IAC-07-B2.6.06

IPv6 and IPsec on a satellite in space

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ABSTRACT

The popular Internet Protocol (IPv4) has been used operationally in space on the Disaster Monitoring Constellation (DMC) satellites for remote sensing tasks since 2003. The UK-DMC satellite carries the Cisco router in Low Earth Orbit (CLEO) as an experimental payload, and use of IPv4 with CLEO and to command and control the UK-DMC satellite was demonstrated in 2004. As a commercial Internet router, CLEO is also capable of using the newer IPv6 protocol, and of securing communications using IPsec. We describe our experiences in using IPv6 and IPsec onboard this satellite, and as part of a larger merged space/ground infrastructure built around use of the Internet Protocol. This is the first time that IPsec and IPv6 have been operated onboard a satellite in orbit.

1. INTRODUCTION

The Internet Protocol (IP) is becoming popular for use onboard small satellites, as it can take the technology and expertise available for terrestrial products and reuse it in the space environment.

A brief history of use of IP in space has been documented,[1] to which can be added the March 2007 joint launch of CFESat, the Cibola Flight Experiment built by Surrey Satellite Technology Ltd (SSTL) for Los Alamos Laboratory, alongside MidSTAR-1, built by the US Naval Academy and carrying the ICSat Internet Communications Satellite experiment. Both of these satellites owe a design debt to Keith Hogie, who advised the naval students while earlier influencing SSTL's move to use IP onboard its satellites with experiments and demonstrations done onboard UoSAT-12.[2]

Hogie's suggested architecture, which sets out how IP can be supported on wireless space links using standard Frame Relay and HDLC mechanisms, has been described in detail.[3]

SSTL's Disaster Monitoring Constellation (DMC) remote-sensing satellites adopted Hogie's design, and used IP and HDLC serial communications to deliver useful imagery data from orbit.[4] (A sample image is shown in Fig. 1). Five DMC satellites are currently operational in orbit, while construction of three more satellites has been announced.[5,6,7]

The use of IP and HDLC serial streams made for straightforward integration of an assembly of a Cisco Systems 3251 Mobile Access Router and supporting serial card, as the CLEO Cisco router in Low Earth Orbit, onboard the UK-DMC satellite as a secondary experimental payload.

2. TESTING THE CLEO ROUTER

CLEO was tested and demonstrated in June 2004 as part of a larger internetworking exercise run from Vandenberg Air Force Base, showing that a commercial Internet router could function in orbit and be tasked by remote users 'in the field'.[1] This successful testing was conducted using the widespread version 4 of IP, along with mobile routing.

However, CLEO already had onboard the capabilities to run both the newer version 6 of IP, IPv6,[8] and the IP security protocol, IPsec.[9] (IPv5 was reserved for an experimental protocol that is now unused.[10]) These software features had launched onboard CLEO and the UK-DMC satellite in the firmware that flew into space in September 2003, but had lain dormant and unused until the terrestrial ground station infrastructure was upgraded with IPv6 capabilities to match.

CLEO was configured for IPv6 and IPsec use in March 2007, and successfully tested with both features on 29 March 2007.[11]

Configuration and testing on orbit required few passes, as working configurations had already been debugged using the ground-based testbed, carrying a sister router to CLEO, that is operational at NASA Glenn's facility in Ohio [Fig. 2]. This testbed is now being used as a basis for development of Delay Tolerant Networking software for use onboard the UK-DMC satellite.[12]

3. WHY TEST IPV6 IN SPACE?

IPv6 is intended to eventually replace IPv4 terrestrially, as the larger address space and simpler routing tables of IPv6 ameliorate the most pressing problems with the scalability of IPv4:

a. exhaustion of availability of unused address space, requiring workarounds such as Network Address Translation (NAT) that become unneeded in IPv6,

b. size of backbone routing tables needed to keep the Internet fully interconnected.

Modern operating systems all include IPv6 as well as IPv4 functionality in their network stacks. A discussion of the advantages of IPv6 is given elsewhere.[13]

Fig. 1: Example DMC imagery - New Orleans, aftermath of Hurricane Katrina, NigeriaSat-1, 2 September 2005. False-colour imagery. Green is vegetation; red is flooded. Full image taken is shown in corner thumbnail. Supplied to the US Geological Survey by DMC International Imaging.

Fig. 2: CLEO ground-based configuration testbed –
a. top view before addition of heatsinks/fans
b. front view with interfaces and flexible patchbay.

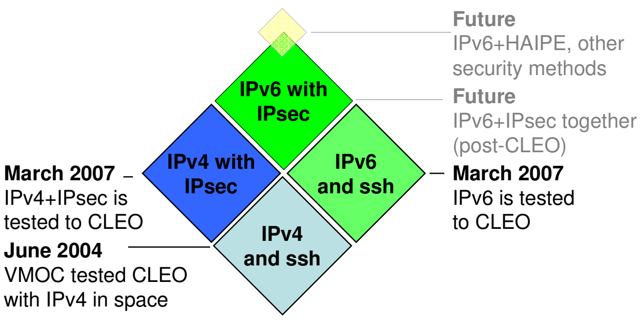

Fig. 3: Steps made with CLEO in showing advanced networking capabilities onboard satellite in orbit.

The US government has mandated that all purchased network-capable equipment be IPv6 capable, while its Department of Defense has required that IPv6 be used for advanced satellite communications programs, such as TSAT, the Transformational Satellite Architecture. Security is also a requirement.

We have realised three of the five operational steps towards the eventual in-space goal of the US Department of Defense [Fig. 3] by demonstrating IPv6 and IPsec with CLEO onboard the UK-DMC satellite [Fig. 4].

4. WHY TEST IPSEC IN SPACE?

IPsec is the common, popular, way to secure network assets terrestrially, so it makes sense to reuse this technology for the space environment.

Demonstrations of IPsec in space show how the very similar HAIPE (High Assurance IP Encryptor) protocols, mandated for US DoD and NATO use, could be used in these environments.

5. NETWORK TOPOLOGY USED

Diagrams are given showing the various ways in which access to CLEO can be made [Fig. 5] and how connectivity is set up for access to CLEO [Fig. 6].

Two Frame Relay DLCI links are set up across the wireless link between the satellite and the router in the ground station.

One, using the first unreserved Data Link Connection Identifier (DLCI 17), and common to all DMC satellites, carries unencrypted IPv4 and IPv6 traffic multiplexed together.

The other (DLCI 18) is set up for encryption by the routers, and carries IPv4 IPsec packets to be passed to CLEO. IPv6 can be transmitted encrypted through a 6-over-4 tunnel over this link.

NASA Glenn relies on Mobile IP from its home agent in Ohio to the corresponding node that is CLEO. This allows access to CLEO and other satellite payloads once CLEO has registered with the Home Agent while over any compatible ground station. However, Mobile IP is completely unnecessary and optional for access to the CLEO router. When Mobile IP is in use, it is terminated by a roaming interface on an unencrypted link. IPv6 can then be carried in a 6-over-4 tunnel within the Mobile IP tunnel. The use of the routers permits very flexible configurations. In taking advantage of Mobile IP as well as IPsec, this flexibility has been exploited, allowing access to CLEO in a number of different ways for testing purposes.

Telnet, ssh and web configuration of CLEO were carried out, making CLEO the first IPv6 webserver in space.

Operational use of IPv6 is likely to be far simpler than the impression given by these diagrams, without the many Mobile IP and 6-over-4 tunnels used in this configuration. IPv6 link-local addresses are likely to prove useful for ad-hoc single-hop connectivity.

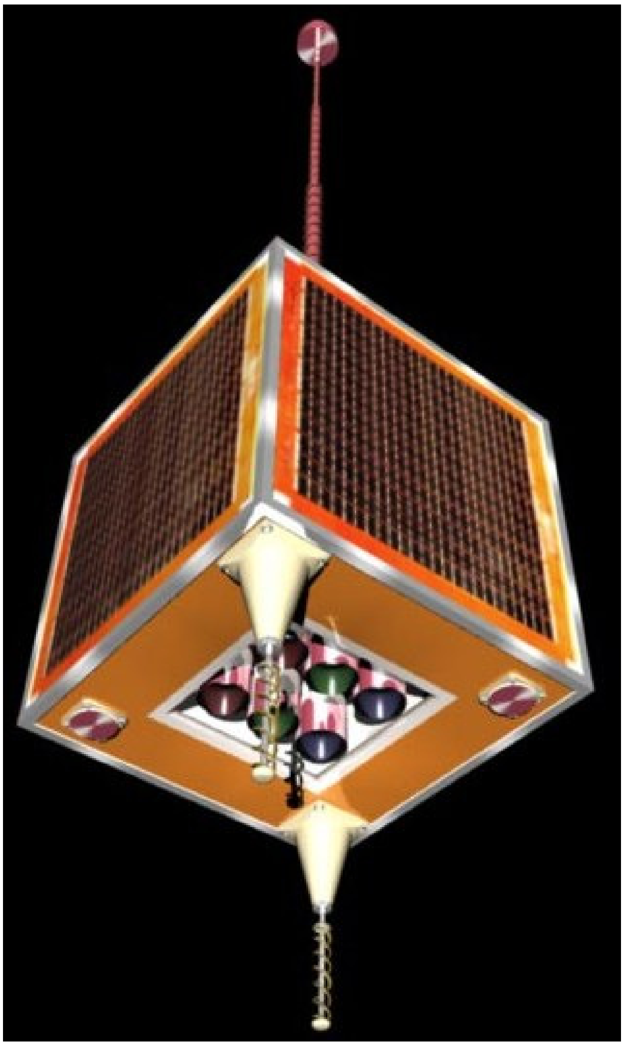

Fig. 4: Rendering of UK-DMC satellite carrying CLEO router, showing:

top – gravity boom for backup attitude stabilization
middle – solar panels on box chassis.
bottom – six imaging cameras (three channels, two cameras per channel, one each side of nadir) and antenna.

6. USE OF OTHER GROUND STATIONS

Use of other ground stations with CLEO and the UK-DMC satellite for IPv6 capability testing has been mooted and is underway.

Universal Space Network (USN) was involved in previous testing of CLEO with IPv4,[1] and is examining similar testing for IPv6, as is the Japanese National Institute of Information and Communications Technology (NICT). In configuring unique IPv6 addresses with these groundstations, we can step away from the existing SSTL network model used by DMC ground stations. This uses a private IPv4 local area network (LAN), with NAT to the public Internet.

The Multi-Use Ground Station (MUGS) project has also examined IPv6 access to CLEO.[14] However, the phased-array antenna in use with MUGS has been unsuccessful at closing the downlink at the high-rate of 8.1 Mbps, making access to CLEO during a pass problematic, because CLEO is currently only reached using this high-rate downlink.

The MUGS antenna can successfully close a low-rate 38.4kbps downlink from the UK-DMC satellite. Access to CLEO via the low-rate downlink would be possible if the on-board computer controlling that low-rate downlink ran pass-through software to take frames from CLEO to that downlink, as CLEO is not directly connected to any downlink, but bridged through other onboard computers.[1] This software would allow successful testing with the MUGS antenna, and is being considered for further work.

7. OTHER POSSIBLE TESTS

Now that IPv4, IPv6 and IPsec have been shown to work onboard the UK-DMC satellite with the CLEO router, the major testing of this Cisco router in space is complete, and the router has been shown to be just as functional as its terrestrial counterparts.

Other tests that could be carried out would involve network management, to show that a space payload could be managed from ground systems with the Simple Network Management Protocol (SNMP) and using commercially-available network management software, to manage space assets just as terrestrial networked devices are managed.

8. HEADER COMPRESSION

One complaint about IPv6 is that its larger address space leads to larger IP headers, which decreases link utilization. While this becomes an important concern for small packets, such as Voice over IP (VoIP), where the payload size is roughly similar to the header size, the impact on larger packets, especially at maximum link transmission unit (MTU) sizes, is minimal. One way to decrease header overhead still further is to use header compression across serial links.

However, header compression is always the last part of a networking or link-layer standard to be agreed and then implemented; in this case header compression over standard Frame Relay links was only agreed in 2001.[15] The IOS firmware flown onboard CLEO does not implement header compression over frame relay or of IPv6 headers, so header compression could not be used.

If IPv6 header size is really a concern, given that IPv6 header compression will, again, be the last to be implemented, we can imagine IPv6 users deliberately doing 6to4/4to6 network address translation[16] across constrained links, simply to be able to use the smaller IPv4 headers and take advantage of more mature IPv4 header compression across those links, while appearing as IPv6 nodes to the rest of the network.

9. CCSDS PROTOCOLS?

This paper has not discussed the use of protocols designed for space by the Consultative Committee on Space Data Systems (CCSDS) in any way, because these protocols are not used by the DMC satellites. In fact, CCSDS link protocols can carry HDLC bitstreams, providing a simple way for CCSDS to carry and support IP, as described by Hogie,[3] and allowing a very well-known and popular ISO standard[17] to run over the other CCSDS-specified ISO standards.

CCSDS has specified an IP-alike network stack called the Space Communications Protocol Standards (SCPS). The SCPS network layer is similar to, yet incompatible with, IPv4. A security protocol, SCPS-SP, is similar in concept to, but incompatible with, the widely used and tested IPsec. Although SCPS has been approved for use by CCSDS as an ISO standards working group, SCPS is nowhere near anywhere as widely used or as easily available for diverse platforms as the Internet stack and protocols standardised by the Internet Engineering Task Force (IETF).

10. BEYOND CLEO

The successful demonstration of CLEO has now led to follow-on work taking the concept further, with the announcement of the IRIS (Internet Routing in Space) project to place a router as a payload on a geostationary Intelsat satellite.[18] This router will interconnect C- and Ku-band transponders, allowing communication between different frequencies without having to switch between them on the ground,[19] and this use of onboard switching can later lead to the use of onboard routing functionality with intersatellite links.[20]

11. CONCLUSIONS

IPv6 and IPsec have been tested successfully onboard a satellite in space. This shows that these additions to the Internet protocol, developed for terrestrial use, can also be used successfully onboard satellites.

The DMC satellites and the Cisco router in orbit continue to show that terrestrial Internet technology can be successfully reused in the space environment to form part of a combined merged space/ground architecture.

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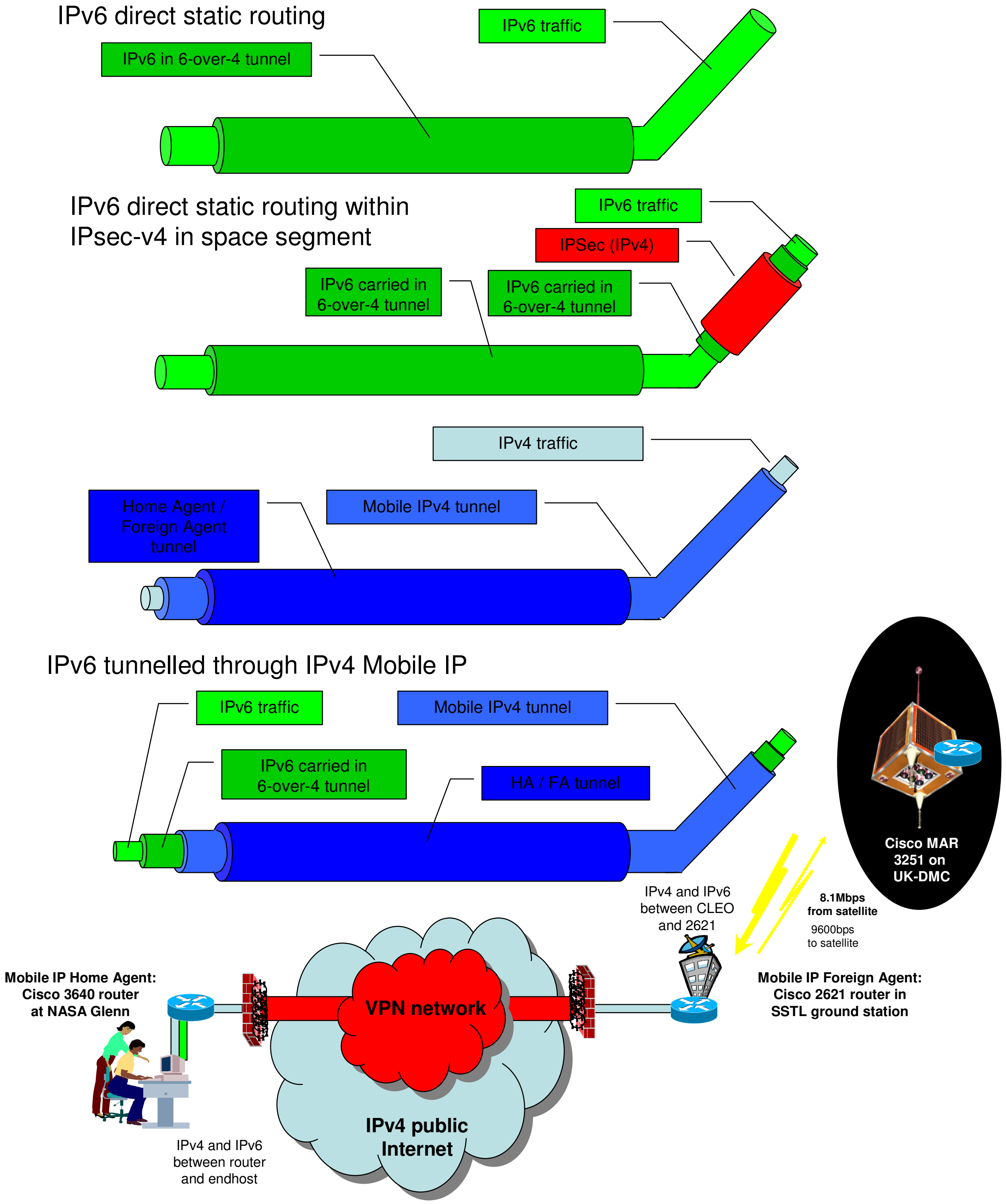

Fig 5: various access scenarios using the available tunnels

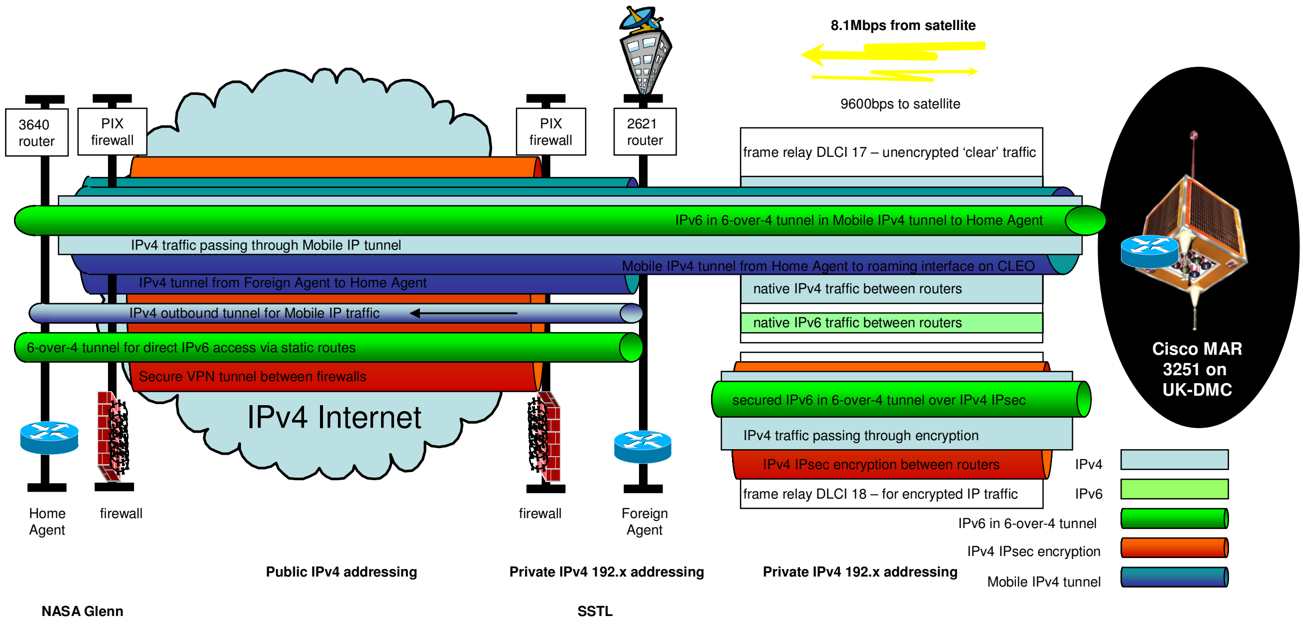

Fig 6: Conceptual illustration of IPv6 and IPv4 connectivity to CLEO, including tunnels