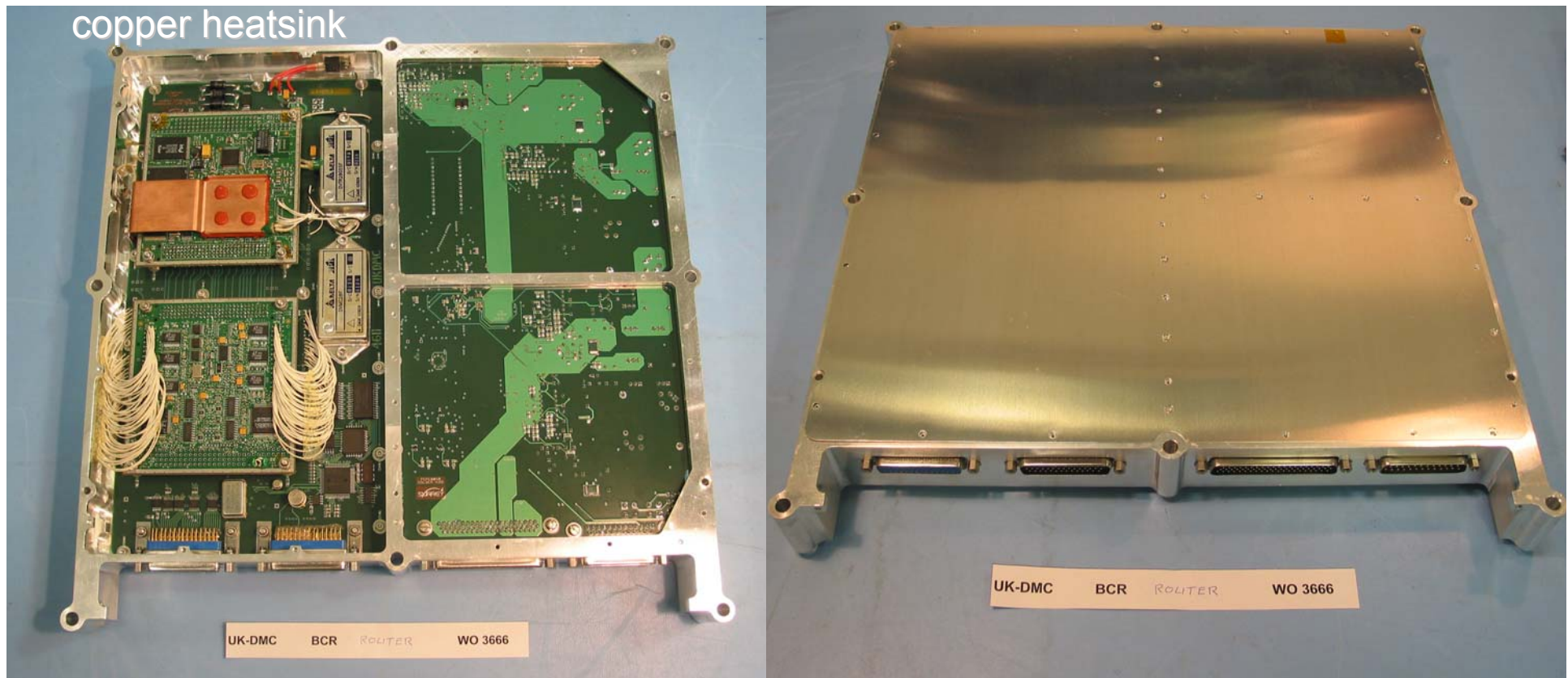
Minor physical modifications made to router and serial card.

- 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 – 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.



VMOC and Vandenberg demonstration



Virtual Mission Operations Center (VMOC)

Software developed by General Dynamics intended to task satellites and provide imagery via a simple GUI interface for military users.

VMOC was rated second out of 120 projects in importance by the US Office of the Secretary of Defense, Rapid Acquisition Incentive - Network Centric (RAI-NC) program. So became one of four pilots receiving advance funding.

VMOC intended for use with TacSat-1 (not yet launched), and then TacSat-2 (launched Dec 2006). UK-DMC provided early opportunity to test VMOC.

VMOC requests images of ground from SSTL mission planning system for DMC satellites. Images are taken for VMOC by UK-DMC only. VMOC monitors UK-DMC satellite telemetry and accesses CLEO router.

VMOC is simply an IP-based application for satellites, using an available IP-based satellite infrastructure!



VMOC demo, Vandenberg Air Force Base

May-June 2004, VMOC, image request and access to onboard payload (router) were tested by coalition of partners 'in the field' in tent and Humvee at Vandenberg Air Force Base in California.

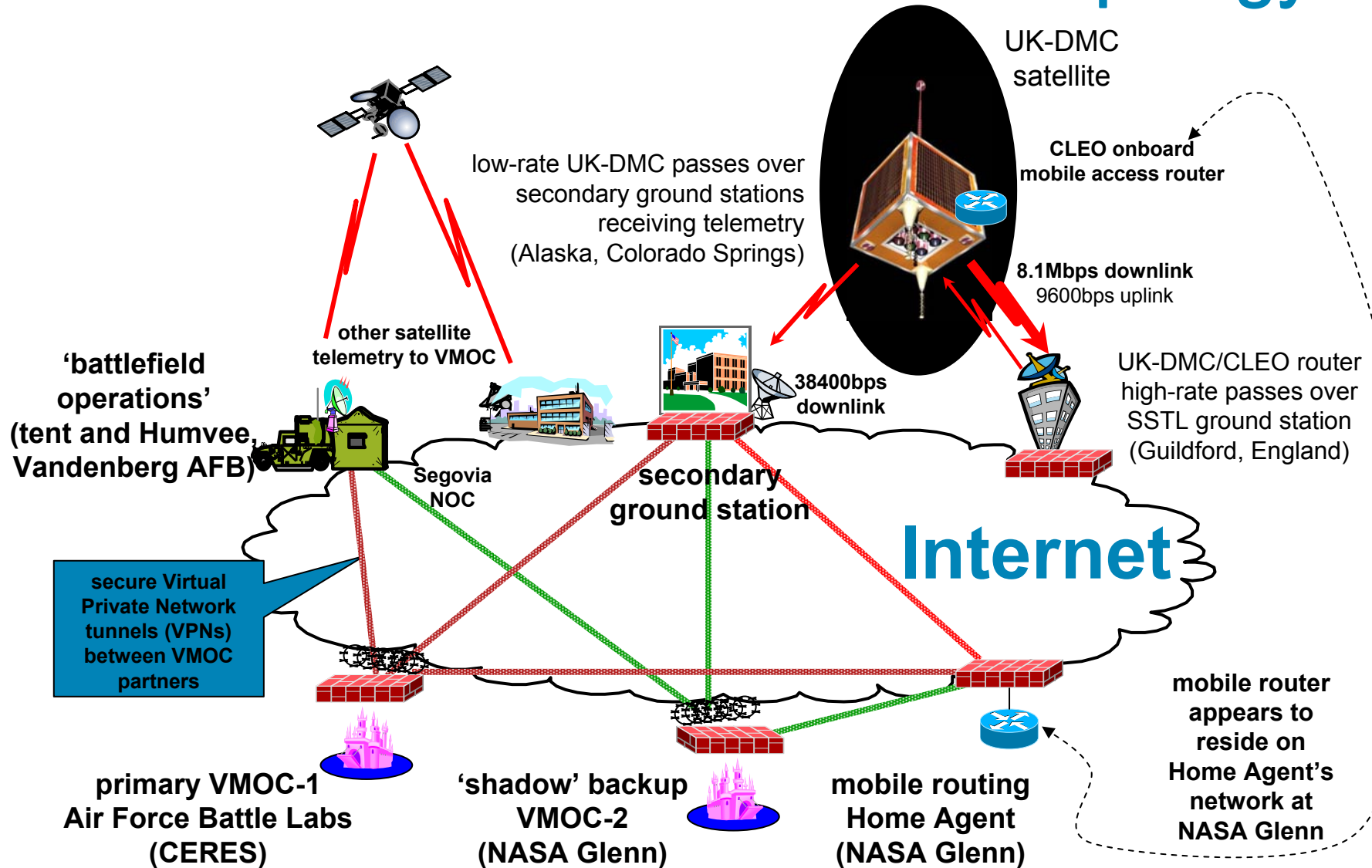
Tested:

- 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 multiple VMOCs.

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'.



VMOC demonstration network topology



CLEO and VMOC – meeting needs of participants

Commercial

Cisco Systems
Show that a commercial
COTS Internet router can
work in space.

Civil

NASA Glenn
Demonstrate utility of
IP and mobile routing
for satellite TT&C.

Military

Air Force Space Battlelab
Test the Virtual Mission
Operations Center in the
field and task space asset.



Cisco gets its router
launched as secondary
experimental payload.

NASA Glenn uses router
in space to test mobile
routing for satellites.

VMOC is tested across
Internet from Vandenberg
with CLEO & UK-DMC.

CLEO router works in space. VMOC works with space asset. Mission success!

Limits to use of CLEO

As a secondary experimental payload, CLEO spends most of its time turned off. CLEO is only active when being tested during passes over ground stations, or when being used to transfer data between SDRs.

The mobile router 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.

Available satellite 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.

Onboard software cannot be easily upgraded – no plans to ever upload 6MB router IOS software over multiple passes via 9600bps uplink.

Status of CLEO

CLEO remains operational.

IPv6 and IPsec have now been tested in orbit.

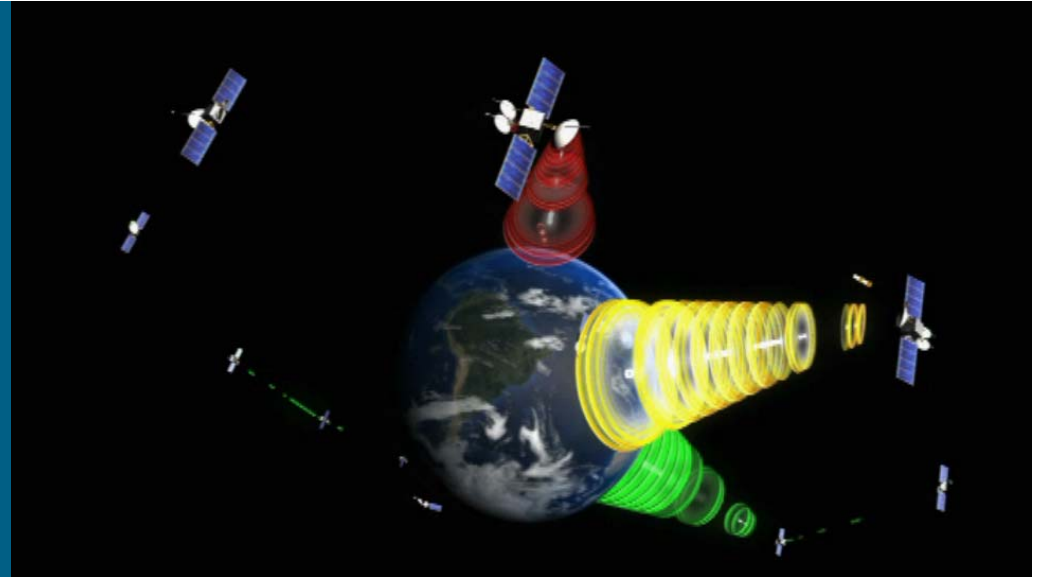
As a secondary experimental payload, use of CLEO is on a best-effort basis, balanced against the other demands on the UK-DMC satellite. When not being tested, CLEO is simply switched off to save power.

CLEO has now spent over four years in orbit.

Operation of CLEO has continued over three years.

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

Further developments



IPv6 and IPsec testing with CLEO

**IPv6 and IPsec are now being 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. (*ssh* to CLEO and a passworded web interface were configured in 2004.)

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

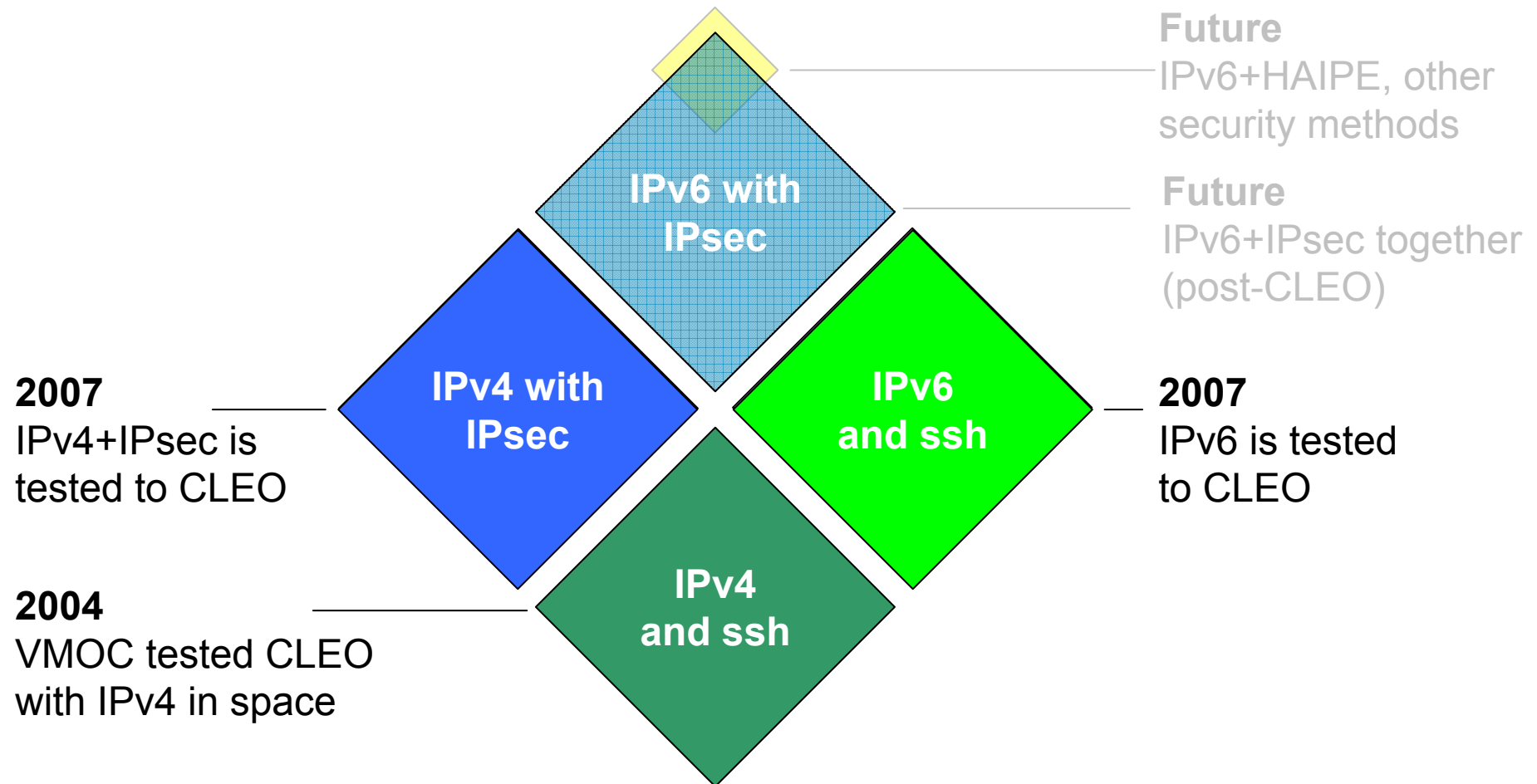
- unencrypted IPv4 and IPv6.
- IPv4 encrypted with IPv4 IPsec, able to carry IPv6 in a 6-to-4 tunnel.

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

Could also use SNMP and MIBs to show that a satellite payload can be managed just as you would manage a terrestrial network asset.

Just how far can we take CLEO?

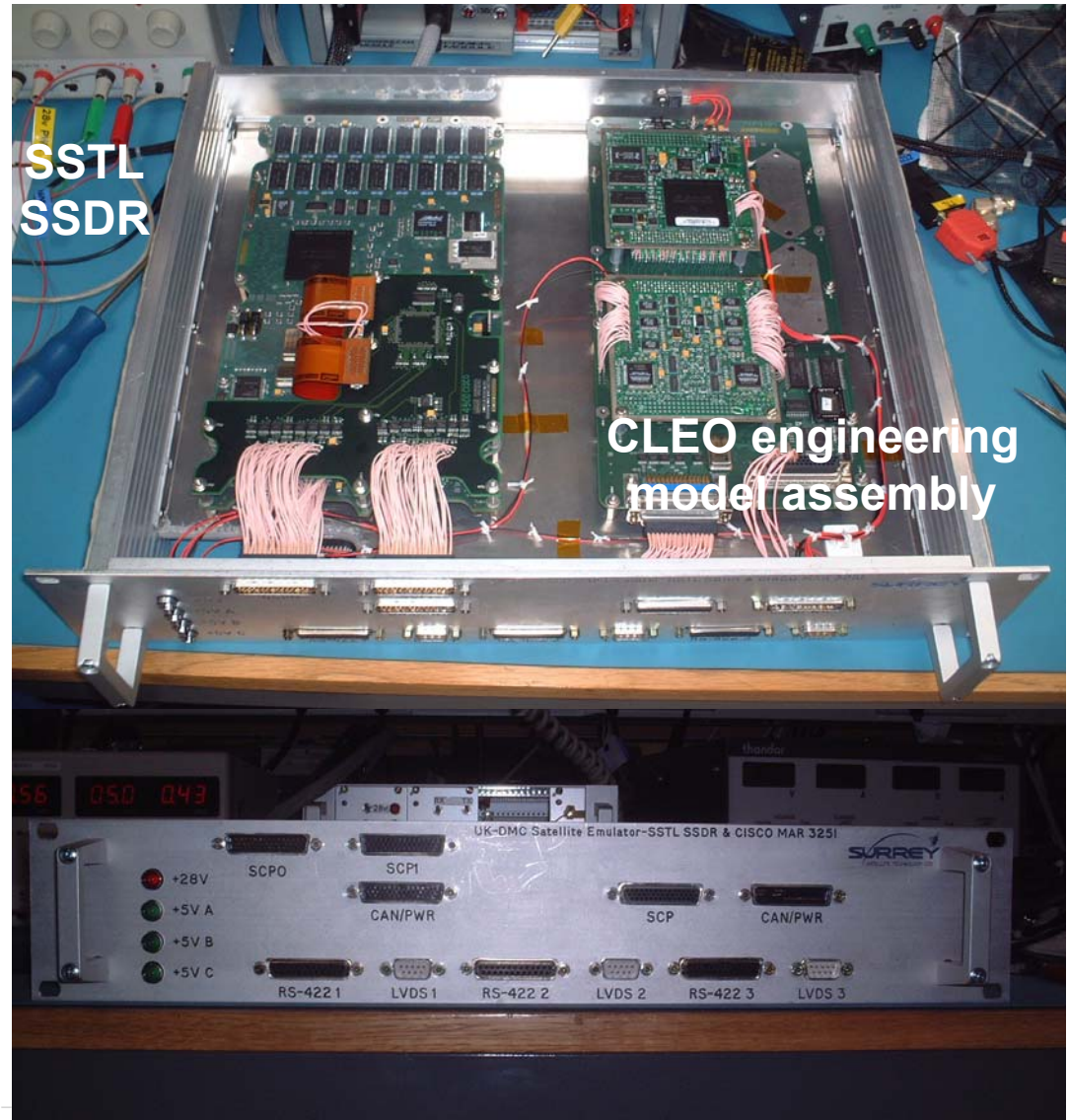
IPv6 and IPsec are now being tested in orbit



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

Ground testbed enables new development

- Ground-based testbed loaned to NASA Glenn was key to success of VMOC testing to deadline.
- IPv6 configs prepared and tested by NASA Glenn, before being copied to CLEO on orbit.
- Testbed now being used for software development.
- Focus on running Delay Tolerant Network 'bundle' protocol over IP.



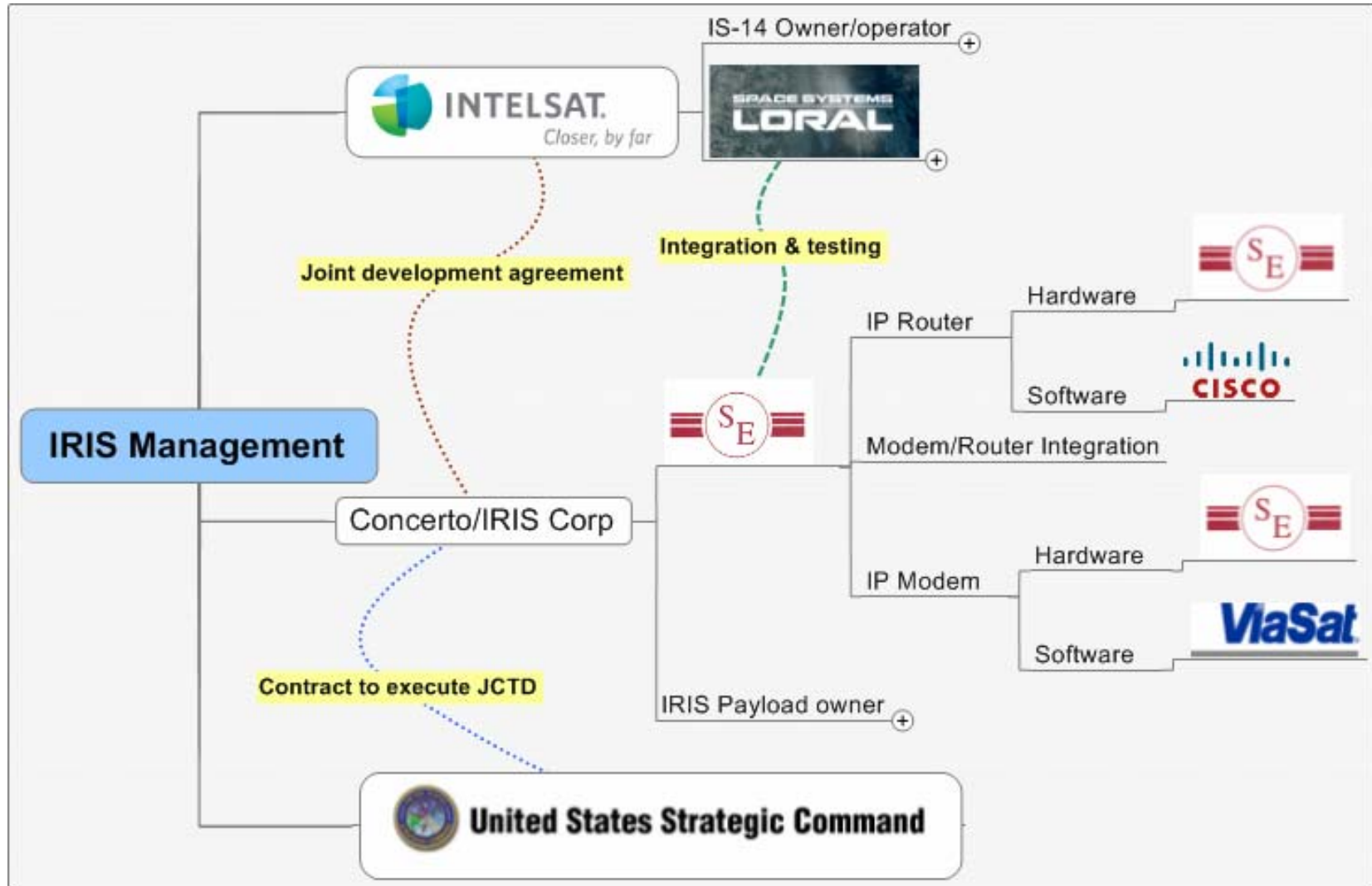
Delay-tolerant networking (DTN)

- 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.
- NASA Glenn has ported DTN bundling code to SSTL's onboard computers, using CLEO testbed.
- Choice of 'convergence' (transport) layers for DTN – UDP more useful here than TCP; SSTL's custom *Saratoga* UDP transfer (which was written to replace CCSDS CFDP) is a simple, high-performing choice.
- DTN code tested on UK-DMC satellite January 2008, using *Saratoga* for high-performance data transfers.

IRIS – IP Routing In Space

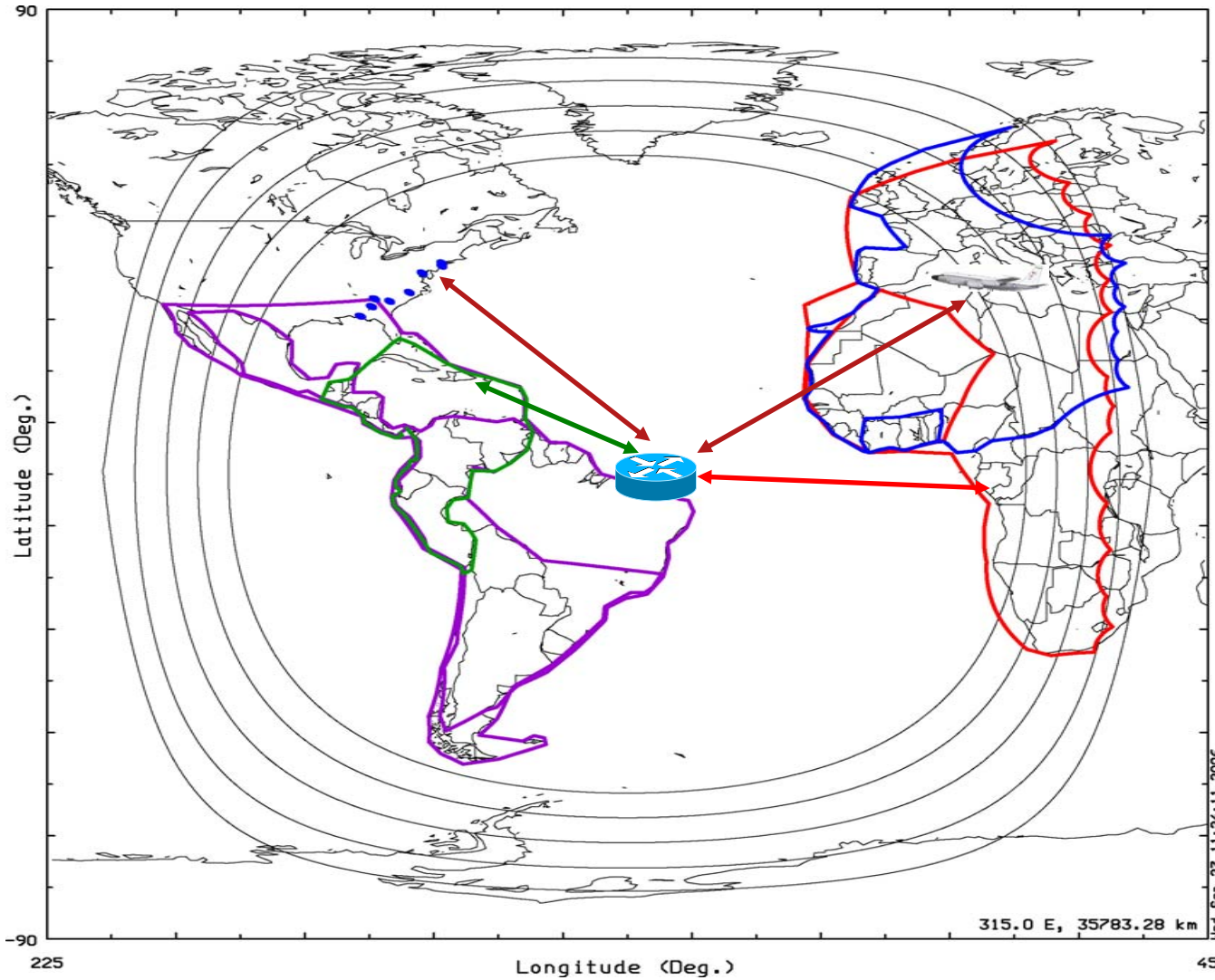
- A US Strategic Command study investigated putting payloads on commercial communications satellites for military use.
- Venture partners with funding pursued this idea, with the aim of having the military as a customer.
- Targeting Intelsat-14 (planned for 2009), with a router in geostationary orbit. Further satellites to follow. Run as a commercial development effort.
- Based around a PowerPC G4 processor. Increased use of FPGAs and ASICs in later payloads, which are also expected to add laser intersatellite links.

Partners in IRIS



IRIS hardware development by SEAKR Engineering in Colorado.

IRIS expected coverage on Intelsat-14



further information:

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

<ftp://ftp-eng.cisco.com/lwood/cleo/README.html>

or just google “cleo router”

Questions?

thankyou



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