Space Network IP Services (SNIS): An Architecture for Supporting Low Earth Orbiting IP Satellite Missions

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Abstract— **The NASA Space Network (SN) supports a variety of missions using the Tracking and Data Relay Satellite System (TDRSS), which includes ground stations in White Sands, New Mexico and Guam. A Space Network IP Services (SNIS) architecture is being developed to support future users with requirements for end-to-end Internet Protocol (IP) communications. This architecture will support all IP protocols, including Mobile IP, over TDRSS Single Access, Multiple Access, and Demand Access Radio Frequency (RF) links. This paper will describe this architecture and how it can enable Low Earth Orbiting IP satellite missions.**

Index Terms—**Networks, Satellite Communication**

I. Introduction

THE NASA Space Network (SN) supports a variety of missions using the Tracking and Data Relay Satellite System (TDRSS), which includes ground stations in White Sands, New Mexico and Guam. The user data is transferred to and from the ground stations over the closed NASA network, known as the Internet Protocol (IP) Operational Network (IONet). Though the data streams on the IONet are all IP, the data streams to and from the user over the TDRSS Radio Frequency (RF) links are usually not. The SN has been providing end-to-end IP service daily to the South Pole via the South Pole TDRSS Relay since 1997 [1]. Various IP experiments and demonstrations have been supported since, culminating with the Communications and Navigation Demonstration On Shuttle (CANDOS) experiment on board STS-107 in 2003 [2][3].

A new set of operational services, the Space Network IP Services (SNIS), is being added to the SN. These services will support users that desire end-to-end IP communications, in order to allow them to interact with their flight systems as IP nodes on the same network. The capabilities that were available on a limited and experimental basis previously, will become fully schedulable with the same availability and reliability as other SN services. Though the terms "flight systems" and "spacecraft" may be used throughout this paper, the SNIS system will work with any SN user's platform whether space-based, ground-based, or sub-orbital.

The use of end-to-end IP communications will enable operations concepts that are either currently cumbersome to implement or not possible. It is also anticipated that the use of commercial standards will reduce system development and integration and test costs, as well as provide flexibility for future requirements expansion.

II. End-to-end IP Communications

Currently the Space Network provides data interfaces between the user's control center and the ground station over the IONet. Though these interfaces use IP, either TCP/IP or UDP/IP, they do not provide an IP connection to the user's spacecraft. Any use of IP protocols for data transfer between the spacecraft and end user is not possible. As seen in the bottom two paths depicted in Figure 1, an SN user's data will currently be encapsulated in an IP packet by a gateway device at WSC and un-encapsulated by a device at the end user's location. These gateway devices require pre-pass configuration of data paths. Therefore, a user must know the source and destination of all spacecraft data a priori. If any distribution of telemetry data is required, it must first be routed to the pre-determined destination (usually the Mission Operations Center (MOC)) and then distributed. For some science applications, the delay of passing data through a MOC first, though possibly only on the order of half a second, may be undesirable.

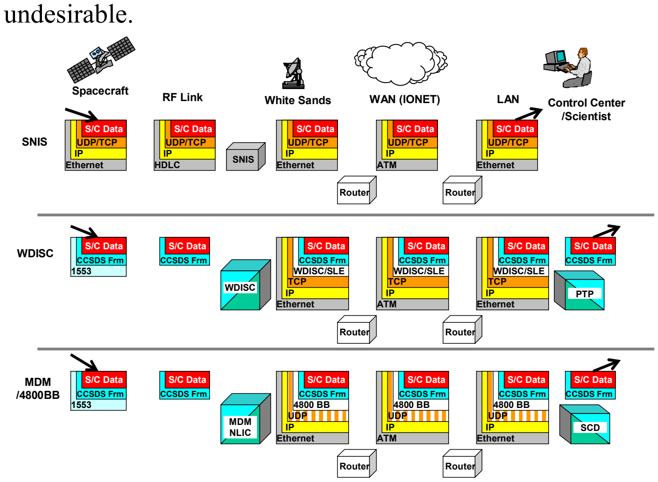

Figure 1 – SN Low Rate Telemetry Data Interfaces

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In the case of the SNIS user, the IP packets either originate or terminate at the spacecraft. This makes the use of any IP protocol for data transfer between the spacecraft and end user possible. There is also no requirement for a priori knowledge of data sources or destinations, eliminating the need for pre-pass data path configurations. Telemetry can also be routed directly to a destination without being sent to a MOC first, thereby eliminating some data delivery latency.

III. Operational Concepts and Scenarios

Once a spacecraft is connected as a node or subnet on a network, many operational concepts and scenarios are either enabled or enhanced. This is due to the combination of data driven data distribution and the many commercially available IP-based protocols and applications. In this section of the paper several sample operational concepts will be described. A reference diagram that will be used in describing the ops concepts is presented in Figure 2. Both Spacecraft A and Spacecraft B are connected to the IONet by their RF links. Spacecraft A is using SNIS and Spacecraft B is using some other ground station. Both MOCs are also connected to the IONet.

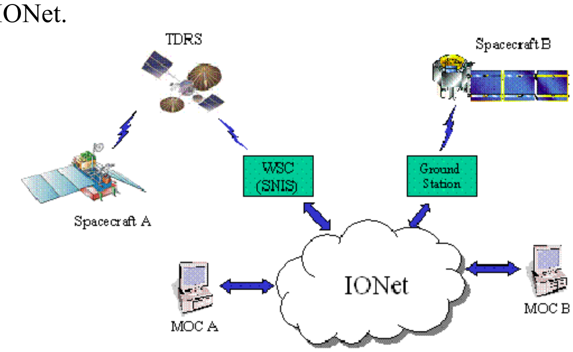

Figure 2 – Ops Concept Reference Diagram

A. Security

All spacecraft operations must be done in a secure manner. Even though operations will occur on the Closed NASA IONet, other safeguards will also be required. The use of end-to-end IP will make possible the use of Virtual Private Networking (VPN), IPsec, and other security solutions currently available and being developed for secure Internet applications.

For example, MOC A may establish a VPN with Spacecraft A. The end points of a secure tunnel are the spacecraft and the MOC. The secure data packets will route through the IONet and the TDRSS links while still being protected. The advantage for the Space Network is that any end-to-end IP security solution, such as a VPN, will be completely transparent to the SN. Since security is a great concern to the Internet community at large, there will be constant developments of IP security solutions. SNIS will be in the position to take advantage of these developments as they occur.

B. Mobile Network Connectivity

SNIS will support the Mobile IP and Mobile Routing standards. These protocols will allow the data paths to the user spacecraft to be automatically configured at the start of a TDRSS event. Routers located at the White Sands Complex will act as Foreign Agents and transmit Mobile IP advertisements over the TDRSS Forward Link. The SNIS user will then be able to register its new connection to the network over the TDRSS Return Link and a Mobile IP tunnel will automatically be established between the spacecraft and its home agent. When a handover between TDRSS satellites or between TDRSS and a ground station occurs, the data paths will switch without the need for any manual reconfigurations at the stations or the MOC.

The Mobile IP tunnels are only required for the routing of forward Link data. Any return link data will be routed as soon as the packets get to a router at White Sands, since they already have a valid destination address. Therefore, the common return link only support mode will automatically route data without pre-configuration or Mobile IP.

The ability to send data to a destination without knowledge of the data path to that destination is now a standard method of operations on the Internet. As more autonomous satellites and satellite operations control centers are developed, this ability will become a requirement for satellite operations. The mobile network protocols will satisfy this requirement.

C. Science Alert Notification

An increasingly common science mode of operations is the immediate notification of other instruments, telescopes, or facilities upon the detection of a specific event, such as a gamma-ray burst. The shortest delays possible in the distribution of the science alert are desirable for maximum science return. A SNIS user will be able to transmit an alert notification that will be routed directly from the ground station to the desired destination or destinations, if multicast is used. The combination of IP data routing and the TDRSS Demand Access System (DAS) Return Link will allow a spacecraft to send data to any destination on the network at anytime.

The example scenario would occur in the following manner: Spacecraft A detects a gamma-ray burst. The spacecraft transmits an alert packet over its DAS Return Link, which is always listening for transmissions from Spacecraft A. At the ground station in White Sands, the alert packet reaches a router after the return link signal has been demodulated and decoded. The router forwards the alert packet to the destination or destinations addressed in the packet's IP header.

Using IP, the science alert packets can be seamlessly inserted into any ongoing spacecraft housekeeping telemetry stream. Quality of Service (QoS) methods may be used to prioritize and route the packets leaving the spacecraft in realtime.

D. Virtual Crosslinks

The destination address of an IP spacecraft's data packet can be another spacecraft or other platform. If it were two spacecraft, they could be on other sides of the planet, but still be communicating as if they had a crosslink. As long as both spacecraft were connected to the network at the same time, they would communicate just like any other network nodes. For example, Spacecraft A could be a low Earth orbiting SNIS user and Spacecraft B could be a geosynchronous Earth science satellite with a continuous IP connection to a ground station. Spacecraft A and B just address their IP packets to the other spacecraft's IP address.

E. Data File Delivery

A common operational requirement is the reliable delivery of files to and from a spacecraft. This is also a common requirement for Internet users, so there are many IP-based file transfer protocols available. There are protocols available using both UDP, such as CFDP, MDP, NORM and TCP, such as FTP and SCP. If Spacecraft A were directly delivering files to MOC A or even Spacecraft B, the entire operation would be entirely transparent to the Space Network. The file packets would just be more IP packets flowing through the system.

The capability to provide Store and Forward file delivery service is also being considered for SNIS. This service would provide a server at White Sands that would temporarily hold user's files until they were either forwarded to the spacecraft, MOC, or other destination. This would provide a rate buffering service and also provide protection from terrestrial network errors.

IV. Preliminary Architecture

In order to implement SNIS such that IP services can be provided at the same levels of reliability as other SN services, two fundamental types of interfaces must be made. The first set of interfaces is to commercial routers. The connections to and from the RF equipment at the White Sands Complex (WSC) must be made to appear as standard serial port interfaces to the routers. Once that is achieved all of the routing, Mobile IP, and other protocols that exist in a standard router will "magically" become possible over the TDRSS RF links. The second set of interfaces is to the WSC scheduling, monitor, and control systems. These interfaces will allow the SNIS users to schedule their services and monitor the performance through the same interfaces that are standard for all SN users. These interfaces to the WSC systems will also give the visibility for the automatic fail over capabilities required for the SN to maintain the high availability and reliability metrics.

As seen in Figure 3, SNIS is basically the addition of a new data path between the existing TDRSS low rate user data streams and the Closed IONet. SNIS is not intended to replace any of the existing data services. It will be a new alternative for future missions.

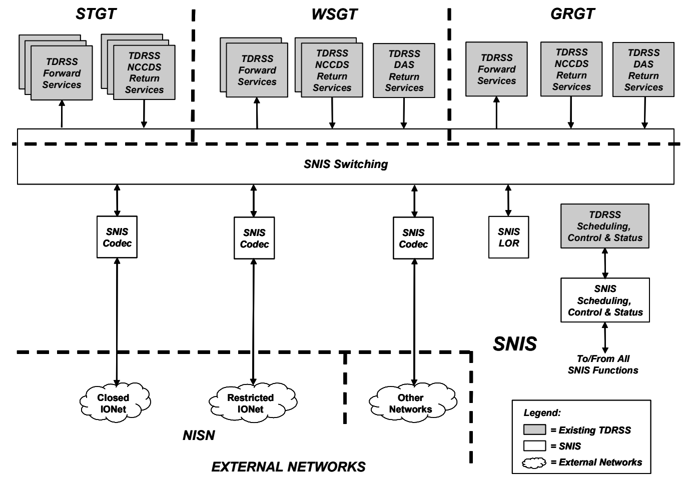

Figure 3 – SNIS Preliminary Reference Architecture

The additional coding and decoding functions included in the SNIS codecs are required since SNIS users will most likely use standard channel coding for RF link performance. Currently, the equipment at White Sands will not perform these functions, such as Reed-Solomon decoding return link data or convolutionally encoding the forward link data. A commercial router will not perform these functions either. Therefore, SNIS will have to add these functions to WSC. The SNIS codec will also provide the electrical interface required by a standard router serial port. The data stream to and from the router will be IP packets in frame relay/HDLC frames.

The interfaces to the WSC scheduling, monitor, and control systems increase the SNIS implementation complexity due to the existing WSC system. Because these issues are unique to the Space Network, they would not have to be duplicated for any ground station IP service implementation. Each ground station would have its own scheduling, monitor, and control system, but they typically do not have the same interface complexities as White Sands.

The goals for the SNIS implementation are to maximize the use of commercially available hardware. The system should be modular and scalable in order to expand the capabilities and services as the user requirements increase and/or new IP technologies develop.

V. Conclusion

The SNIS development is underway. The Systems Requirements Review is scheduled for Spring 2005 and 2007 is the year targeted for transition to full operations. Missions supported by SNIS may include Space Science and Earth Science LEO missions, Lunar Exploration missions, the Crew Exploration Vehicle, Earth Science unmanned aerial vehicles, and scientific balloons.

Current updates about the status of the SNIS development can be found at http://snis.gsfc.nasa.gov.

REFERENCES

[1] D.J. Israel, "The South Pole TDRSS Relay (SPTR)," Astrophysics From Antarctica, ASP Conference Series Volume 141, G. Novak and R. Landsberg, Eds. Astronomical Society of the Pacific, 1998, p. 319-321.

[2] D. Israel and D. Zillig, "CANDOS Experiment Overview," presented at SpaceOps2002, Houston, Texas, October 2002.

[3] D. Israel et al, "STS-107 Case Study: End-to-End IP Space Communication Architecture," Ground Systems Architectures Workshops (GSAW) 2003, Manhattan Beach CA, March 2003.

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