

# TESTING A ROUTER ONBOARD A SATELLITE IN SPACE

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## Abstract

A Cisco Internet router is orbiting onboard the UK-DMC satellite as a secondary experimental payload, and has been tested successfully. Testing a router onboard a satellite is one step towards extending the terrestrial networking model to the near-Earth space environment as part of a merged space-ground architecture. Here, we describe the integration of the router and satellite and on-orbit testing, and suggest possible future steps combining Internet and satellite use.

## 1. Introduction

Satellites have been carrying Internet Protocol (IP) traffic since the 1970s (1, 2), but making a satellite an active part of the Internet is a more recent development. Some example experiments that have made satellites Internet nodes are given briefly here.

In 1996, an experiment onboard the STRV-1b satellite, conducted by NASA's Jet Propulsion Lab, gave the satellite an IP address and communicated with it (3).

In 2000, a TCP/IP stack was uploaded to the UoSAT-12 satellite, and experiments were run by NASA Goddard (4, 5). Surrey Satellite Technology Ltd (SSTL), who built UoSAT-12, went on to move from AX.25 and adopt TCP/IP fully for satellite control and telemetry in their Disaster Monitoring Constellation (DMC) satellites. The first of these satellites, AISAT-1, was launched to orbit in November 2002 (6). The UK-DMC satellite, carrying the Cisco router, and its sister satellites (BILSAT-1 and NigeriaSat-1) were launched in September 2003. SpaceDev's CHIPSat, which uses TCP/IP for its communications with ground stations, was launched for NASA in January 2003 (7).

Internet devices have also been used in shirtsleeves environments in orbit by astronauts. For example, in 2001, Cisco's SoftPhone was used on a laptop PC onboard the shuttle Atlantis, using voice over IP (VoIP) to talk across a local Ethernet LAN that was connected to the shuttle's custom equipment that communicated with NASA Johnson Space Center and the ground phones there (8, 9). The Russian International Space Station (ISS) module contains a terrestrial router and network (10).

The CCSDS link protocols can also optionally carry IP, and CCSDS protocols have been used by ESA and NASA for communication with a variety of deep-space missions.

## 2. Networking aspects of the Disaster Monitoring Constellation

Each of the sun-synchronous-orbiting DMC satellites carries an optical imaging payload developed by SSTL to provide 32m ground resolution with a swath width of over 640 km. (The payloads on the Turkish BILSAT-1 and the forthcoming Chinese contribution to the DMC have better resolutions.) All payloads use green, red and near-infrared bands equivalent to Landsat TM+ bands 2, 3 and 4.

Images are stored onboard in PowerPC-based computers designed by SSTL, typically with a gigabyte or more of RAM. During passes over groundstations, images are returned as files to the SSTL mission operations centre or partner groundstations via an 8.1Mbps S-band downlink. Satellite communications can be highly asymmetric; as well as the high-speed downlink, there is also a low-rate 38.4kbps downlink to provide satellite status telemetry, while commands are received via a low-rate uplink at 9600bps. All links carry IP packets inside frame relay and HDLC encapsulation.

Image transfer between satellites and ground stations uses a custom rate-based UDP file transfer protocol designed and implemented by SSTL (11); this gives increased performance and smaller code footprint size when compared to SSTL's implementation of the CCSDS File Delivery Protocol (CFDP) that it replaced.

Each of the ground stations belonging to SSTL and to partner countries is internetworked using IP. The satellite downlink comes into the serial interface of a Cisco 2621 router; the 8.1Mbps speed was chosen to match the capabilities of that serial interface. PCs on each ground station Ethernet local area networks (LANs) run applications for dealing with satellite telemetry and images. As the ground-station LANs are connected to the public Internet, network security is needed. Cisco PIX firewalls are used.

Scheduling of images to be taken of an area of Earth can be done via a web-based application developed by SSTL that can task any of the satellites in this large IP-based merged space-ground network.

### 3. Integrating the router and UK-DMC satellite

The UK-DMC satellite is unique in carrying a Cisco Systems 3251 Mobile Access Router as an experimental secondary payload. This commercial off-the-shelf router consists of a stack of small (less than 10cm x 10cm) cards using the PC/104-Plus electrical specification.

Integration of the router and satellite was made relatively straightforward by the DMC satellites' existing use of IP and of 8.1Mbps serial links for the downlink and for interconnections between onboard computers. The mobile access router serial card interconnected the router processor card (itself capable of 100Mbps Ethernet) to all onboard computers via an SSTL-designed 'motherboard' that provided power control and physical support, as well as interfacing to the console port on the router to ensure command access to the router (12). This three-card assembly was then placed into half of a modular tray for insertion into the UK-DMC satellite.

The router cards were modified for a vacuum environment; lead solder was used instead of tin solder, wet capacitors with vents that would leak in a vacuum were replaced with dry capacitors, and the clock battery was removed. Connections between router cards and the motherboard were directly soldered, replacing plastic sockets to resist launch vibrations and temperature cycling during orbits passing from sunshine to eclipse.

No radiation hardening was done for low Earth orbit, as this would have required significant development effort and export of this custom development work would have been affected by US International Traffic in Arms Regulation (ITAR) restrictions. Commercially-available Cisco IOS software was used unmodified on the router.

As an experimental payload added late to the UK-DMC satellite, the router was not connected directly to the satellite downlink. Instead, when testing the router during a ten-minute pass over a groundstation, the onboard computers form a virtual star topology with the router at the centre, and frames are passed from the router to an onboard computer to be copied out to the downlink.

Although the mobile access router is less power-hungry than traditional 19" rack-mounted routers, the 10W it draws, combined with the 10W taken by the S-band downlink when that is operational, forms a significant proportion of the UK-DMC satellite's 30W power budget. For that reason, the router is powered off when not being tested.

### 4. Testing the onboard router

In June 2004, after lying dormant while the UK-DMC satellite's primary payloads were used, the router successfully completed a number of tests demonstrating use of IP communication with satellites. This testing was done under the aegis of the Office of the Secretary of Defense (OSD) Rapid Acquisition Incentive Net Centricity (RAI-NC) "Virtual Mission Operations Center" (VMOC), and involved an international collaboration of a wide range of organizations across public, private and civil sectors.

The Cisco router in Low Earth Orbit (CLEO) project, funded by Cisco Systems, and the VMOC project, funded by the RAI-NC programme, are separate but complementary in their shared use of the Internet Protocol, and the overlapping organisational groups involved in these projects gain mutual benefit from working together. The VMOC and router testing was a collaborative experiment centred on the Air Force, the Army and NASA Glenn Research Center, and involving other organisations.

Nautilus Horizon, an IP-based user application created by General Dynamics, was used to monitor the status of the UK-DMC satellite using satellite telemetry information delivered as UDP streams from a number of separate ground stations during passes, to request images of the Earth to be taken by the UK-DMC satellite and to fetch images from SSTL via IP internetworking of VMOC and SSTL's mission planning system. The VMOC was also used to perform real-time access to an on-orbit satellite IP node – the Cisco mobile access router.

The Army and Air Force Battle Labs provided support and performed the overall metrics collection and evaluation as part of the OSD-sponsored VMOC effort. The VMOC experiments occurred 'in the field' from an operations tent at Vandenberg Air Force Base in California during 1-13 June 2004, followed by a three-day demonstration during 14-16 June. The VMOC camp at Vandenberg specified areas of the Earth, received satellite images and telemetry, and commanded the router (13).

The VMOC relied on mobile routing to communicate across the Internet via a home agent at NASA Glenn's headquarter in Cleveland, Ohio, to SSTL's ground station and up to the Cisco router onboard the satellite. The addressing for SSTL's existing network design of ground stations is flat, with all ground stations numbered similarly, and addresses are translated to the outside world if necessary. Use of mobile routing enabled the capability to shield onboard computers from changes to ground network addressing.

## 5. Possible future steps

Both the router and the IP-based VMOC software were able to build upon SSTL's adoption of IP and the IP-based infrastructure of the satellites and ground stations that was being built, and so could treat the satellites as nodes on a large IP-based network that seamlessly merged space and ground assets. The evolution towards a merged space-ground architecture based on IP was relatively straightforward here.

An evolution towards increased networking capabilities onboard satellites appears to be gradually taking place, as onboard processing capabilities increase and satellite functionality grows to encompass ever-higher layers of the networking stack. In the commercial satellite broadcast realm, the HispaSat Amazonas satellite carries AmerHis for layer-2 DVB/DVB-RCS onboard processing and conversion, while Hughes' Spaceway satellites are also intended to be layer-2 bridges. It is likely that such satellites will carry IP traffic across their custom link layers; embedding IP switching and routing functionality into such satellites to act directly on the IP traffic that is being carried can offer advantages (14).

## Conclusions

This experiment and demonstration has shown that a commercial off-the-shelf router can be adapted to and work in the space environment in low Earth orbit. These router experiments and the Disaster Monitoring Constellation's operating network show that an approach to handling satellite command and telemetry and data delivery based around the Internet Protocol is possible and can be successful.

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