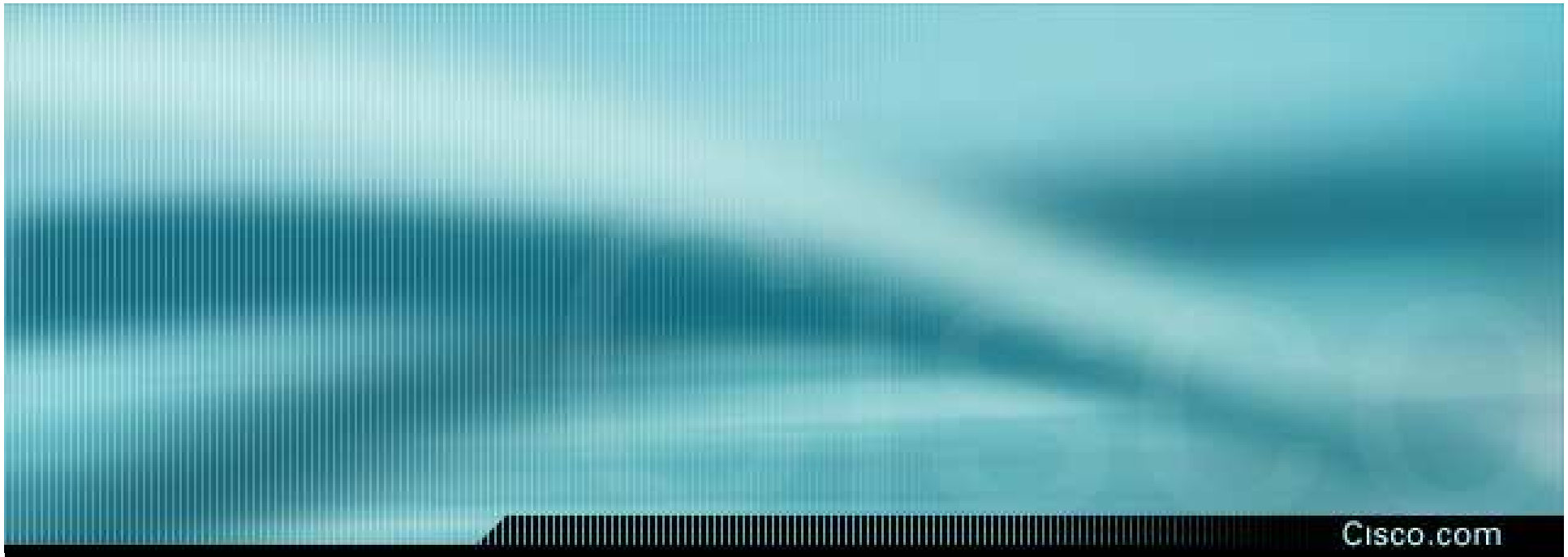


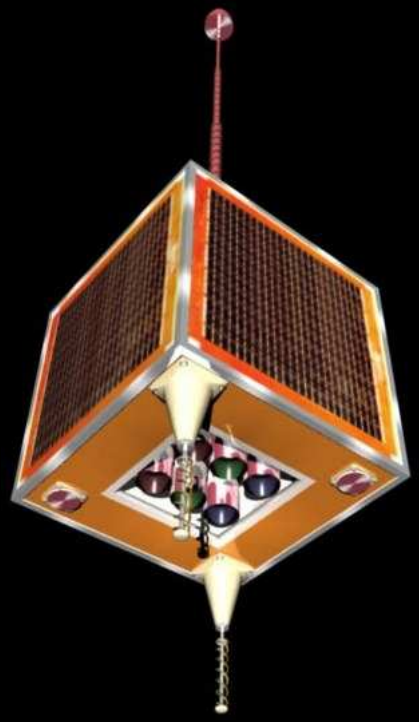
CLEO
Cisco router in Low Earth Orbit

Lloyd Wood, Cisco Systems

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

ISU summer session, Strasbourg, July 2006.

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

- The Disaster Monitoring Constellation
- Cisco's mobile access router
- The existing network environment for the DMC
- Router modifications and satellite integration
- Virtual Mission Operations Center
- Vandenberg demonstration
- Current status and future plans
- Awards won by this space payload work

Images shared by other organisations are used with thanks.

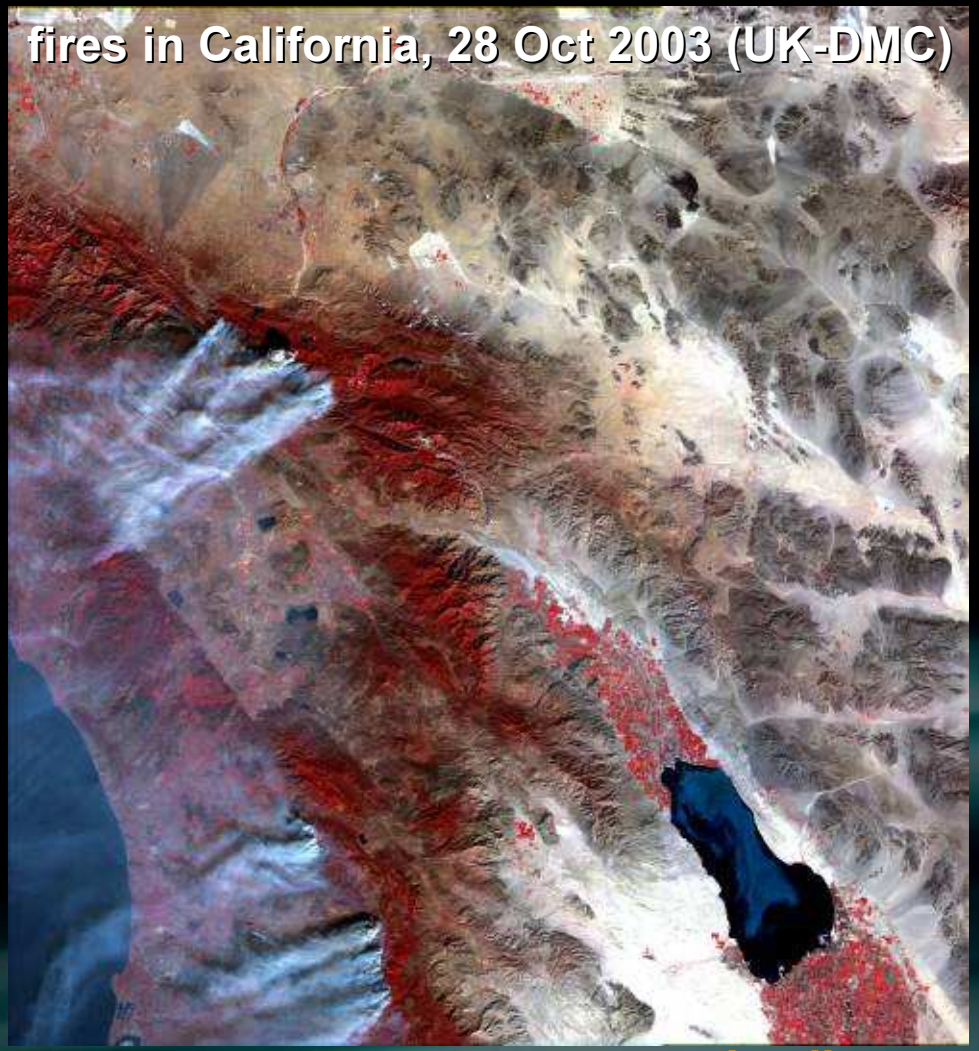
Disaster Monitoring Constellation (DMC)

Surrey Satellite Technology Ltd (SSTL) built and help operate an international constellation of small 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, Turkey, United Kingdom, and China.

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)

www.dmcii.com

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: AlSAT-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 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.

27 September 2003

DMC can image anywhere on Earth

Cisco.com

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

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

www.dmcii.com

DMC put to use: after Hurricane Katrina, 2005

Cisco.com

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.dmcii.com

What is the CLEO router?

Cisco.com

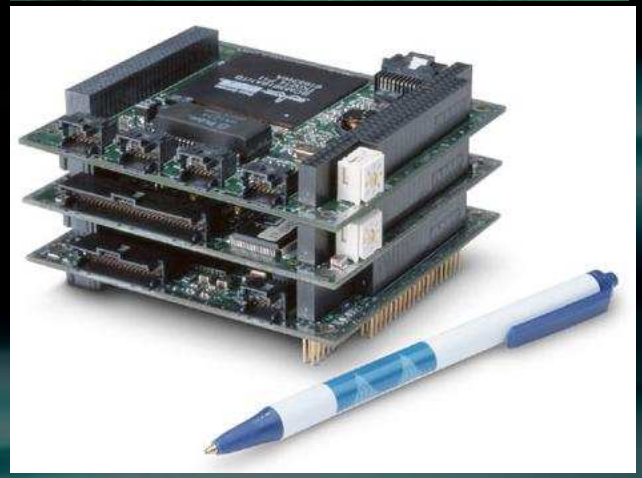
A Cisco 3251 Mobile Access Router (MAR). The MAR is a commercial off-the-shelf (COTS) product family – 3251 and 3220 series. Runs Cisco's IOS (Internetwork Operating System) router code.

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.



Other tests of Mobile Access Routers

Cisco.com

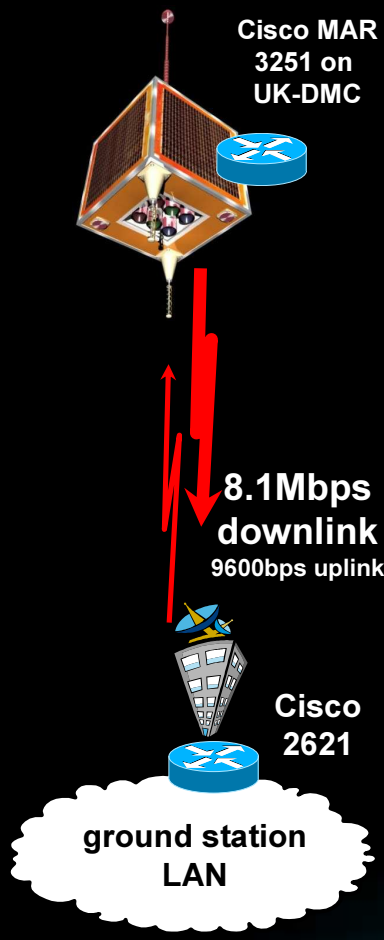
2002

NASA Glenn Research Center tested MAR on *Neah Bay* icebreaker in Great Lakes. Mobile routing roamed seamlessly between wired link when docked, and long-range WiFi and *Globalstar* satellite links when sailing.

2005

Cheever Racing put WiFi and VoIP, for secure telemetry, voice, and video, in its cars, pit and garage. Two cars carrying MARs were raced in the 89th Indianapolis 500.

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.

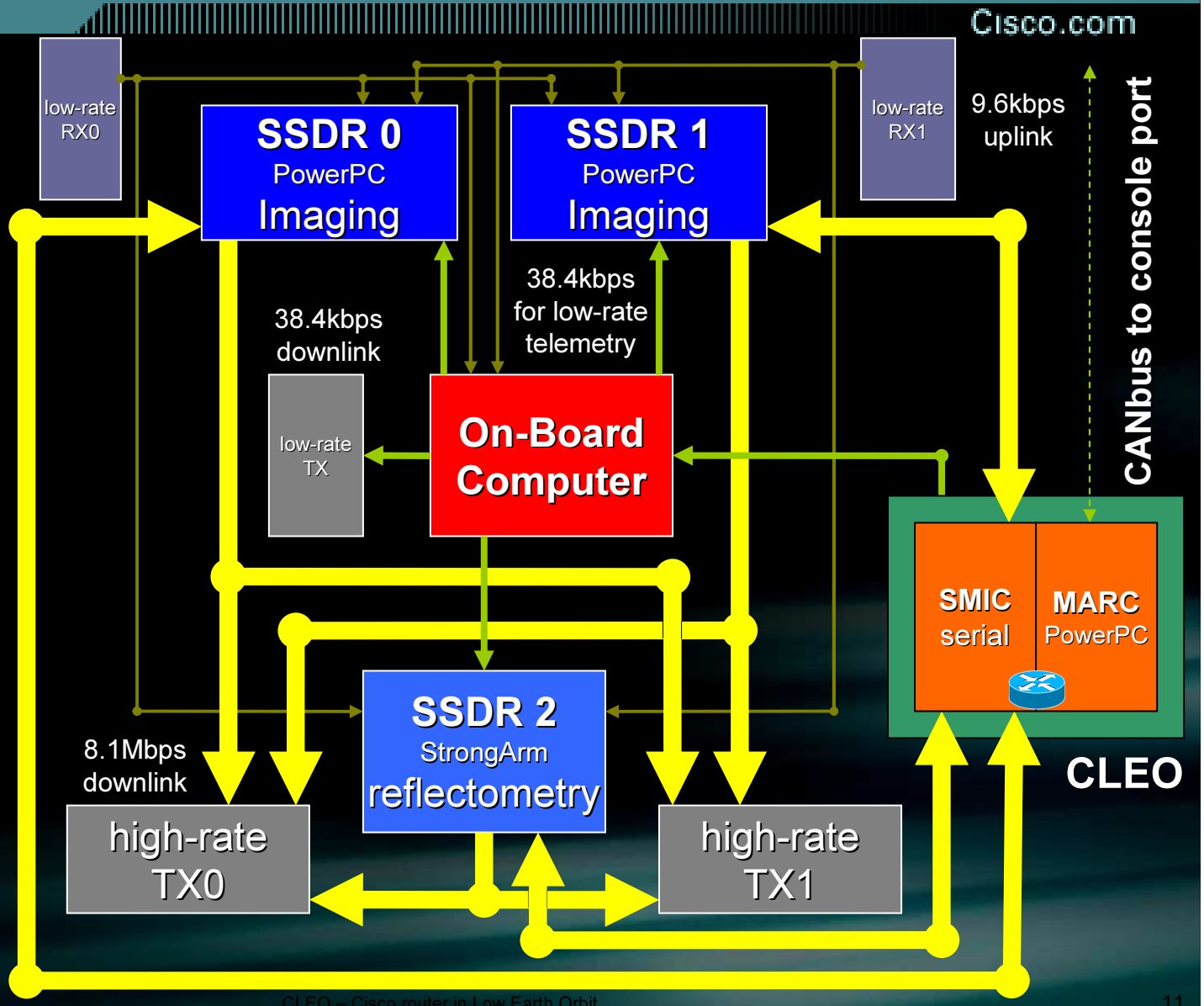
UK-DMC payloads… connected to CLEO

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



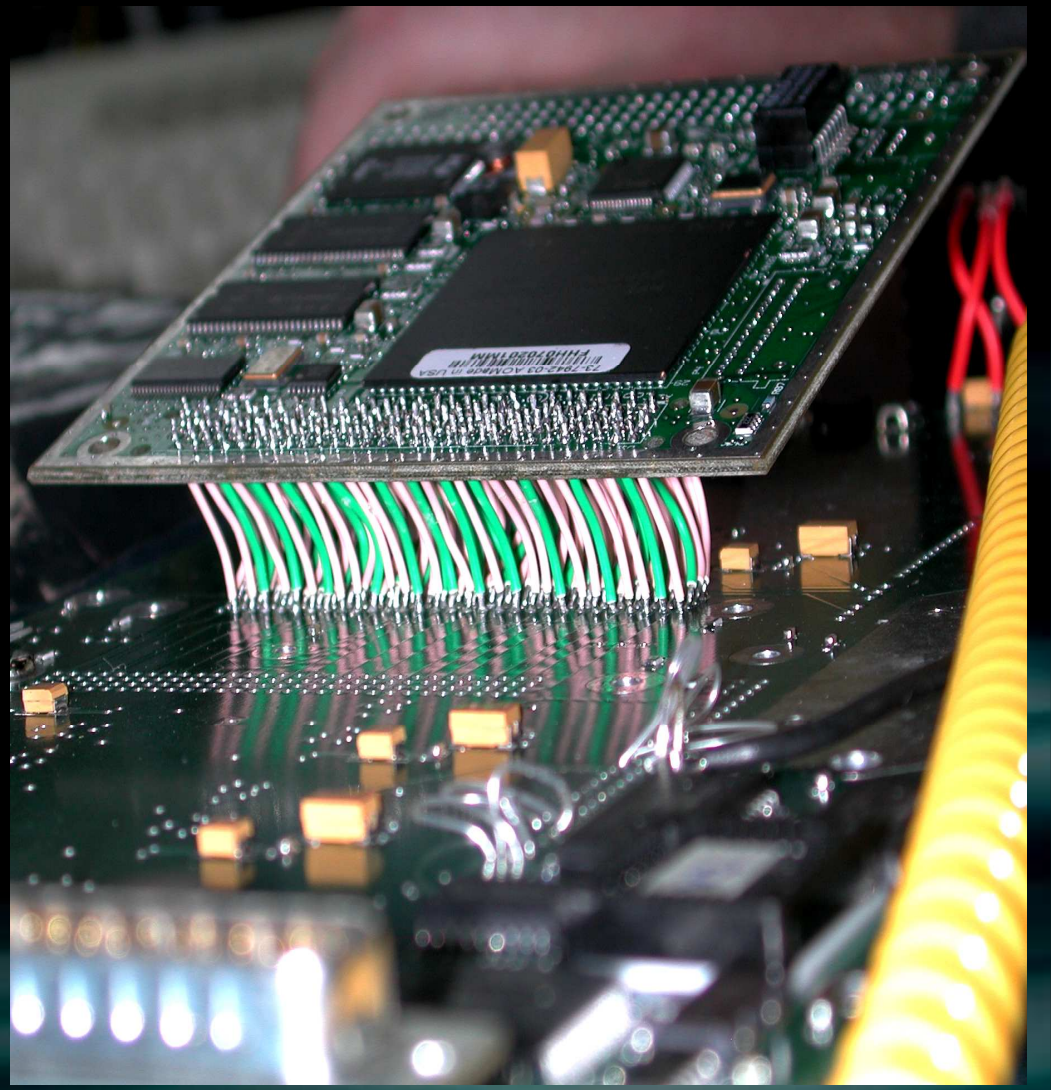
Alterations to CLEO for launch and space

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.

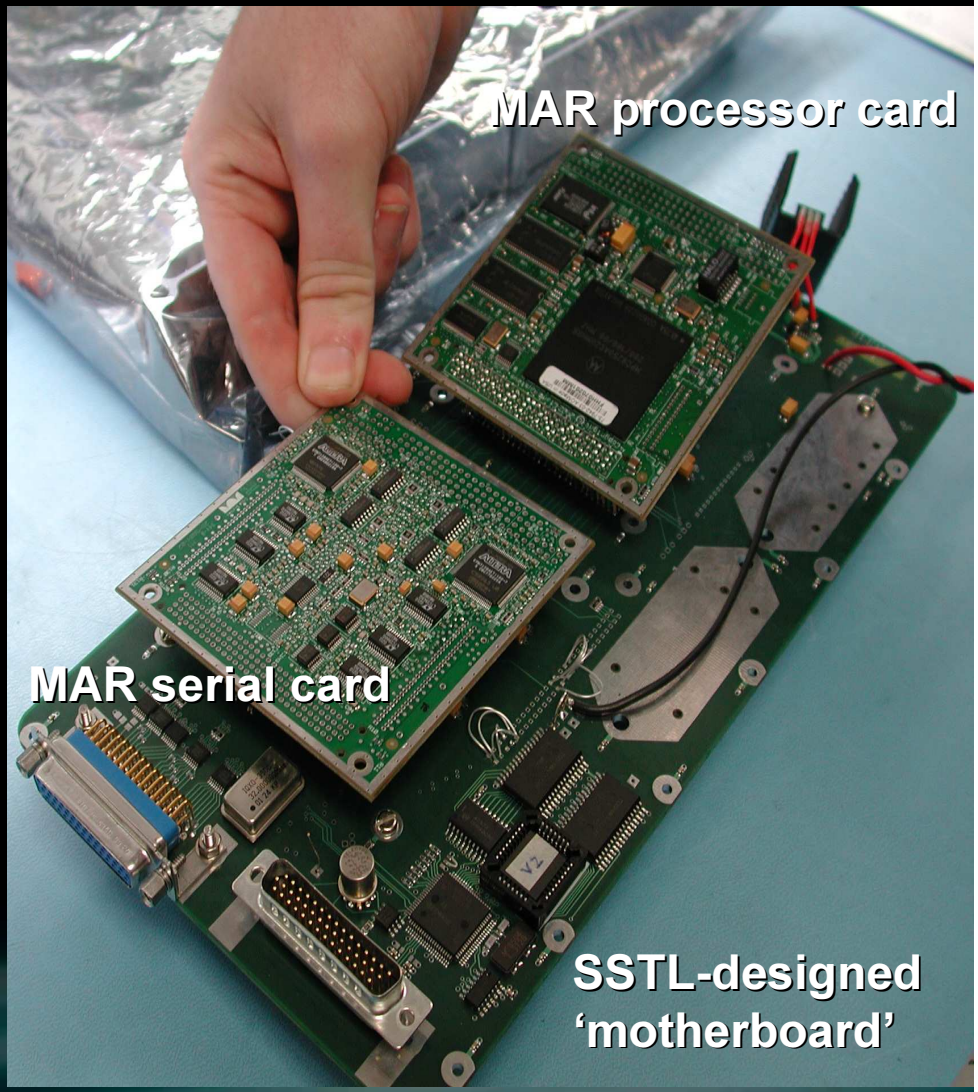


CLEO integration 1 – the router assembly

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.

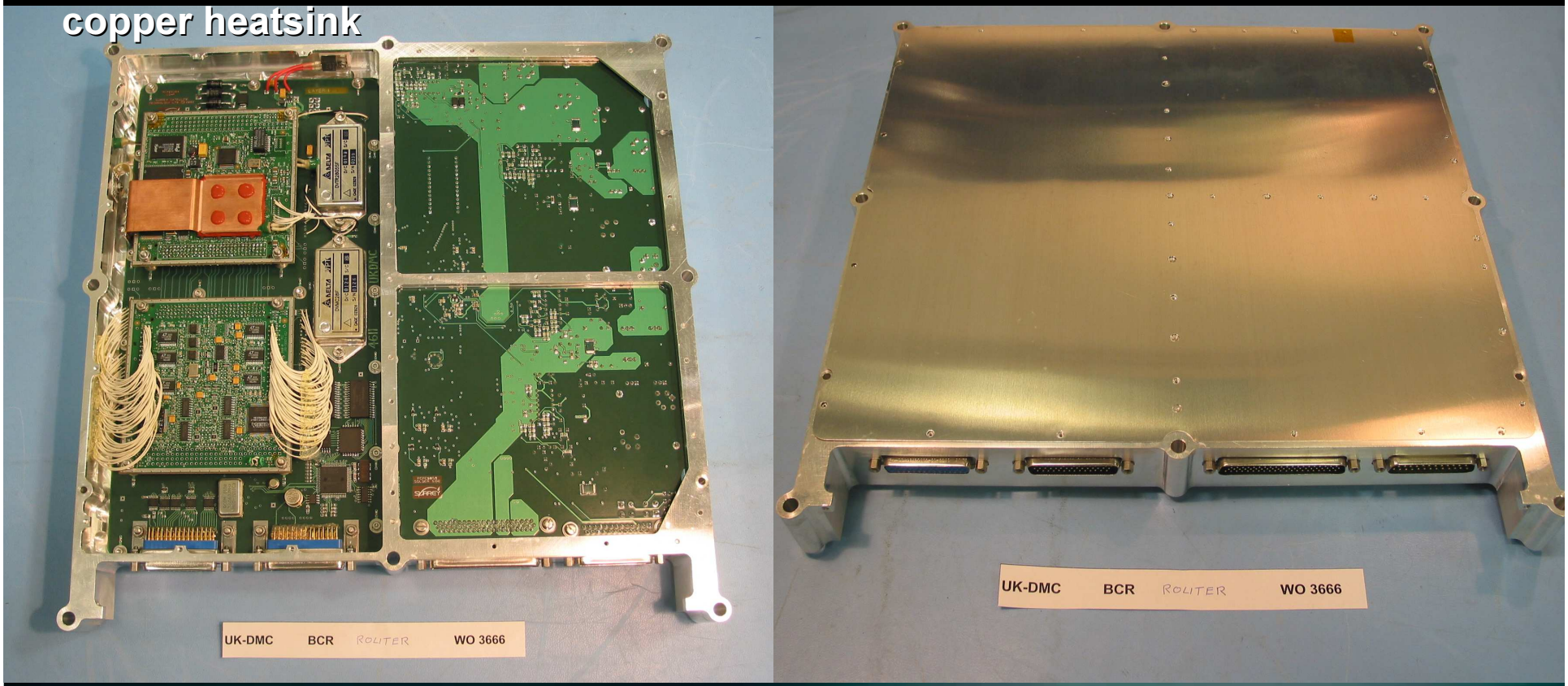
Router console port was used to ‘bootstrap’ router configuration in orbit from nothing. After basic networking was configured during passes, telnet and ssh were then used.



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. Satellites are built *rapidly*, using COTS parts, in under 18 months. Router card assembly takes up half of stackable tray.



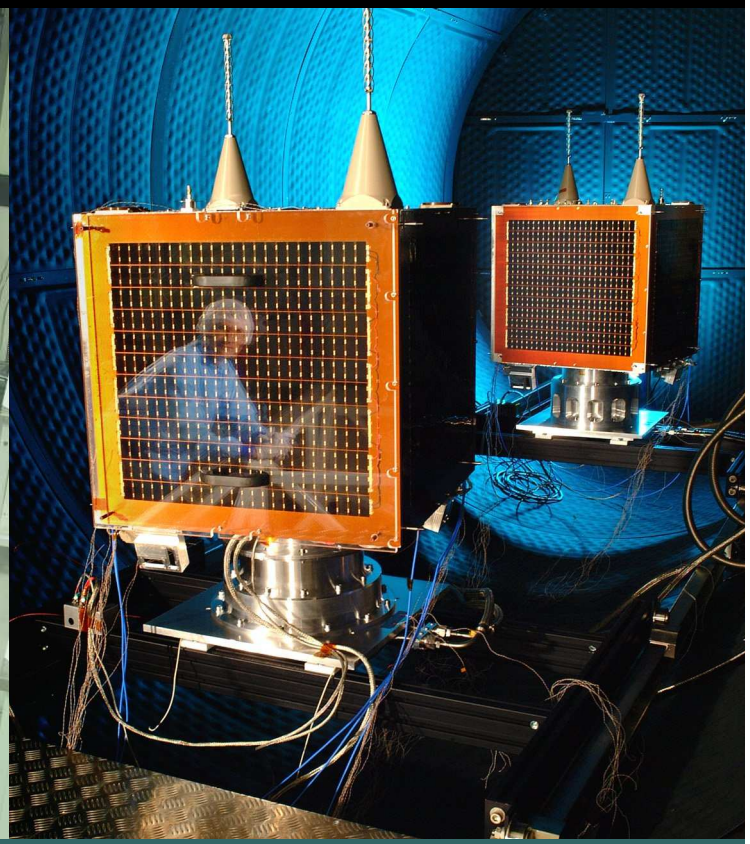
CLEO integration 3 – testing before launch

Cisco.com

Satellite assembly, subsystems and router operated in partial vacuum of less than $1x10^{-5}$ torr ($1x10^{-3}$ Pa), temperature range of -35°C up to +60°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 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. Then left dormant 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)

- 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!

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.

CLEO: Cisco router in Low Earth Orbit placed on UK-DMC satellite by SSTL

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!

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:

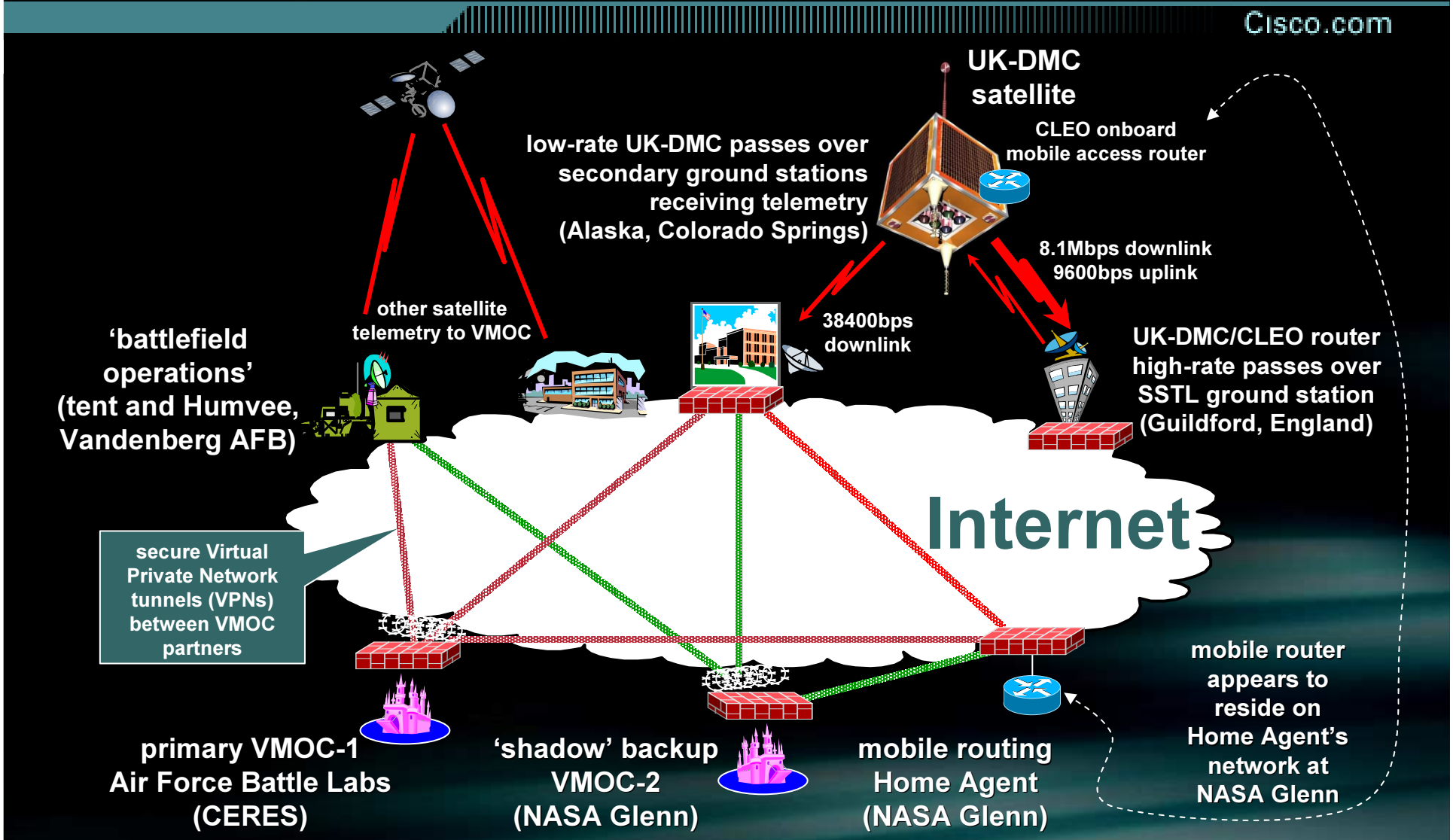
- requesting sensor data (imagery) from the UK-DMC satellite.
- use of IP for field operations.
- tasking a satellite payload (the CLEO router, accessed using mobile networking).
- failover between multiple VMOCs.

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 tent, Vandenberg

Humvee

VMOC demonstration network topology

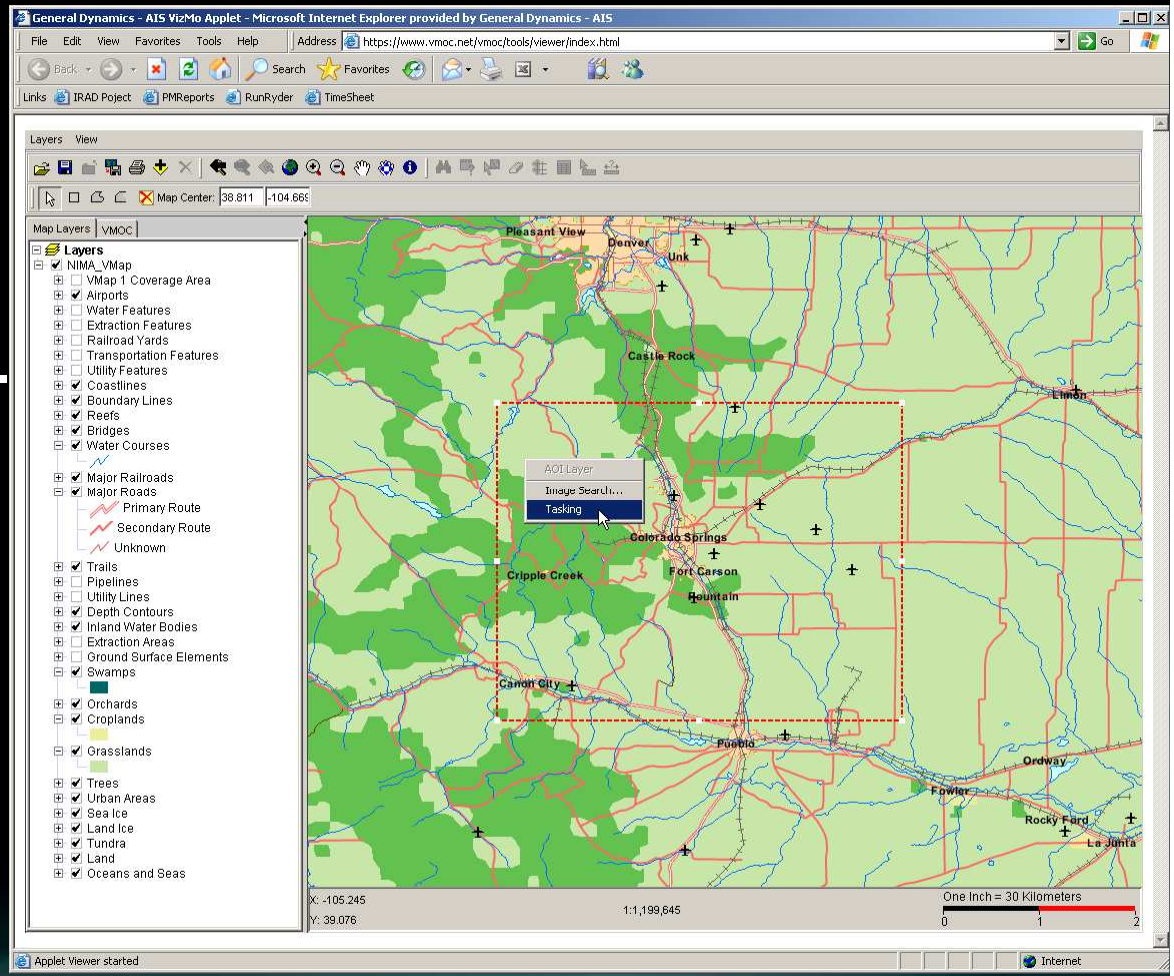


VMOC/CLEO demonstrations to US military

5 November 2004, VMOC imaging request operations were demonstrated at Air Force Space Command Headquarters in Colorado Springs to Gen. Lance Lord.

18 November 2004, to Air Force Space Command during its Commanders' Conference in Los Angeles.

2 December 2004, to the leadership of the Air Staff and Joint Staff in the Washington, DC area.



Tasking to request an image of Colorado

Demonstration involved many organisations

Some limitations 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 SSDRs.

The mobile router is a commercial product, not a space instrument. 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 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. 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 conserve energy.

CLEO has spent over two years in orbit. Testing of CLEO has been carried out for over a year. CLEO has been powered up for use over fifty times.

Timeline of CLEO testing events

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

15 October 2003
– CLEO router power cycled during satellite 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
– First public demonstration of VMOC and CLEO at Vandenberg.

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

18-20 October 2005
– Public demonstration of CLEO and VMOC at IEEE MILCOM 2005.

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 CLEO demonstration.

Cisco Systems is interested in working with others to take IP and routing functionality to new places… including high altitude and geostationary orbit.

Other CLEO testing onboard

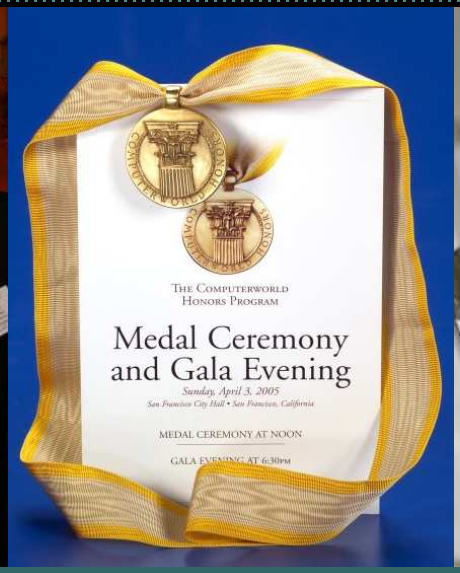
GPS – UK-DMC satellite also has onboard a GPS reflectometry experiment. Moving data from the SSDR running that experiment to ground requires dedicating passes to that SSDR. Data can be moved through the router to be stored on a primary imaging SSDR while the satellite is not passing a ground station – uses router without using high-speed downlink, takes advantage of router being connected to all onboard computers in onboard LAN. First done October 2005.

IPv6 – CLEO and ground routers are IPv6-capable, but UK-DMC payloads and ground stations use IPv4 only. IPv6 is not yet enabled.

IPsec – CLEO and ground station routers can use this, and could secure unencrypted ground-space link by tunnelling IP traffic through the router. (*ssh* to CLEO is already configured, as is a passworded web interface.) Could also use SNMP and MIBs to show that a satellite payload can be managed just as you would manage a terrestrial network asset.

Acknowledgment of success of CLEO and VMOC

Cisco.com



Computerworld Heroes recognition

GD Technology Award

- NASA Glenn – Computerworld Heroes finalists
- Internal awards in Air Force, General Dynamics and NASA (*Turning Goals into Reality* 2005)
- Internal awards for project management

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

Questions?
thankyou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