CANDOS IP MISSION SUPPORT DEMONSTRATIONS

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ABSTRACT

The Low Power Transceiver (LPT) Communications and Navigation Demonstration On Shuttle (CANDOS) flew onboard STS-107 as part of the Fast Reaction Experiments Enabling Science Technology Applications and Research (FREESTAR) Hitchhiker Payload. The flight hardware consisted of a first generation Low Power Transceiver (LPT) integrated with a commercial processor board functioning as the flight computer. The LPT development by ITT Industries has been funded as part of the NASA SOMO/SCDS Technology program. The CANDOS experiments included Space Network (SN) communications, Ground Network (GN) communications, Space-based Range Safety, Global Positioning System (GPS) Navigation, Mobile Internet Protocol (IP), and other IP in Space Applications. This paper will focus on how the ground stations were configured to support the Mobile IP and IP applications provided by the Goddard Space Flight Center (GSFC) Operating Missions as a Node on the Internet (OMNI) project, how the use of these protocols and applications benefited the operations and data delivery for all of the CANDOS experiments, and how this could be applied to future missions.

1. INTRODUCTION

The Low Power Transceiver (LPT) Communications and Navigation Demonstration on Shuttle (CANDOS) experiment had a fully successful flight in the cargo bay of STS-107. CANDOS was a part of the FREESTAR (Fast Reaction Experiments Enabling Science Technology Applications and Research) Hitchhiker Payload. Throughout the course of the sixteen-day mission, CANDOS had almost 60 hours of total contact time via its own communications system.

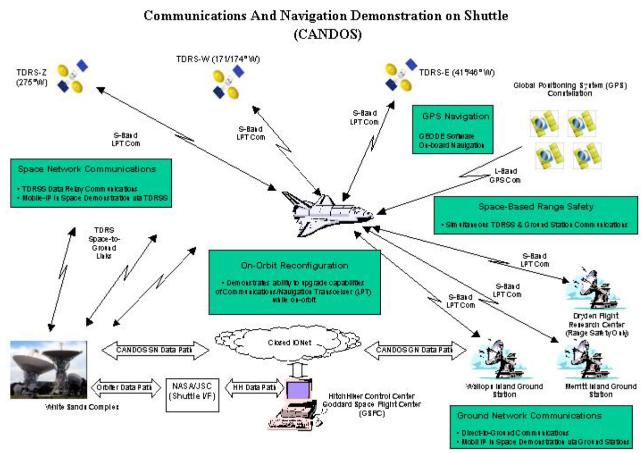

Figure 1 - CANDOS Experiment Overview

The experiment had five primary components. (See Figure 1.) These included Space Network (SN) communications and Ground Network (GN) communications, GPS Navigation, Space-Based Range Safety, On-Orbit Reconfiguration, and Mobile Internet Protocol (IP). The use of IP for all communications proved beneficial for all of these experiments.

2. CANDOS Flight Hardware

The CANDOS flight hardware consisted of a first generation Low Power Transceiver (LPT) integrated with a commercial processor board functioning as the flight computer, along with an S-Band Receive Antenna, GPS Antenna, Low Gain S-Band Transmit Antenna, and High Gain S-Band Transmit Antenna.

The LPT is a multi-channel, software programmable transceiver, capable of transmitting and receiving SN mode or GN mode S-Band signals while simultaneously receiving L- Band GPS signals. ITT Industries has developed the LPT, as part of the SOMO/SCDS Technology program.[1]

The flight computer integrated with the LPT for the experiment was a 686 processor running Redhat Linux 6.1. The Linux operating system provided the basic IP stack. A synchronous serial card provided the data interfaces between the LPT and the flight computer. The antennas were fix-mounted in the Shuttle payload bay, so antenna pointing was achieved by moving the entire Shuttle's attitude.

3. The CANDOS IP Network

All of the CANDOS communications links used the standard IP protocol and HDLC data framing.[2] The Tracking and Data Relay Satellite System (TDRSS) ground terminals located in White Sands, New Mexico – the White Sands Ground Terminal (WSGT) and the Second TDRSS Ground Terminal (STGT) – and the NASA ground stations located in Wallops Island, Virginia and Merritt Island (MILA), Florida were outfitted with additional equipment to support these links. (See Figure 2.) Each station was already connected to the closed NASA operational network, known as the Closed IONet. The additions to each station were a Cisco router and a Ground Station Router Interface Device (GRID). The additional equipment allowed the RF links to appear as serial port connections between the flight hardware and a ground station router serial port.

The Cisco routers were standard Cisco 2621 units. They were each tied into the Closed IONet and had one serial port connected to the ground station RF system via the GRID. Each router was configured to be a Mobile IP foreign agent, which is a standard Cisco IOS configuration option.

The GRID provided the channel coding functions and physical and electrical interfaces required to connect the standard router serial port to the ground station interfaces. This was only required because the already existing ground station interfaces do not match existing router interfaces and there was nothing available in the system to perform the channel coding functions. In the future the GRID functionality may be absorbed into either the ground station RF equipment or data handling equipment.

For the CANDOS mission, the GRID provided data scrambling and de-scrambling for all links and also performed Convolutional coding on the TDRSS forward links. The GRID does not perform any data routing or any other functions to the bit streams. The GRID has been developed at GSFC as part of the SOMO/SCDS Technology program.[3]

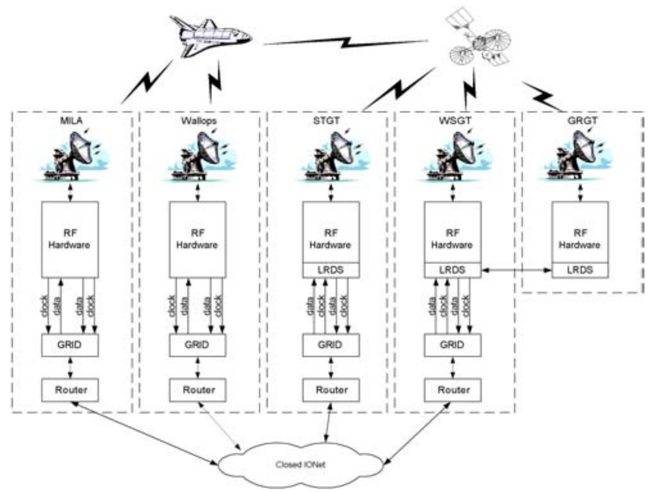

Figure 2 - CANDOS IP Network

4. CANDOS Mission Operations

CANDOS had 134 different events – TDRSS or ground station passes – over the course of the mission. Though it was a payload onboard STS-107, it was scheduled and operated as if it were a free flying satellite. TDRSS and ground station passes were possible when the LPT was the primary objective in the Shuttle attitude timeline, when Shuttle's attitude was adjusted specifically to point the experiment's antennas, and during other opportunities when a TDRS or ground station happened to be in view during other Shuttle activities. The data rates were limited to a maximum of 128 kbps in either direction due to the RF link margin. Typical links were 2 kbps up and 128 kbps down to ground stations and 32 kbps forward, 128 kbps return through TDRSS. A discussion of how the mission operations were achieved using IP follows. Other references are available which describe the IP experiments and results in greater technical detail.[4]

Mobile IP re-configured the data paths between the control center and the payload automatically as the link switched between ground stations. (See Figure 3.) The CANDOS flight was the first on-orbit demonstration of Mobile IP. At the start of a two-way event, the flight hardware would receive Mobile IP advertisements from the ground station router and provide the necessary responses to register the ground station router as the new path to the LPT. This would typically occur within seconds from the start of the event. At that point, any two-way IP operations were possible, including TCP/IP applications such as Secure Shell (SSH), Secure Copy (SCP), and Network Time Protocol (NTP). SSH was used to run scripts to configure the flight hardware and also to perform other onboard computer and file maintenance activities. SCP was one of the methods used to reliably transfer data files. NTP successfully kept the onboard clock synchronized within the experiment requirements.

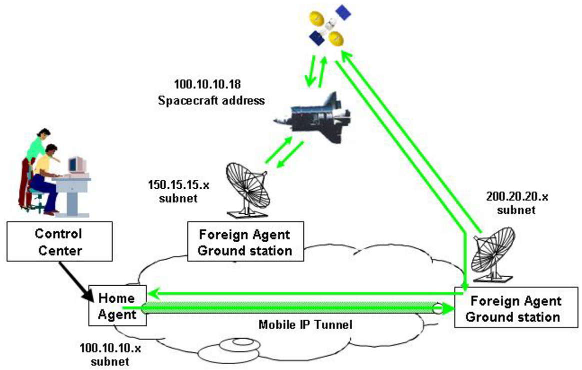

Figure 3 - Mobile IP

The use of Mobile IP aided the use of these TCP/IP protocols, since it allowed the LPT IP address to be static. In one case, the transfer of experiment data using secure copy (SCP) or FTP could begin during a ground station contact and seamlessly complete during a TDRSS contact. Another demonstration included experimenters logging into the flight payload from Marshall Space Flight Center. These experimenters only needed to know the IP address of the LPT and did not need to know which ground station was providing the data service. This transparency is highly desirable for Principal Investigators in the future who may desire to interact with their flight experiment without needing to get involved in the details of the data connection.

During all events, payload telemetry was being transmitted in UDP packets continuously. This provided the real-time housekeeping data stream. The IP routing allowed UDP packets to be sent to different destinations as determined onboard. The flight computer could decide where to send a message and it was properly routed without any changes at the ground station. This capability will enable future missions to transmit data to particular users based on events determined onboard. Data routing directly from the ground station, without having to go through the mission control center, will minimize the data latency – an important factor in the notification of a network of instruments or experimenters to short duration science events.

UDP based reliable file transfers were performed using the Multicast Dissemination Protocol (MDP).[5] By utilizing a UDP based file transfer protocol, files could be downloaded even during return link only passes. Data from the various experiments, as well as housekeeping data, were all kept in files onboard. Instead of "tape playbacks" or "recorder dumps", all data was retrieved using IP based file transfer protocols, either MDP or SCP. Both protocols guarantee a complete, error-free file delivery. Though it was checked as part of the experiment, there proved to be no need for any additional processing of the telemetry data to ensure that all the data was received correctly.

This reliable file delivery was also critical for the transfer of data to the payload. For the on-orbit reconfiguration experiment, for example, new software for the LPT's Digital Signal Processor (DSP) was to be installed during the flight. Reprogramming the communications hardware while in flight obviously must be done carefully. A straightforward method to ensure that the new software was transferred from the ground to the flight computer completely without error was critical. This was successfully accomplished by using SCP to transfer the file up to the payload.

The blind commanding operational scenario – commanding a spacecraft without a telemetry link – was demonstrated using UDP based commands. The UDP protocol does not require any acknowledgements, so the lack of a telemetry link was not an issue. Mobile IP, however, was not available to automatically configure the data path. For the blind commanding case, a tunnel had to be configured manually in the ground station router, so the commands would be routed from the control center to the correct ground station. This was the only time during the mission that any manual configuration of data paths was necessary.

5. Future IP Mission Support

The ALSAT-1[6] and CHIPSat[7] satellites are both currently operating in orbit using IP links through their own ground stations. The CANDOS mission successfully demonstrated the use of IP and standard IP applications on orbit via the NASA Space and Ground Network, however it was only a two-week experiment. In order to support IP operationally with the NASA Space and Ground Network, upgrades will need to be made to the station.

The use of TDRSS for IP communications to satellites provides some unique capabilities. An orbiting user can have line of sight to TDRSS for essentially an entire orbit. The recently implemented Demand Access System (DAS) Multiple Access (MA) return link allows a user to receive return link data at any time without scheduling, even continuously if desired. The combination of an on demand RF link with IP data routing allows a spacecraft to transmit data to any destination at any time without any ground controller interaction. The addition of this IP capability into the DAS MA return link is still in development, as well as a complementary DAS forward link. (See Figure 4.) The design of the TDRS satellites precludes the option of a true on demand forward link. An automated queued data delivery system is being investigated. A major benefit of the addition of a TDRSS DAS F/L capability would be the capability for one spacecraft to send a message to another without ground controller interaction or line-of-sight visibility between the spacecraft.

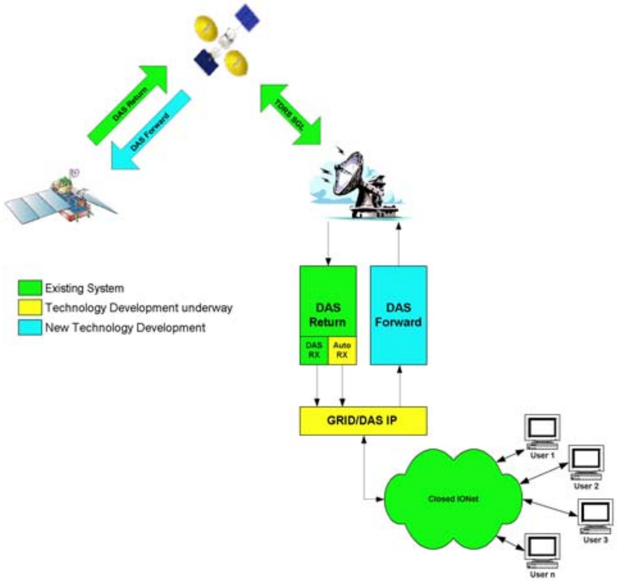

Figure 4 - Two-way DAS IP Service

Topics such as security, redundancy, line outage recording, IP addressing, and data quality monitoring, for example, still need to be dealt with in a manner that meets project requirements and is still scalable for multiple missions. As mission operations evolve to be based more on Internet technology, the role of the ground stations and the Space Network essentially evolves to that of an Internet service provider (ISP), albeit an ISP with some more stringent requirements. The application of standards, methods, and technology developed for the commercial Internet market whenever possible should minimize the maintenance and operations costs of the ground stations and missions.

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