CLEO

Cisco router in Low Earth Orbit

Adopting Internet standards for orbital use

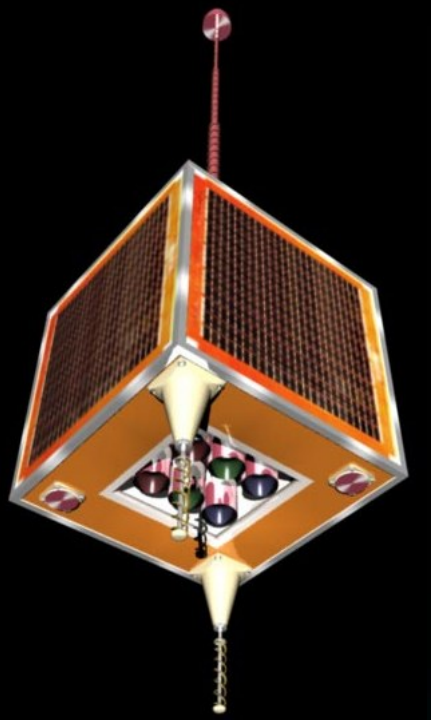
Lloyd Wood, space team
Cisco Systems Global Defense, Space, and Security

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

19th Annual AIAA/USU Conference on Small Satellites,

SSC05-IV-03, Tuesday 9 August 2005

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 internetworking of satellite and router tested and validated by international collaboration and demonstration at Vandenberg Air Force Base, June 2004.
- IP works for satellite and payload communication and control.
- Cisco router works in orbit.

Overview

Cisco.com

- The disaster monitoring constellation (DMC)
- Steps in extending the Internet into space
- The existing network environment for the DMC
- Cisco router, modifications, satellite integration
- Work before and after launch
- Virtual Mission Operations Center
- Vandenberg demonstration
- Awards won by demonstrations and testing
- Timeline, limitations, current status, future plans

Images shared by other organisations are used with thanks.

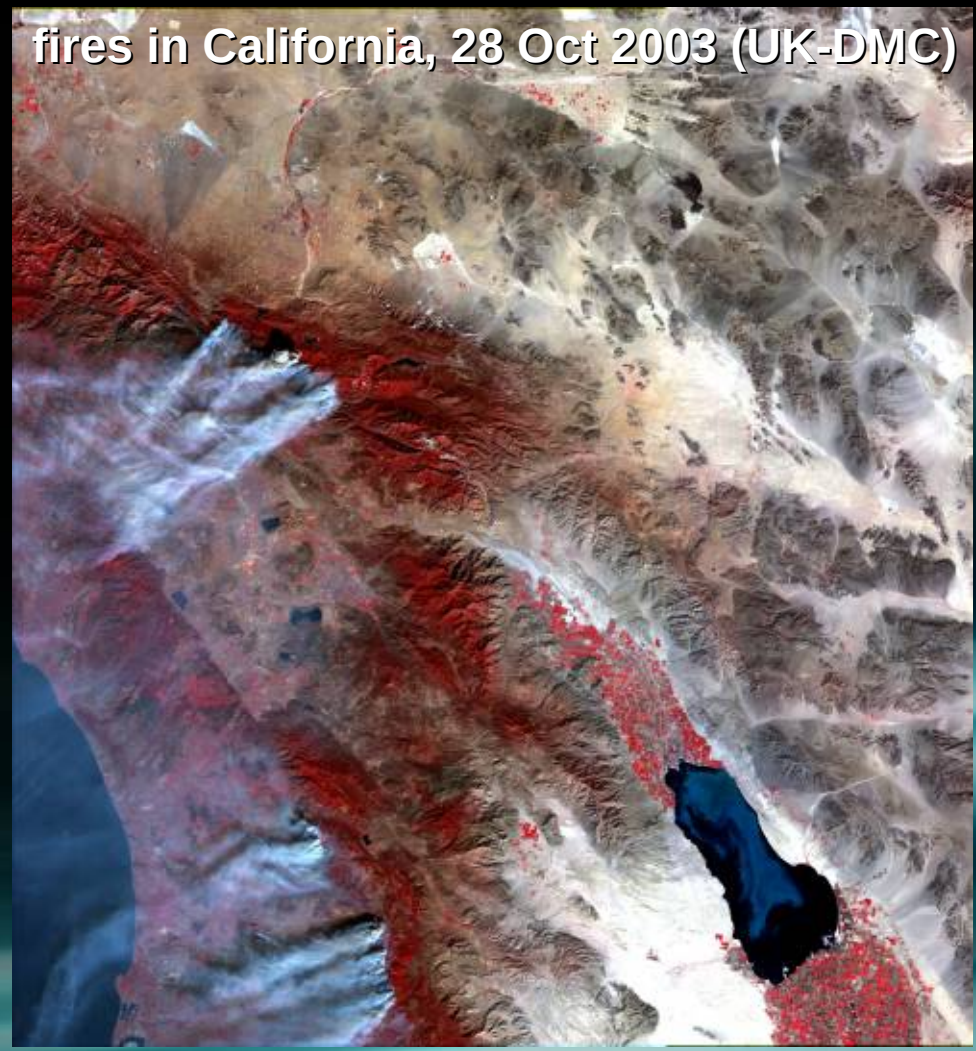
Disaster Monitoring Constellation (DMC)

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

The satellites share a sun-synchronous orbital plane for rapid daily large-area imaging (600km swath width with 32m resolution). Can observe effects of natural disasters.

Government co-operation: Algeria, Nigeria, Turkey, UK. Chinese contribution being built.

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



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

http://www.dmcii.com/

DMC can image anywhere on Earth

Palm Island Resort, Dubai, 14 Dec 2003 (UK-DMC)

Three Gorges Dam, China, July 2004 (UK-DMC)

http://www.dmcii.com/

DMC satellite constellation launches

Four satellites launched so far. Similar base designs, with modifications for each country.

Satellites launched from Plesetsk in Siberia on affordable shared Russian Kosmos-3M launches:
November 2002: AlSAT-1 (Algeria)
September 2003: UK-DMC, NigeriaSAT-1 and BilSat (Turkey)

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

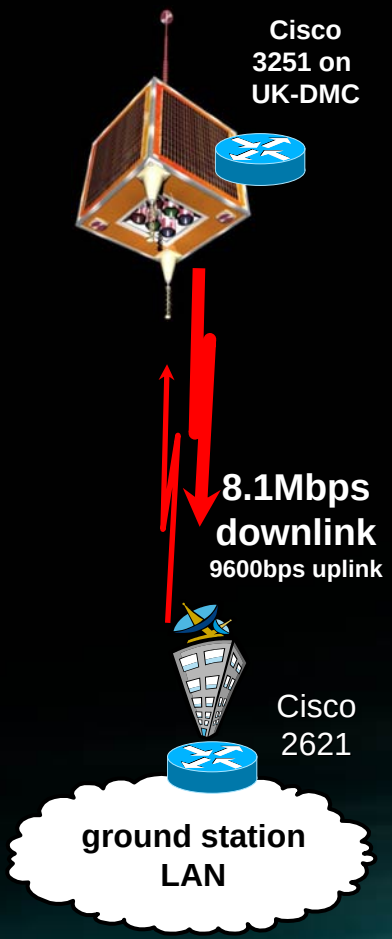
SSTL migrated from AX.25, as used on previous missions. Use of IP makes a good fit with Cisco's IP router onboard UK-DMC satellite.

Extending the Internet into space

- NASA JPL gives DERA's STRV-1b IP address (1996).
- NASA Goddard flies IP on SSTL's UoSAT-12 (2000).
- Cabletron router on Russian module of ISS. NASA uses IP in shuttle experiments, last being CANDOS (tested onboard Columbia Jan 2003).
- NASA gets SpaceDev to launch CHIPSat (Jan 2003).
- SSTL adopts IP with DMC (AlSAT-1 launched Nov 2002), UK-DMC and others (launched Sep 2003).
- Cisco and SSTL fit CLEO mobile access router on UK-DMC satellite, alongside imaging payloads.

Existing network environment for the DMC

Cisco.com



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 part of SSTL's corporate IP network.

What is the CLEO router?

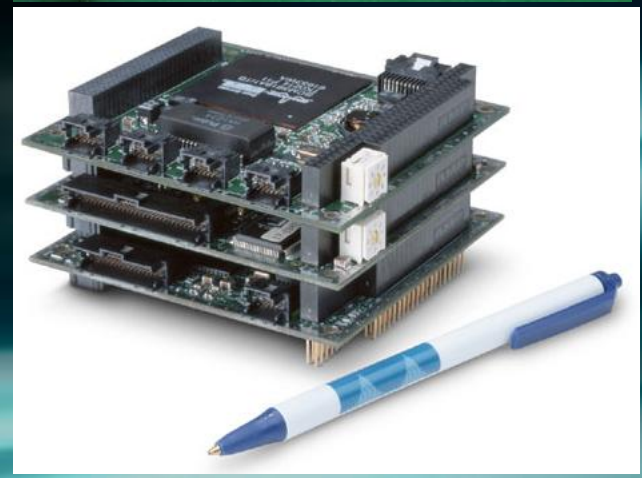
Cisco.com

A Cisco 3251 Mobile Access Router (MAR). The MAR is a commercial off-the-shelf (COTS) product family.

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

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.)



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.

Earlier tests of the mobile access router

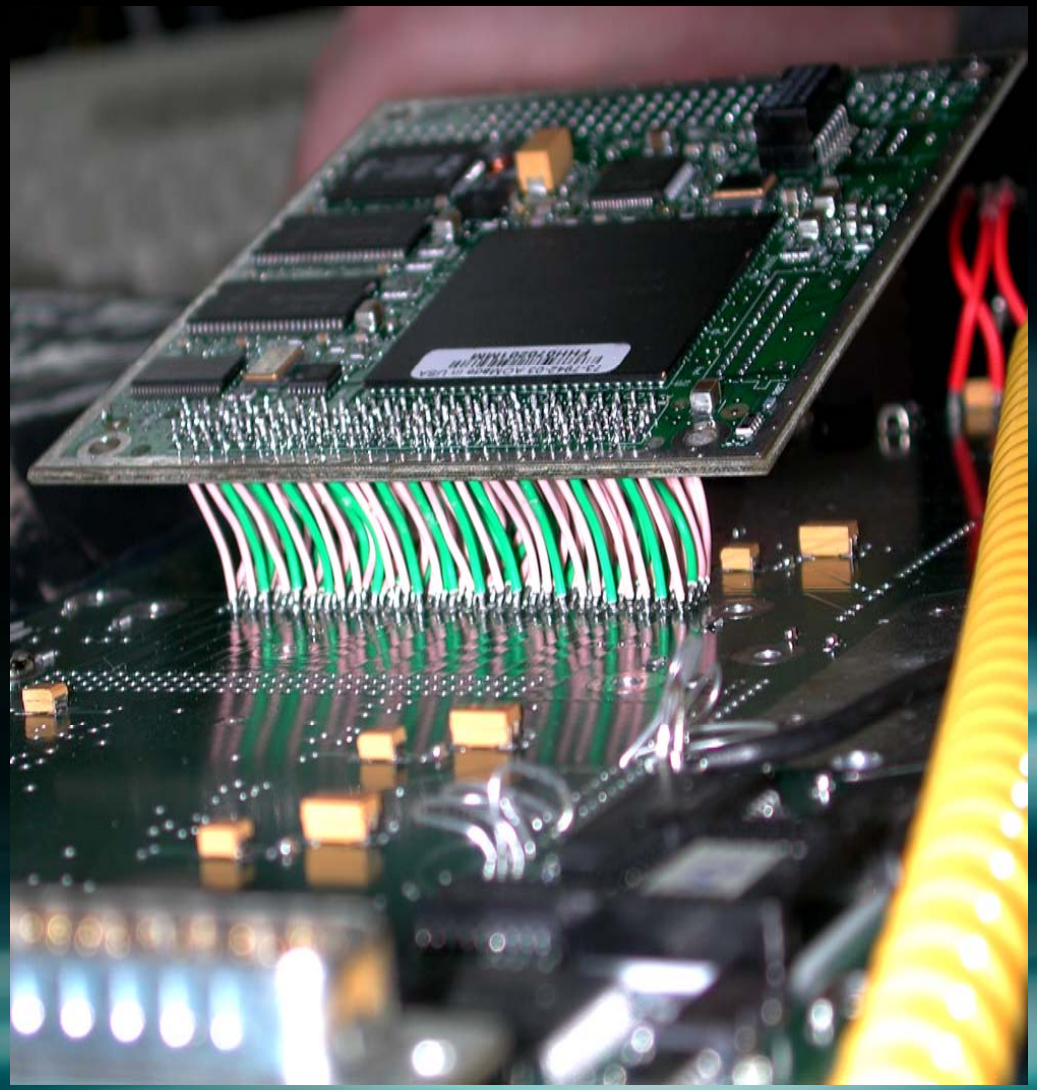
Cisco.com

MAR previously tested for US Coast Guard by NASA Glenn Research Center onboard *Neah Bay* icebreaker in Great Lakes. Used mobile routing to roam seamlessly between wired network when docked, and *Globalstar* satellite and long-range WiFi links when sailing.

Alterations to CLEO for launch and space

Cisco.com

- *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.



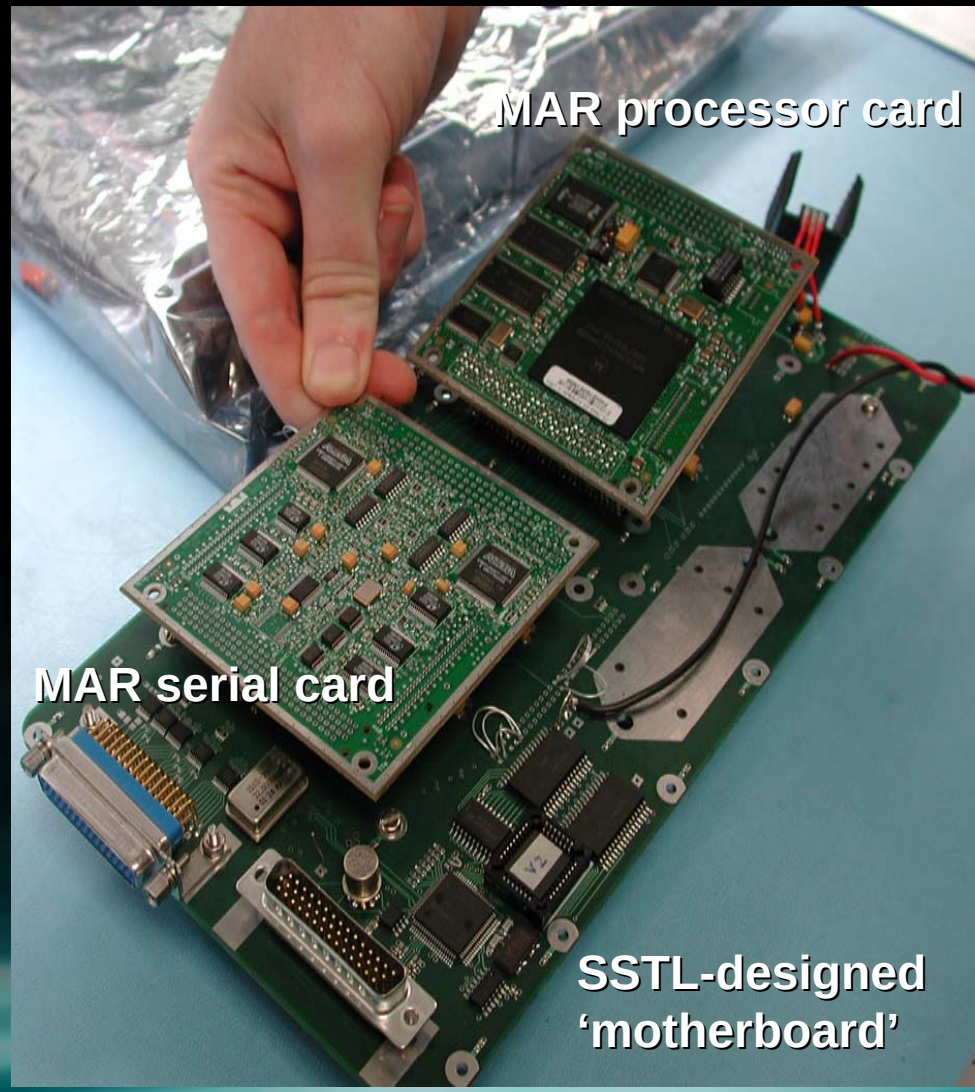
CLEO integration 1 – the router assembly

Cisco.com

MAR processor card and serial card wired to ‘motherboard’ designed by SSTL.

‘Motherboard’ provides physical mounting, power, serial connections and serial/CANbus interface for access to router console port.

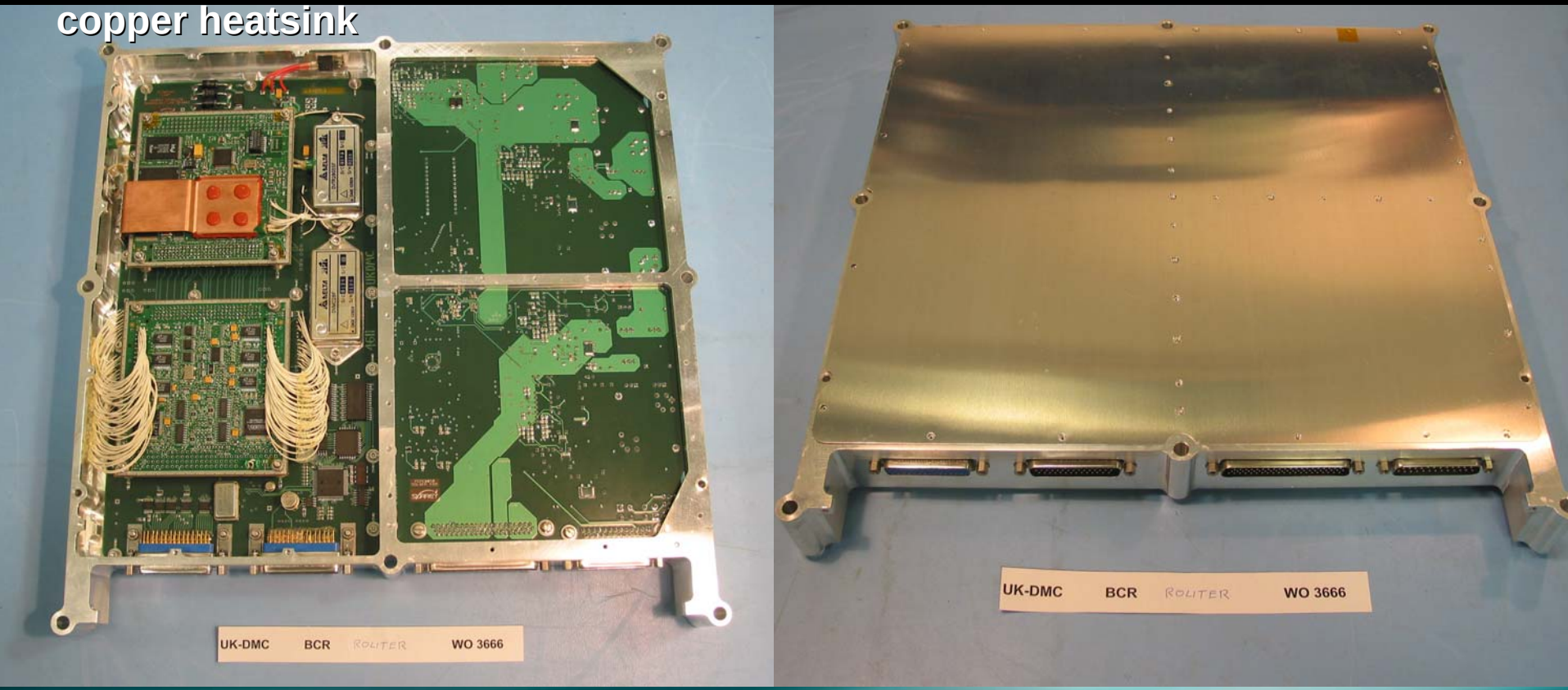
Router console port was used to ‘bootstrap’ router configuration in orbit from nothing. After basic networking was configured during passes, telnet and ssh were then used.



CLEO integration 2 – the payload tray

Cisco.com

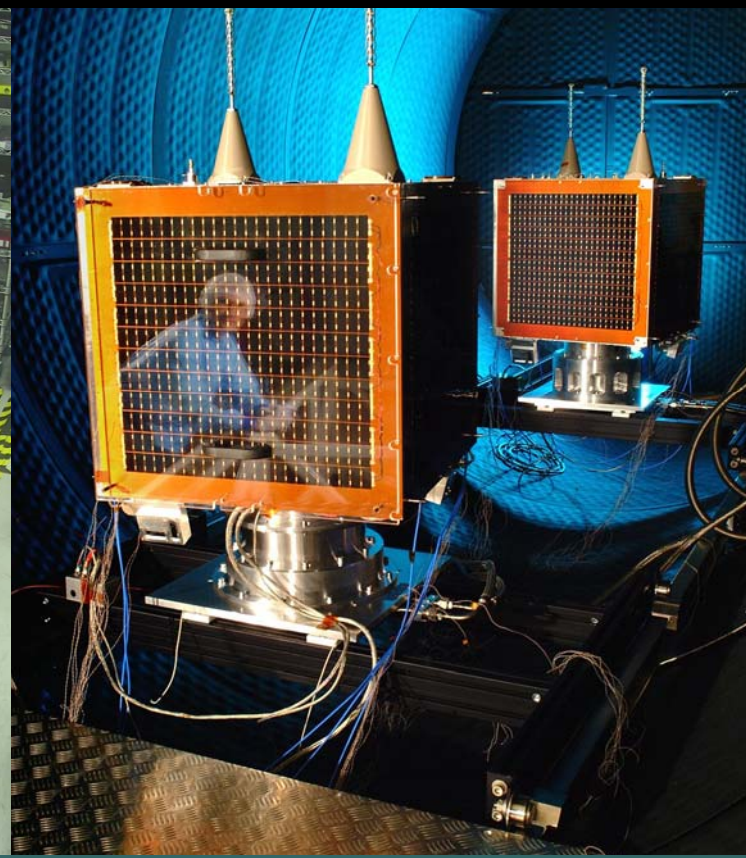
SSTL's satellites are modular stacks of identical aluminium trays, screwed together. Aluminium provides grounding, heat conduction, and structural rigidity. Router card assembly takes up half of stackable tray.



CLEO integration 3 – testing before launch

Cisco.com

Satellite assembly, subsystems and router operated in partial vacuum of less than 1x10^{-5} torr (1x10^{-3} Pa), temperature range of -35^{o}C up to +60^{o}C. Also vibration tested.



satellite assembly **in-house testing** **vacuum chamber testing**

Work before and after launch

Before launch completed:
- low-level embedded software development
- hardware integration

After launch completed:
- commissioning of all new satellites (UK-DMC, NigeriaSat-1, BilSat)
- construction of ground-based testbed for use by NASA Glenn, using engineering model of CLEO.
- development and upload of 'pass-through' software to reconfigure onboard computer to pass frames from CLEO router out to downlink.
  - as an experimental payload, CLEO is not *directly* connected to downlink, although CLEO interconnects a number of onboard computers.
- bringing up ground stations and distributed wide-area imaging network.

Power-on test of the CLEO router on 15 October 2003 showed correct amount of power being drawn; temperatures measured indicated that heatsink was attached correctly. CLEO router then stayed turned off and dormant in orbit for *over six months*.

Work after launch: ground-based testbed

Cisco.com

NASA Glenn needed to gain familiarity with operating and configuring router with SSTL's onboard computers.

Ground-based testbed allows configuration changes to be tested on the ground at leisure before being made to CLEO during a ten-minute pass over a ground station.

Built rack-mounted ground-based testbed ('flatsat') from SSDR and engineering model of mobile router, and networked it from NASA Glenn in Ohio.

Built testbed *after* launch!
Configured CLEO *after* launch!

Virtual Mission Operations Center (VMOC)

Cisco.com

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, planned for launch in 2005, and later TacSat-2. UK-DMC provides an 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

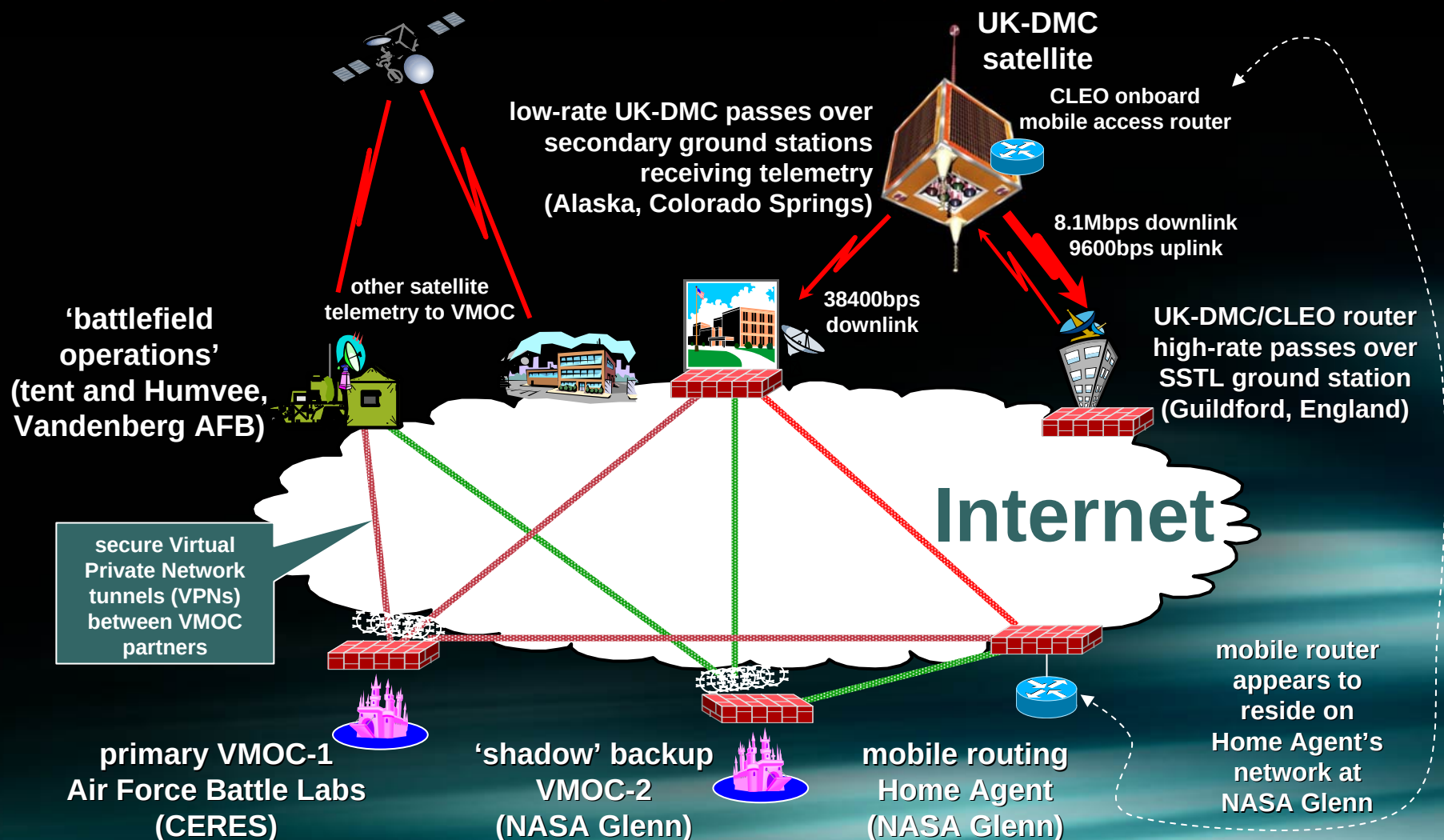
May-June 2004, VMOC, image request and access to onboard payload (router) were tested by coalition of partners ‘in the field’ in tent and Humvee at Vandenberg Air Force Base in California.

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



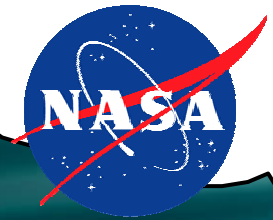
Demonstration involved many organisations

Cisco.com

GENERAL DYNAMICS
Advanced Information Systems

INTEGRAL SYSTEMS

SURREY
SATELLITE TECHNOLOGY LTD

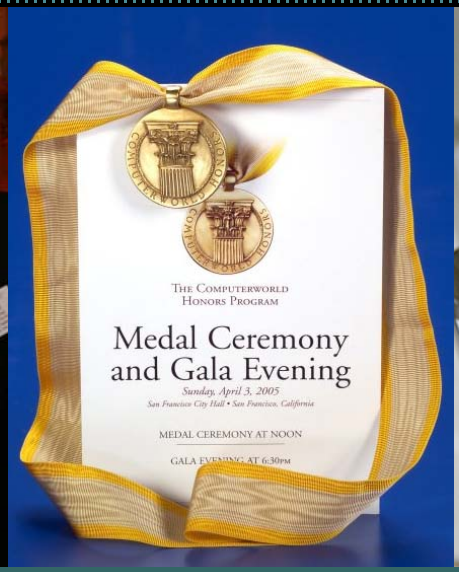


CISCO SYSTEMS

GRC
GLENN RESEARCH CENTER
at Lewis Field

Recognition of success of CLEO and VMOC

Cisco.com



Computerworld Heroes recognition

GD Technology Award

- NASA Glenn – Computerworld Heroes finalists
- Air Force Space Battlelab awards
- General Dynamics internal technology awards
- Internal awards for project management

Timeline of CLEO testing events

27 September 2003
– UK-DMC and sister satellites launched from Plesetsk.

15 October 2003
– CLEO router power cycled during commissioning tests.

29 April 2004
– CLEO router activated and tested with console access.

May – June 2004
– Testing of VMOC and CLEO from Vandenberg Air Force Base.

14 – 16 June 2004
– Public demonstration of VMOC and CLEO at Vandenberg.

10 May 2005
– Public demonstration to AFEI Net-Centric Operations Conference.

Some limitations of CLEO

As a secondary experimental payload, CLEO spends much of its time turned off. CLEO is only turned on when being tested during passes over ground stations.

The mobile router is not designed as a space instrument; it's a commercial product. CLEO does *not* contain 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 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 router software cannot be easily upgraded – no current plans to upload 6MB router IOS software across multiple passes using 9600bps uplink.

Some future CLEO testing – aspirations

Cisco.com

Router gives scope for use of SNMP and MIBs, showing that a satellite payload can be managed and queried by a ground operator just as you would a terrestrial network asset.

Router can use IPsec, and secure unencrypted ground-space link by tunnelling IP traffic through the router. (*ssh* to CLEO is already configured, along with passworded web interfaces.)
Router also capable of IPv6, but UK-DMC payloads are IPv4 only.

UK-DMC satellite also has a GPS reflectometry experiment onboard. Moving data from the SSDR controlling that experiment to ground requires dedicating passes to that SSDR. Data can be moved through the router to be stored on a primary imaging SSDR while the satellite is not passing a ground station – uses router without using high-speed downlink, takes advantage of router being connected to all onboard computers in onboard LAN.

Status of CLEO

CLEO remains operational. As a secondary experimental payload, testing is on a best-effort basis, balanced with the other demands on the UK-DMC satellite. When not being tested, CLEO is simply switched off to conserve energy.

CLEO has completed over a year of on-orbit testing, after almost two years in orbit. Further public demonstrations are planned.

Questions?

thankyou


CISCO SYSTEMS