In-Space Networking On NASA’s SCAN Testbed

Presented By: David Brooks/Vantage Partners LLC, Cleveland, Ohio
David.E.Brooks@nasa.gov

Authors:
David E. Brooks/VPL
Wesley M. Eddy and Gilbert J. Clark III/MTI Systems
Sandra K. Johnson/NASA Glenn Research Center
Agenda

- Motivation and Goals/Objectives
- Overview of SCaN Testbed
- Design Implementation Details
- Software Instrumentation
- Summary and Future Work
SCaN shall “provide Space Internetworking services to mission users” and “interoperate with external space networks that are compliant with space internetworking standards.”
Solar System Internet Implementation Challenges

- Requires protocol support across mission-developed and SCaN elements
- Limited number of reusable flight or ground software components
- Necessary standards still under development

- Commercial IT products do not support space mission needs
- Different operations concept between networking and legacy point-to-point communication services.
Goals and Objectives

SCaN Testbed Networking Portfolio

- Gain long-term operations experience with Space Internet
- Produce robust, flexible implementations for future missions
- Support network topologies that represent future mission complexity
- Mature the operational concept
- Integrate networking with realistic on-board data interfaces
- Include native support for security protocols operating across multiple layers
SCaN Testbed System Overview - Architecture
**SCaN Testbed Overview - Flight System & Initial Capabilities**

**Comprehensive testing of:**
- Ability to perform on-orbit updates
- RF and physical layer development platform
- Point-to-point physical and bit layer services between Software Defined Radios and Mission Operations Center
- Command and telemetry services

**Launch Software Capabilities**
- Launch waveforms: Compatible with the TDRS Space Network. Limited CCSDS Advanced Orbiting System (AOS) implemented.
- Avionics software: Focus on system control.

*Launched with minimal software to meet schedule constraint*
Baseline Network Point to Point Links Overview

**Flight Segment**
- **Fwd 72 Kbps** (GRC to STB)
- **Rtn 192 Kbps** (STB to GRC)

**Ground Segment**
- **CCSDS S-SN GW**
- **CCSDS Ka-SN GW**
- **CCSDS DTE GW**

**Flight Computer Aitech s950**
- **Fwd 18-769 Kbps** (GRC to STB)
- **Rtn 24-769 Kbps** (STB to GRC)

**Ground computer exchange**
CCSDS AOS Transfer Frames, Internet Protocol packets and Encapsulation Packets with the three ground gateways.

**Experiment Network**
- **IPv4**
- **DTN** (Nodes and BPSec)
- **COTS Application** (firefox ftp)
- **Diagnostic Tools** (ping iperf eping)

**Experimenter Machines (Linux)**

Ground gateways exchange CCSDS AOS Transfer Frames, IP and Encapsulation Packets with flight gateway. IP packets are exchange with ENCAP Internet Protocol Extension.

**Flight Computer Aitech s950**
- **Fwd 3-3.5 Mbps** (GRC to STB)
- **Rtn 10.5 Mbps** (STB to GRC)

**Ground computer exchange**
CCSDS AOS Transfer Frames, Internet Protocol packets and Encapsulation Packets with the three ground gateways.

**Ground computer exchange**
CCSDS AOS Transfer Frames, Internet Protocol packets and Encapsulation Packets with the three ground gateways.

**Ground computer exchange**
CCSDS AOS Transfer Frames, Internet Protocol packets and Encapsulation Packets with the three ground gateways.

**Ground computer exchange**
CCSDS AOS Transfer Frames, Internet Protocol packets and Encapsulation Packets with the three ground gateways.
Reusable Software Components

Ground Station/ MOC
Linux / x86-64

- Ground Test Tools
- Applications
- OS Provided
- Services

ENCAP
Network Interface
for VCID/SCID TF
(Kernel Module)

User space
AOS TF
Injection app

PHY Link Sync
Serial to User
space AOS TFs
(Kernel Module)

Flight Computer
VxWorks / PowerPC

- VxWorks
- Application
- ports: ION,
ping, httpd,
iperf

Service
Loopback

ENCAP to
MUX Kernel
Module

AOS-ENCAP
Convergence
Tasks

TDRSS-
compatible
waveform

Space Network
SYNC & CODING
RF

SDR / FPGA
SYNC & CODING
RF

Ground
Test Tools
Applications
OS Provided
Services

COTS
Apps

CFDP
BP / BPsec
LTP-UDP
TCP/UDP
IPsec
IPv4/IPv6
IPE
LTP
PRIV

ENCAP
AOS

COTS
Apps

CFDP
BP / BPsec
LTP-UDP
TCP/UDP
IPsec
IPv4/IPv6
IPE
LTP
PRIV

ENCAP
AOS

User space
AOS TF
Injection app

PHY Link Sync
Serial to User
space AOS TFs
(Kernel Module)
Software Instrumentation

Experiment Front End Processor

CCSDS GW
- Loggable CCSDS Statistics (ENCAP and AOS) in user space
- CCSDS ENCAP capture using COTS libpcap and tcpdump
- eping test application for ENCAP RTT and link errors

GRC GS

SN Statistics

Flight Computer

FS and SDRs
- Physical Link
- Tracking
- Health and Status
- Waveform Status

Encapsulation Packet Statistic @CCSDS GW:
- Number Received/Sent through GW
- Number of various Errors such as bad length, invalid ENCAP header, etc..
=>Readable in user space as a file

Synchronous Serial AOS Statistics @CCSDS GW:
- Number AOS TFs Received/Sent through GW
- Various Errors such as bad length, dropped frames
=>Readable in user space as a file

Networking/Flight
SPW and ENCAP Stats
(Primary Path APID)

Experiment Path Stats
(currently work/NITRO)
Conclusion and Future Work

• SCaN Testbed networking implementation and knowledge gained will enable NASA’s transition to Solar System Internet. This includes demonstrating IPv4 routing on a CCSDS reusable ground and flight software components that served to:
  – Produce a robust, flexible implementations for future missions
  – Create a baseline topology with CCSDS that integrates with future complex missions
  – Help to mature the operational concept by integrating CCSDS with a space testbed
  – Integrate networking with realistic space on-board data interfaces (Spacewire)
  – Include native support for security protocols operating across multiple layers (Secure DTN)
Conclusion and Future Work

• Foundation has been laid for cognitive networking capabilities research and development activities such as NASA Intelligent Routing (NITRO), Cognitive Networking (COGENT) and SCaN Testbed that evolves to Cognitive Communication project.
Space Protocol Research on the SCaN Testbed

**Application Transport**
- CCSDS 734.2-R-3
- CCSDS Bundle Protocol Specification
- Network Management Protocol
- Key Distribution Protocol
- Bundle Protocol Security (BPsec)

**Network**
- CCSDS 702.1-B-1
- IP over CCSDS Space Links
- CCSDS 133.1-B-2
- Encapsulation Service

**Data Link**
- CCSDS 131.0-B-2
- TM Synchronization and Channel Coding
- CCSDS 732.0-B-2
- AOS Space Data Link Protocol

**Physical**
- CCSDS 401.0-B-25
- RF Earth Stations and Spacecraft
- CCSDS 415.1-B01
- Data Transmission and PN Ranging for 2 GHz Link via Data Relay Satellite

**Cross Support SLE**
- CCSDS 911.1-B-3
- Space Link Extension—Return All Frames
- CCSDS 912.1-B-3
- SLE—Forward CLTU
- CCSDS 913.1-B-1
- SLE—IP for Transfer Svc

**Additional Protocols**
- CCSDS 911.2-B-2
- CCSDS 911.5-B-2
- CCSDS 911.1-B-3
- Space Link Extension—Return All Frames
- CCSDS 912.0-B-4
- CCSDS File Delivery Protocol
- CCSDS 912.11-B-01
- Data Transmission and PN Ranging for 2 GHz Link via Data Relay Satellite
- CCSDS 732.0-B-2
- AOS Space Data Link Protocol

**SpaceLink Extension**
- CCSDS 702.1-B-1
- IP over CCSDS Space Links
- CCSDS 133.1-B-2
- Encapsulation Service

**Additional Protocols**
- CCSDS 911.2-B-2
- CCSDS 911.5-B-2
AOS and ENCAP on SCaN Testbed
Acronym List

- **AOS** – Advanced Orbiting Systems
- **BP** – Bundle Protocol
- **CCSDS** – Consultative Committee for Space Data Systems
- **CSO** – Communication Service Office
- **DSE** – Deep Space Element
- **DTE** – Direct to Earth
- **DTN** – Delay Tolerant Networking
- **EBRE** – Earth-Based Relay Element
- **ENCAP** – Encapsulation
- **Fwd** – Forward service
- **GRC** – NASA’s Glenn Research Center
- **GS** – Ground Station
- **GW** – Gateway
- **ION** – Interplanetary Overlay Network
- **ISS** – International Space Station
- **LTP** – Licklider Transport Protocol
- **LTP** – Licklider Transport Protocol
- **NASA** – National Aeronautics and Space Administration
- **NEE** – Near Earth Element
- **NISN** – NASA Integrated Services Network
- **NITRO** – NASA Intelligent Routing
- **OS** – Operating System
- **Rtn** – Return service
- **RTT** – Round Trip Time
- **SCaN** – Space Communication and Navigation
- **SGSS** – Space Network Ground Segment Sustainment
- **SN** – Space Network
- **SPW** – SpaceWire
- **STB** – SCaN Testbed
- **TDRS** – Tracking and Data Relay Satellite
- **TSIM** – TDRS Simulator
- **TF** – Transfer Frame