Practical use of the Internet Protocol to command satellites and payloads

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IPv4-based satellites in orbit

- CHIPSat, built by SpaceDev, launched 2003.
  - used TCP/IP stack for all TT&C/comms.
- Disaster Monitoring Constellation satellites built by Surrey Satellite Technology Ltd (SSTL).
    - Alsat-1 (launched 2002)
    - NigeriaSat-1, UK-DMC, Bilsat (2003)
    - Beijing-1 (2005). More to come…
  - Payloads communicate via IP *only*.
  - AX-25 (but migrating to IP) for TT&C.
  - UK-DMC has also used IP for TT&C – all-IP.
  - Chinese Beijing-1 satellite is IP *only*.
- IP also in use on space shuttles, ISS.

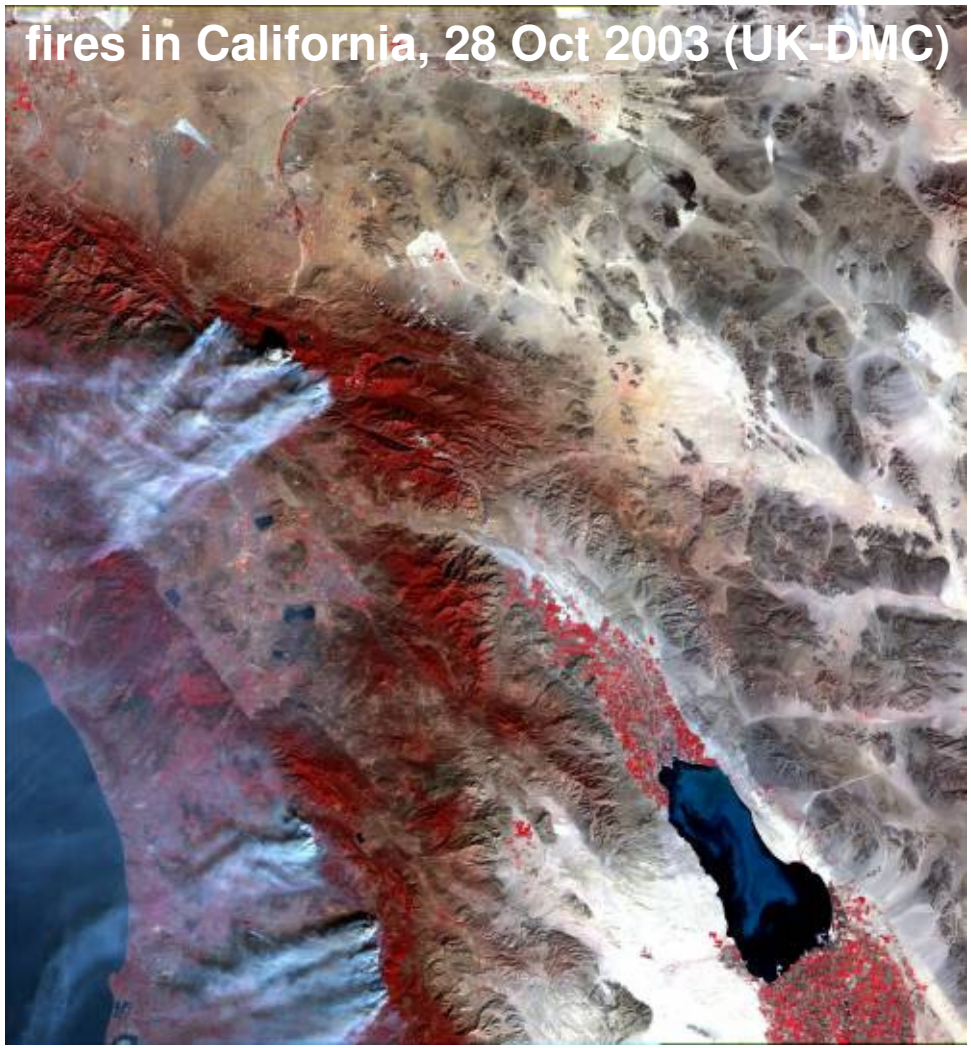
Disaster Monitoring Constellation

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.



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DMC in use: Hurricane Katrina

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.

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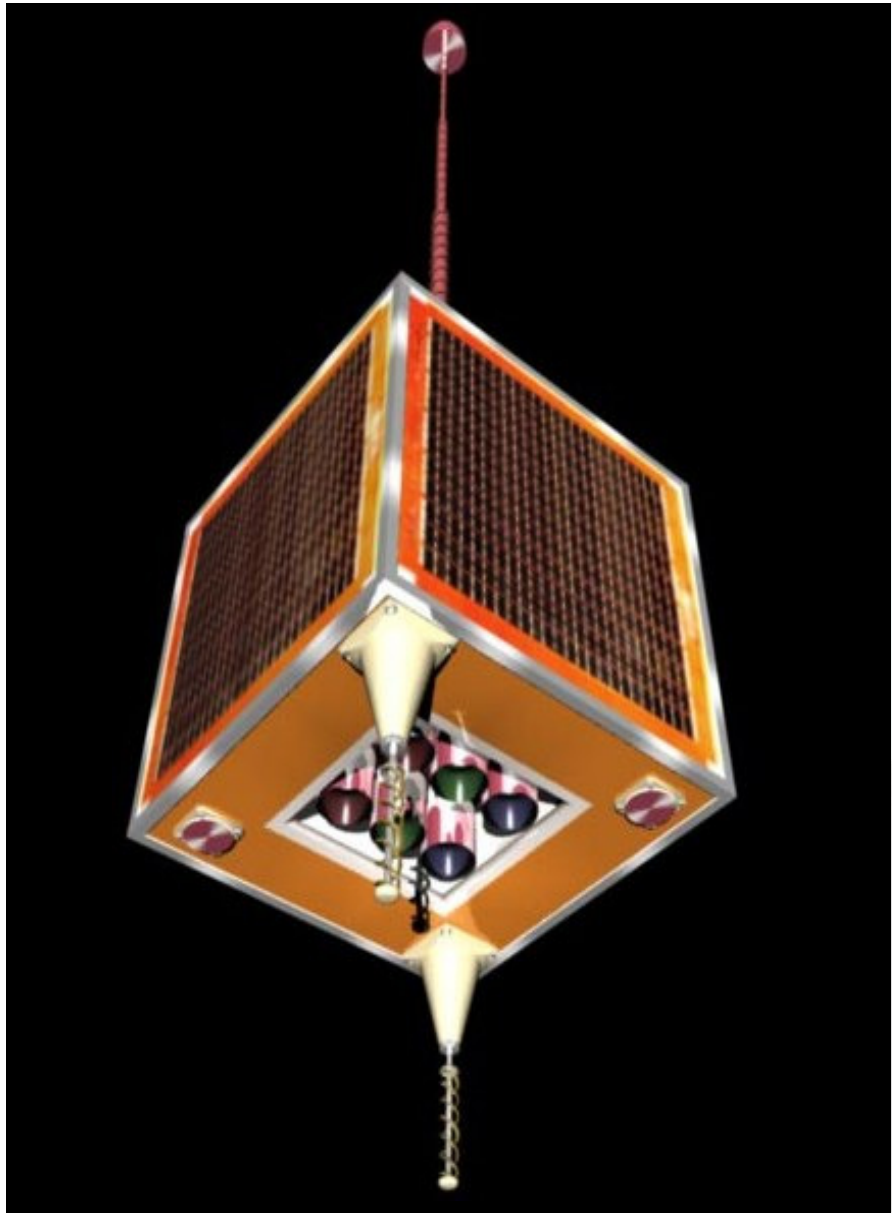
CLEO – Cisco's router in orbit

- Three years in orbit (at end of September 2006) onboard the UK-DMC satellite.
- Has been tested in orbit for over two years after Virtual Mission Operations Center demonstration in June 2004.
- Used for autonomous onboard networking between payloads transferring data.
- Validates and extends DMC's use of the Internet Protocol.
- DMC and CLEO shows value of Keith Hogie's approach to IP, serial HDLC wireless links.

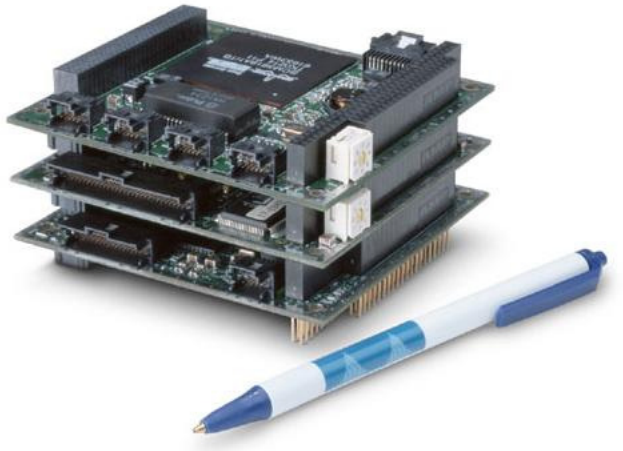


What is the CLEO router?

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.

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.

Alterations to CLEO for launch and space environment

No radiation hardening; low orbit environment is relatively benign.

No unique hardware design or software work done by Cisco.

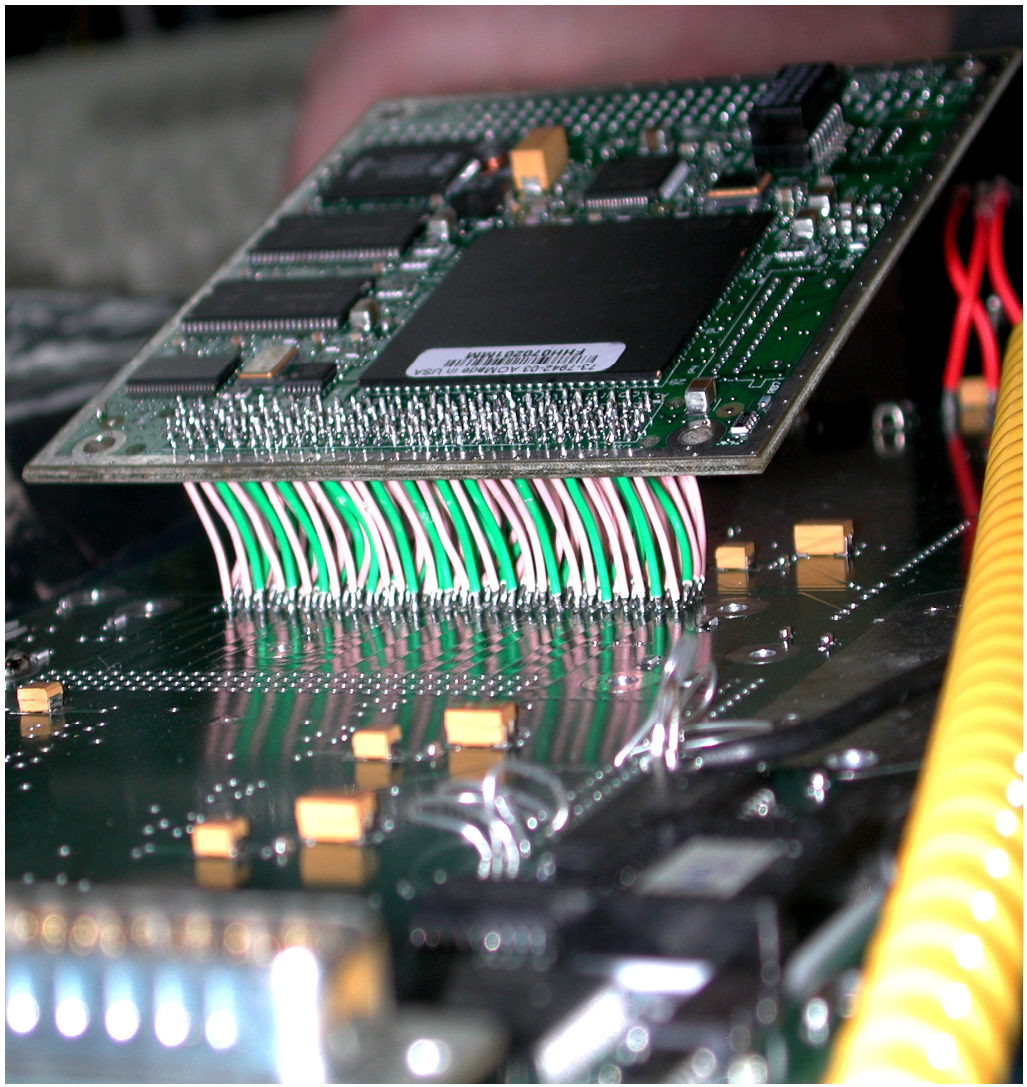
Minor physical modifications made to router and serial card.

• Flow-soldered with solder using lead 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.

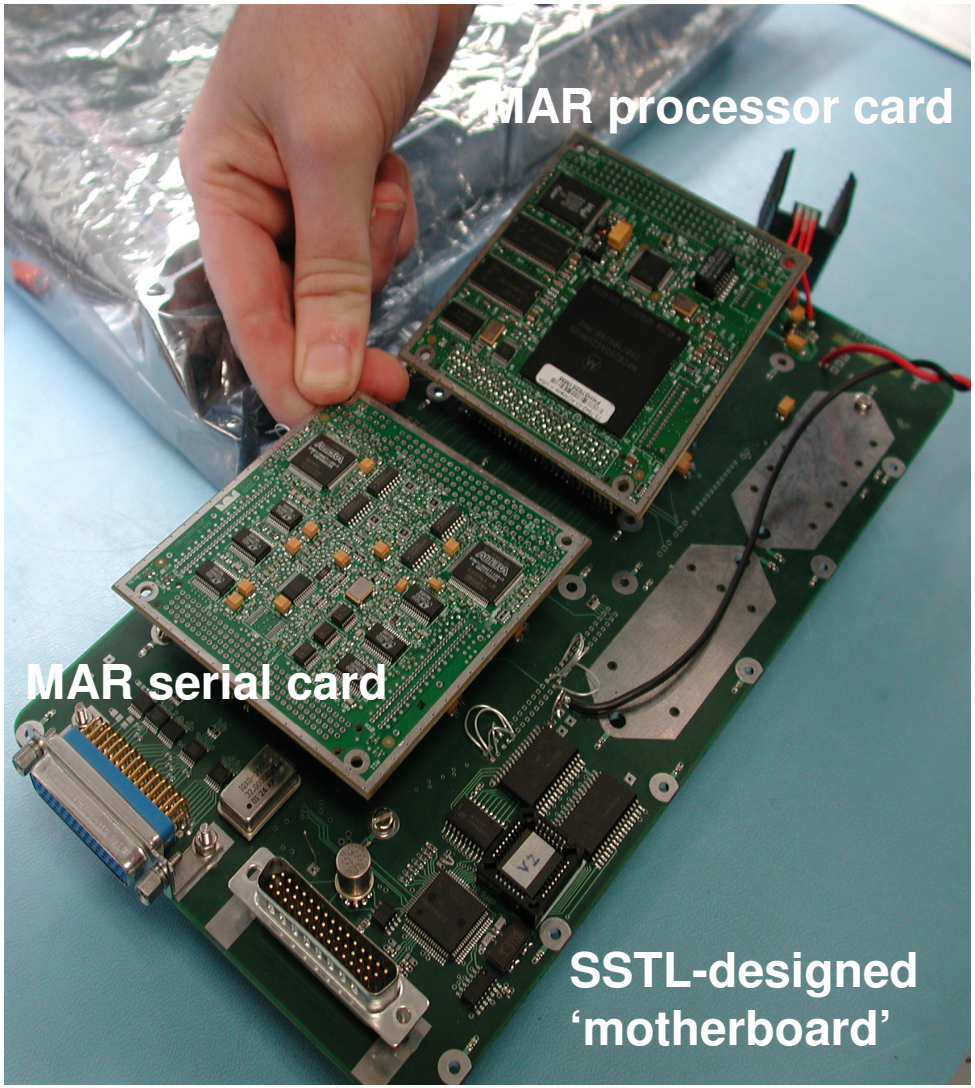


the CLEO router assembly

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. Web interface was set up. Mobile networking also used.



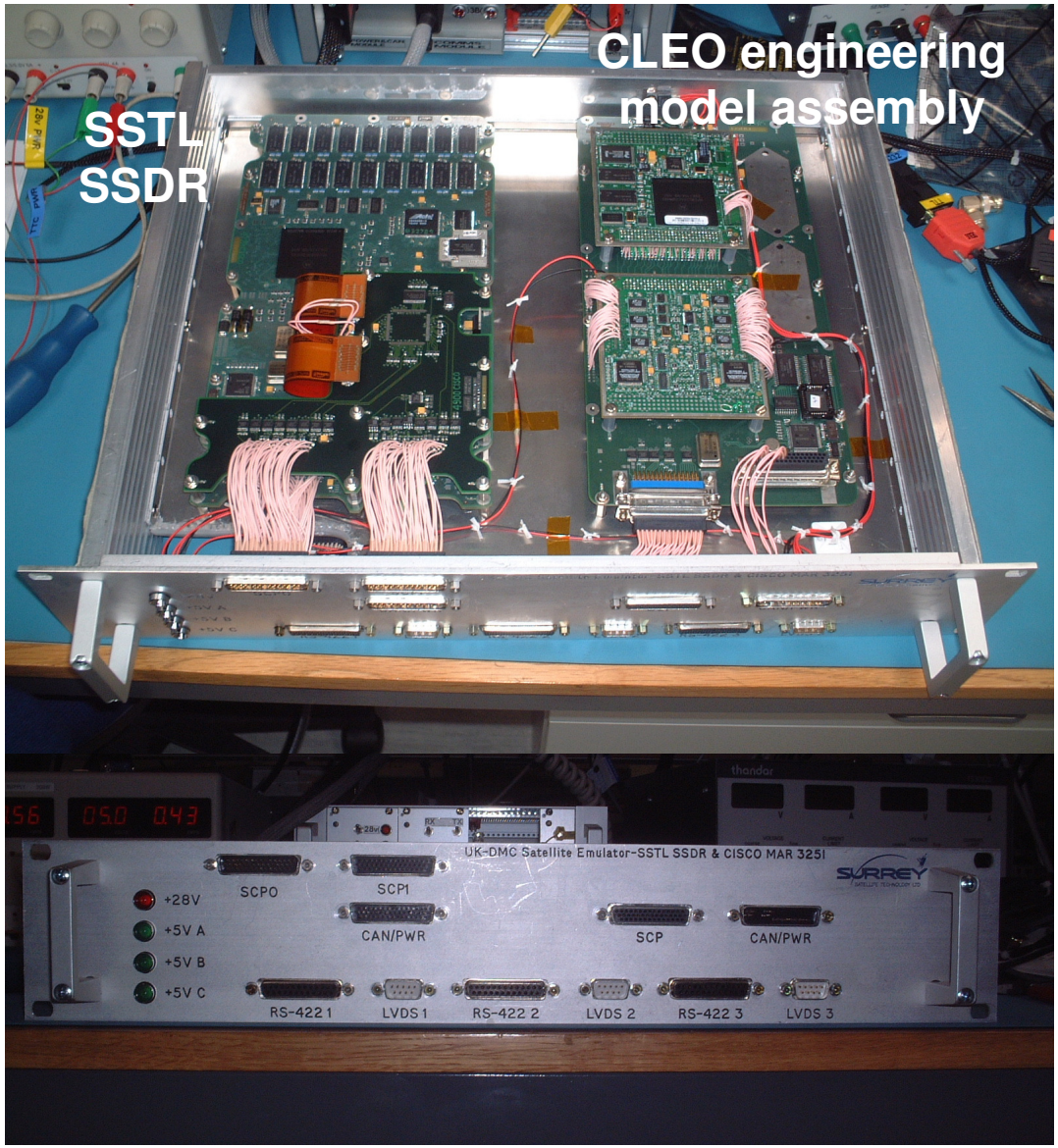
The ground-based testbed

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

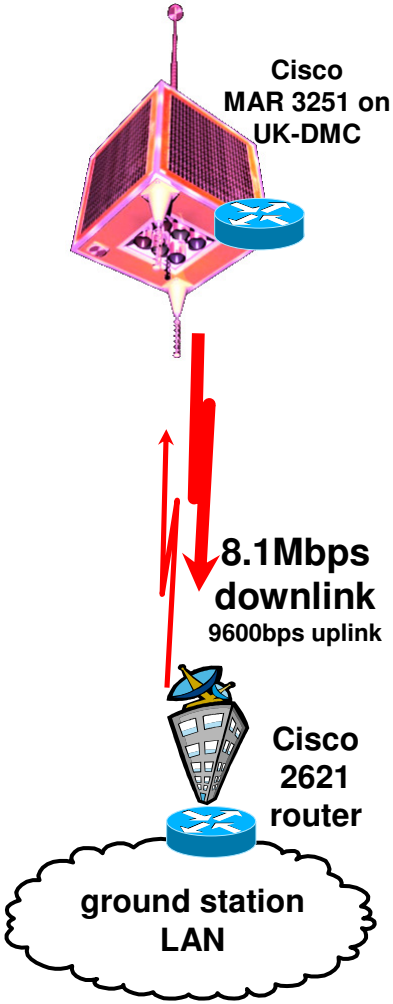
Ground-based testbed allows configuration changes to be tested on the ground at leisure before being made to CLEO during a ten-minute pass over a ground station.

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!



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.

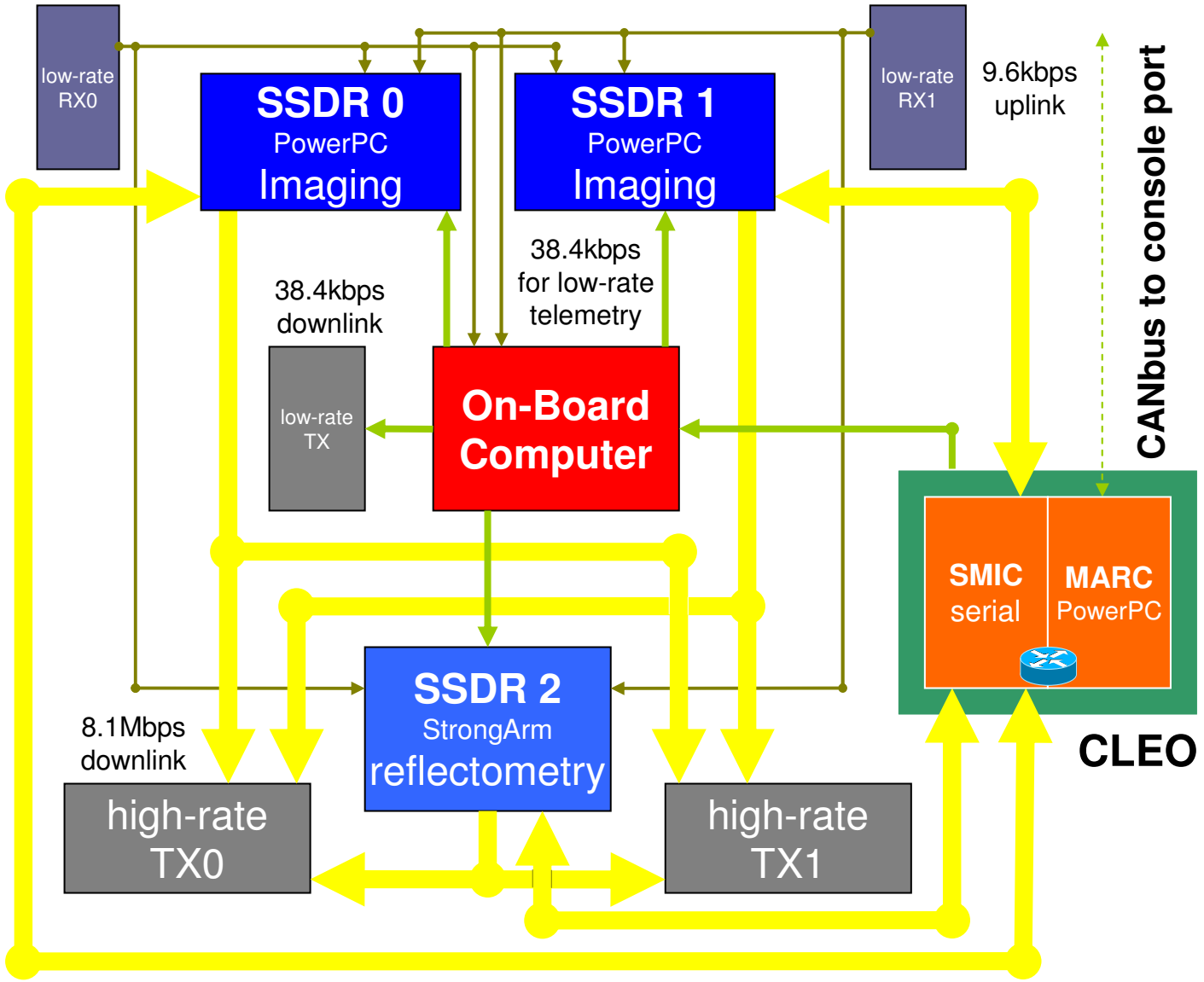
CLEO: Cisco router was able to fit into UK-DMC satellite's onboard network by connecting to OBC and SSDRs using common serial interfaces.

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

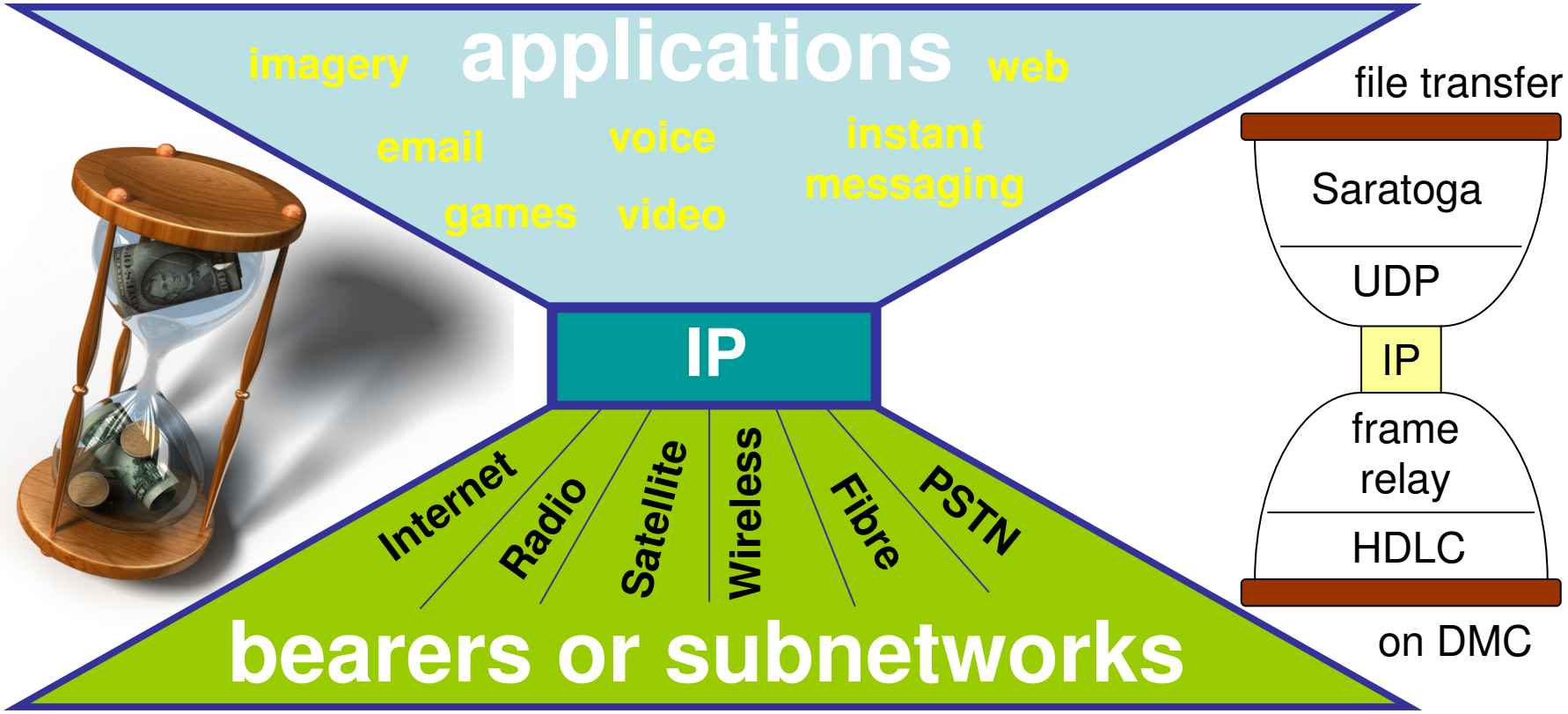
Spacecraft are constrained by available power/CPU.

- SSTL implemented CFDP for Alsat-1, but soon replaced it with their own rate-based protocol using UDP (*Saratoga*) to improve performance, decrease code footprint.
- Messenger is flying CFDP to Mercury – sort of. It's flying a cut-down 'CFDP *lite*'.
- CFDP and DTN define large number of options and run over many layers. (CFDP over TCP? *Why?*) Complexity is hard to implement fully, leading to incompatibility.

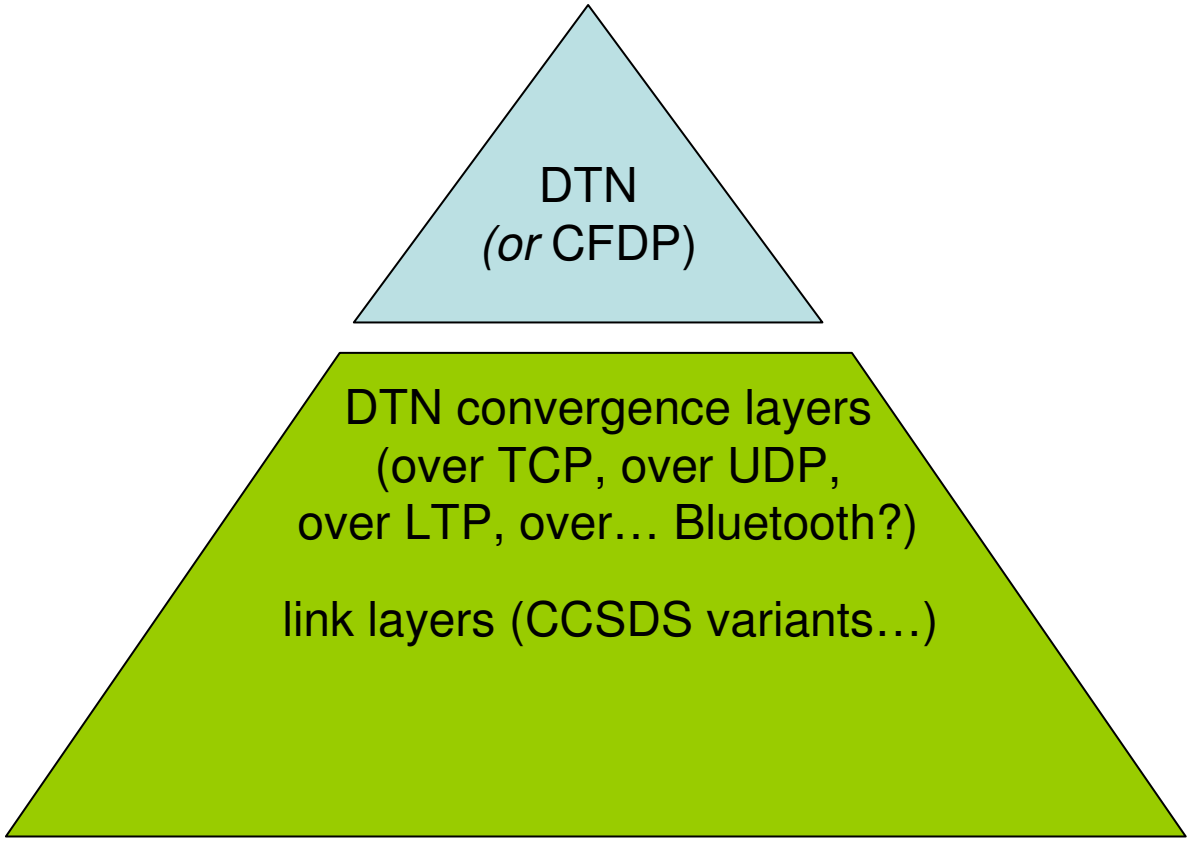
Why talk about DTN?

- Because the DMC is an example of using IP both on the ground and in space, with the ground station acting as a gateway.
- Assumptions governing IP use (link use, shared contention *vs* dedicated scheduling models) differ between ground/space, but the protocols used remain the same.
- DMC can be seen as a prototypical DTN scenario, with long delays between passes over ground stations. Could DMC simply implement DTN over IP?

IP – ‘the waist in the hourglass’



DTN – ‘the eye of the pyramid’?



DTN and CFDP are adapted to run over many things.That makes them complex.

…or is this just the bottom half of a really big hourglass?
what applications use CFDP/DTN?

Next for IP in space?

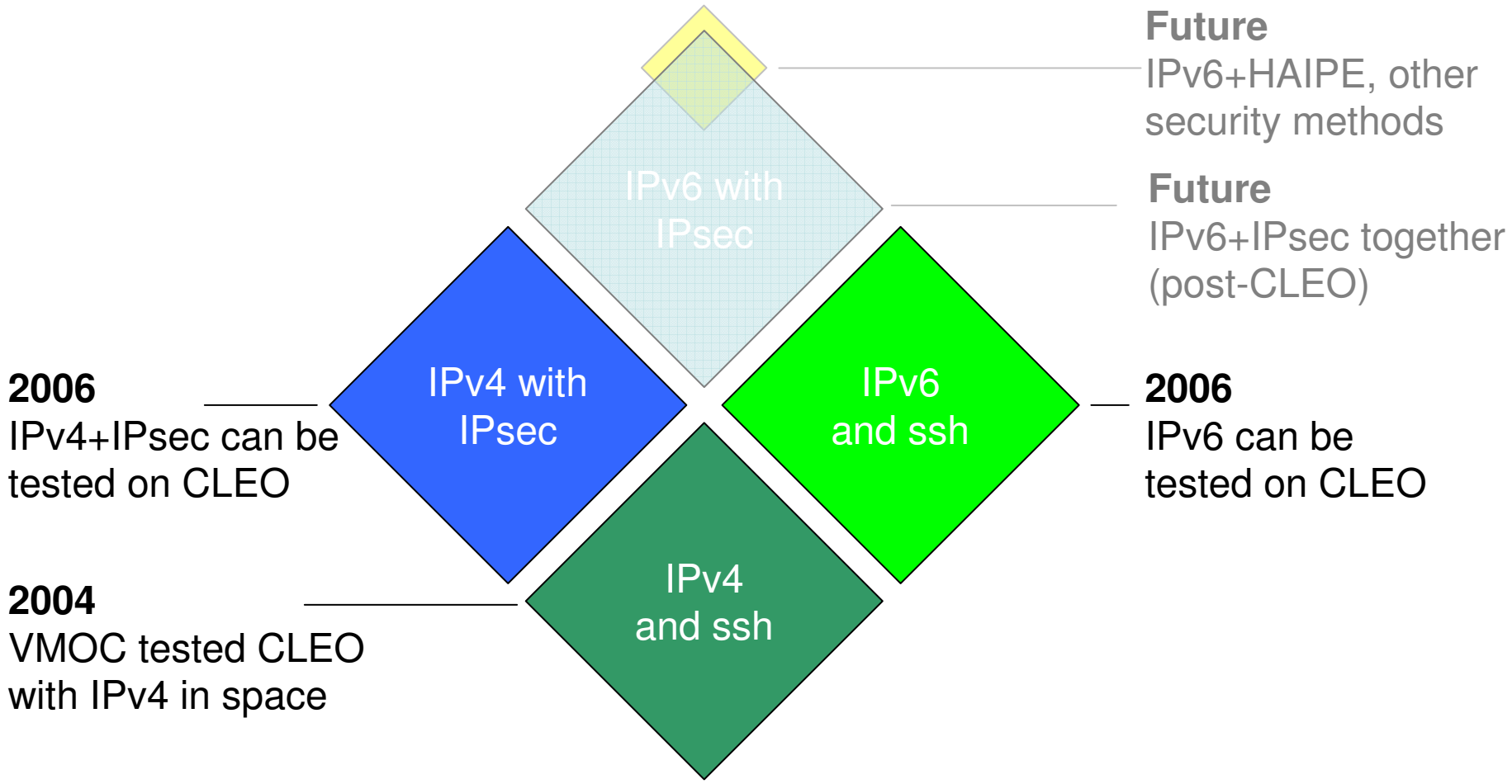
- Geostationary orbit is an obvious target; can combine routing/switching functionality with spot beams, intersatellite links to integrate well with terrestrial IP networks.
- Such onboard routing functionality won’t resemble this first CLEO demonstrator in either design or performance.

Just how far can IP go?

- IP isn't limited to geostationary orbit (although some protocols using IP suffer badly with distance, most famously TCP).
- IP itself is addressing only. No timers, no delay assumptions.
- Protocols with timers are based on assumptions about their use. Are the assumptions valid for deep space?
- UDP via a static route from Pluto? Why not? With the right simple rate-based protocol over UDP, it *will* work.

How far can CLEO go?

IPv6 and IPsec already in orbit



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

Questions?

thankyou

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