Internet Data Delivery for Future Space Missions[1]

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Abstract— **Ongoing work at National Aeronautics and Space Administration Goddard Space Flight Center (NASA/GSFC), seeks to apply standard Internet applications and protocols to meet the technology challenge of future satellite missions. Internet protocols and technologies are under study as a future means to provide seamless dynamic communication among heterogeneous instruments, spacecraft, ground stations, constellations of spacecraft, and science investigators.**

The primary objective is to design and demonstrate in the laboratory the automated end-to-end transport of files in a simulated dynamic space environment using off-the-shelf, low-cost, commodity-level standard applications and protocols. The demonstrated functions and capabilities will become increasingly significant in the years to come as both earth and space science missions fly more sensors and as the need increases for more network-oriented mission operations. Another element of increasing significance will be the increased cost effectiveness of designing, building, integrating, and operating instruments and spacecraft that will come to the fore as more missions take up the approach of using commodity-level standard communications technologies.

This paper describes how an IP-based communication architecture can support all existing operations concepts and how it will enable some new and complex communication and science concepts. The authors identify specific end-to-end data flows from the instruments to the control centers and scientists, and then describe how each data flow can be supported using standard Internet protocols and applications. The scenarios include normal data downlink and command uplink as well as recovery scenarios for both onboard and ground failures. The scenarios are based on an Earth orbiting spacecraft with downlink data rates from 300 Kbps to 4 Mbps. Included examples are based on designs currently being investigated for potential use by the Global Precipitation Measurement (GPM) mission.

Table of Contents

Introduction

The goal of an Internet data delivery approach is to provide the simplest, most cost-effective delivery of science data when and where needed. The Operating Missions as Nodes on the Internet (OMNI) Project at Goddard Space Flight Center (GSFC) has been demonstrating these concepts and working with future missions to baseline these approaches. This paper describes how Internet technologies can facilitate new kinds of space operations and support a vision for operations of earth and space science missions. The application of Internet technologies in space systems will increase mission flexibility. The key issues for future National Aeronautics and Space Administration (NASA) missions have less to do with protocols and more to do with basic communication problems. Higher data rates, radio frequency (RF) versus optical, longer distances, and cross-link communications are but a few of the issues.

Over the past 40 years, NASA has gone from developing and operating custom solutions to adopting more commercial off-the-shelf (COTS) products and industry standard solutions. There was a time when NASA drove communication technology not only in space, but also on the ground. The NASA need to move large volumes of data reliably over noisy channels in a time-critical environment was out in front of any other organization. Now, with the explosion of growth in commercial terrestrial communications, the space community has the opportunity to use technologies into which the private sector has poured billions of dollars. NASA Communications (Nascom) has demonstrated the value to NASA in changing to IP on the ground. The opportunity now exists for NASA to complete this transition in space.

This paper will briefly describe the methods and protocols that NASA previously used to communicate with its spacecraft. The discussion then describes newer approaches, some of which are being studied under contract for the GSFC for the Global Precipitation Measurement (GPM) mission. This possible GPM approach uses standard Internet technologies and protocols to support all aspects of data communications with the spacecraft.

NASA/GSFC LEGACY MISSION SUPPORT INFRASTRUCTURE

Operations and the necessary infrastructure for early NASA spacecraft communications and control was very labor intensive, requiring a large support staff to monitor and maintain the communications lines between ground stations, control centers, and users. In addition to the support staff, other factors had to be reflected in each mission's design, often in form of unique application code. The first factor was the large ratio of data rates for downlink (telemetry) and uplink (commanding). Another factor stemmed from the problems typically encountered during the integration and test (I&T) phase of the mission.

The Nascom group provided the support to develop, manage, and operate the NASA communications backbone. The early paradigm for mission support also required a dedicated (normally either 24x7 or 12x5) operations team to monitor the spacecraft's health and safety and generate command loads to support spacecraft operations and the instrument's science collection activities.

Nascom Support

NASA initially used a communications backbone that consisted of specially developed hardware and software components. This legacy system required constant monitoring to support all of the on-orbit missions. Installing new features required extensive development and testing efforts. The Nascom group provided the support personnel who were responsible to continually manage the lines and circuits to ensure that the operations team could communicate with the spacecraft on an as-needed basis. Using this type of a legacy system from the 1980s, Nascom employed a staff of 70 programmers to develop and maintain the communications systems. Figure 1 identifies the underlying data delivery protocols that Nascom has used since the early 1960s as well as the network throughput capacity using these protocols during that period.

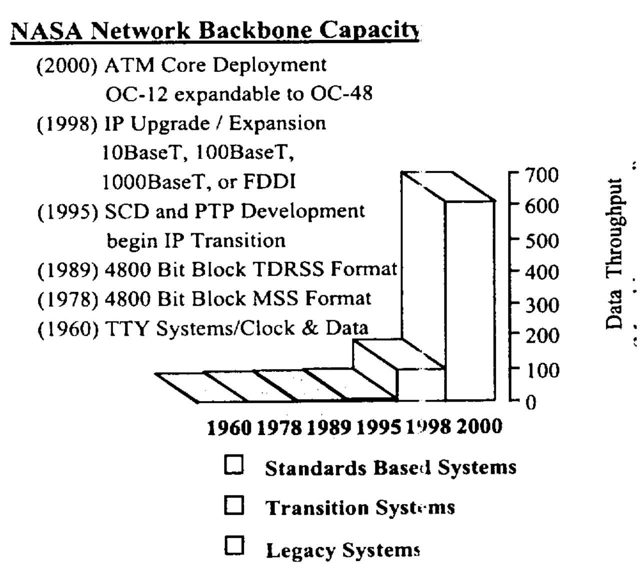

Figure 1. NASA Data Delivery Protocols – Evolution and Throughput Capacity Upgrades

As can been seen from Figure 1, as Nascom moved to more standard protocols the throughput capacity increased. This allowed Nascom to support missions with progressively higher data rates.

Flight Operations Team (FOT)

The FOT provides spacecraft support to ensure the health and safety of both the instrument suite and the spacecraft, monitoring the spacecraft for anomalies and generating command uploads on a daily basis to support the spacecraft and science operations. An operations team was often required to provide continuous, 24-hour operations for spacecraft support. At best, the spacecraft required less than full-time support by an operations team for either an 8x5 or 12x7 effort.

Earlier NASA missions employed an old style tape recorder to store science and housekeeping data. When the spacecraft was in contact with a ground station, the recorder was commanded to rewind and begin a playback. This was the only operational method to downlink data; the reliable transfer of this data was accomplished by using various data coding and forward error correction (FEC) schemes, such as convolutional encoding or Reed-Solomon encoding. These methods were normally sufficient to ensure reliable data delivery even with a noisy RF link, albeit at the sacrifice of some throughput.

With the advent of the next generation of missions, NASA moved to a space-qualified solid-state recorder (SSR), but the SSR still emulated the older style tape recorders. The use of the on-board SSR was a step forward for the spacecraft; however, the FOT was still charged with the complex task of data management and playback of the recorder's storage. With either of the previous data storage techniques, there was no concept of files; the data was simply stored on-board as a stream of data. Whenever a station contact occurred, the operations team would request a data downlink based upon the on-board computer's addressing scheme. In addition to the overhead associated with this version of NASA's legacy systems, each mission required unique development to use the Nascom-standard 4800-bit block communications protocol. Once the spacecraft transmitted the data, the mission-unique ground-based systems would reassemble the data and begin the initial level-zero processing, the purpose of which was to verify that all data was received without errors; any problems would result in a request to retransmit the stored data.

Another time-consuming role for the FOT was the formatting of command loads and ensuring that the commands were reliably uplinked to the spacecraft. While supporting legacy missions, the FOT employed various methods to ensure command uplink occurred correctly. These methods were normally predicated upon a form of command operations procedures (COP) protocol [1]. Possible variations of this protocol (a) allowed commands to be received in sequence (normal commanding), (b) allowed commands to bypass the sequence checks (bypass commanding), or (c) allowed special HW commanding to reset the on-board computer (OBC) to a "safehold" or cold-start state.

Command Uplink and Telemetry downlink differences

Under the legacy mission domain, a major concept was that the telemetry downlink formats and protocols were different from those in the corresponding command uplink, e.g., the COP protocols. These different formats and protocols had to be tested prior to launch to ensure that the spacecraft had been successfully checked out. Under this approach, the telemetry downlink was used to provide a return link to verify that the commands were received in the correct sequence. To correctly design this type of an approach, unique application SW was required both on the ground and on the spacecraft to ensure that commands were not received out of sequence. This unique application code also required extra test time to ensure that the code worked as designed.

Integration and Test (I&T) Phase Support

During the I&T phase of the mission, unique HW and SW were required to completely check the instrument suite and the spacecraft. Also, the testing process was repeated numerous times between instrument I&T and then final spacecraft I&T. Typically, the instruments were all tested independently at their distant development facilities, and then a whole new test phase was conducted as each instrument was mated to the spacecraft. With this "waterfall style" approach to I&T, interface problems often are not detected and corrected until the end when the cost of fixing the problem has increased dramatically.

NASA/GSFC Nascom Transition

As indicated in Fig. 1, Nascom began an evolution towards a ground-based IP routing mechanism by developing and deploying the small conversion devices (SCD) and programmable telemetry processors (PTPs). These devices supported the use of IP for the ground transport of data; however, at that time there still were no modifications to the spacecraft on-board systems or the ground support system.

After the IP transition (which could be regarded as a watershed event), Nascom only required a staff of 5 programmers to maintain the communications system. Additionally, with the switch to an IP ground-based communications system, Nascom was able to reduce the operations staff by consolidating systems and responsibilities. Another benefit of the IP transition was that Nascom could now more thoroughly use commodity-level standards and COTS HW solutions to transport the data received at a ground station. With the IP transition approach, Nascom ultimately supported a dramatic increase in the overall data throughput rates. However, the basic spacecraft and ground systems were still based on the legacy concepts; NASA/GSFC had not begun to incorporate the concepts of the Internet protocols in a complete end-to-end approach.

This all changed in the mid-1990s; NASA/GSFC began funding concepts and prototyping efforts to explore the use of a full IP-based communications protocol for space missions. This approach is leveraged against the Open Systems Interconnection (OSI) seven-layer reference model for data communications as noted in Figure 2.

The OMNI Project at GSFC provided a focal point not only for IP-based prototyping to identify concepts, rationale, and requirements for the full use of IP for space missions but also for testing and evaluating the various IP-based approaches and solutions.

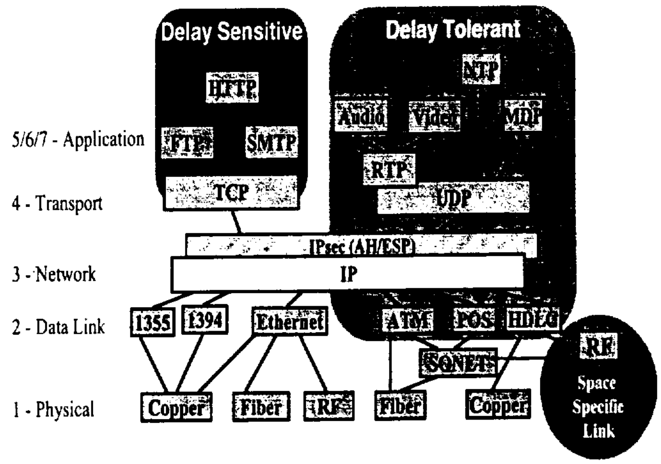

Figure 2. OSI Reference Model for space missions

Potential New Approach for GPM

In 2002, the OMNI Project began studying data system concepts for the GPM mission to identify and document how IP could be used in both the space segment and the ground segment. The essential objective was to route data from the instruments on-board the spacecraft all the way to the end users at either the mission operations control center or any group of science users. The GPM mission architecture, data flows, and concepts are described in greater detail in the draft Global Precipitation Measurement (GPM) Spacecraft and Instrument Telemetry Data Flow Interfaces and Operations Concepts document [2]. A draft spacecraft architectural system, as depicted in Fig. 3, was identified to support the GPM mission. This architectural concept employs fault-tolerant concepts with dual Ethernet Local Area Networks (LANs), dual on-board computers (OBCs), and dual up/down cards that also perform more routing functions.

A major shift for the GPM mission is to replace the storage concept, since the GPM spacecraft will be designed with a modern operating system that supports file management. The GPM spacecraft will store the science data as files rather than storing the data as a stream onto a SSR.

Another conceptual change under review is the data transport mechanisms used to support the spacecraft data transfer (both uplink and downlink of data). A fully redundant Ethernet LAN is being considered to support data transfer between the science instruments, the on-board computers (OBCs), and the up/down cards using UDP/IP packets to transport the data. However, a MIL-STD 1553 data bus is used as the data transport mechanism among other spacecraft subsystems using the current data packet concepts (e.g., between the attitude control subsystem and the OBC). With the insertion of the IP suite, any previous unique application code to support data transport could be removed since the data transport layer is inherent within IP.

Additionally, the OMNI Project suggested the use of HDLC framing for the link layer for the space-ground RF transmissions. The proposed use of HDLC is not considered risky, because HDLC is the dominant link layer standard in terrestrial networks. Further, currently there are eighty spacecraft that currently employ this link layer framing technique. GSFC has funded additional studies on the use

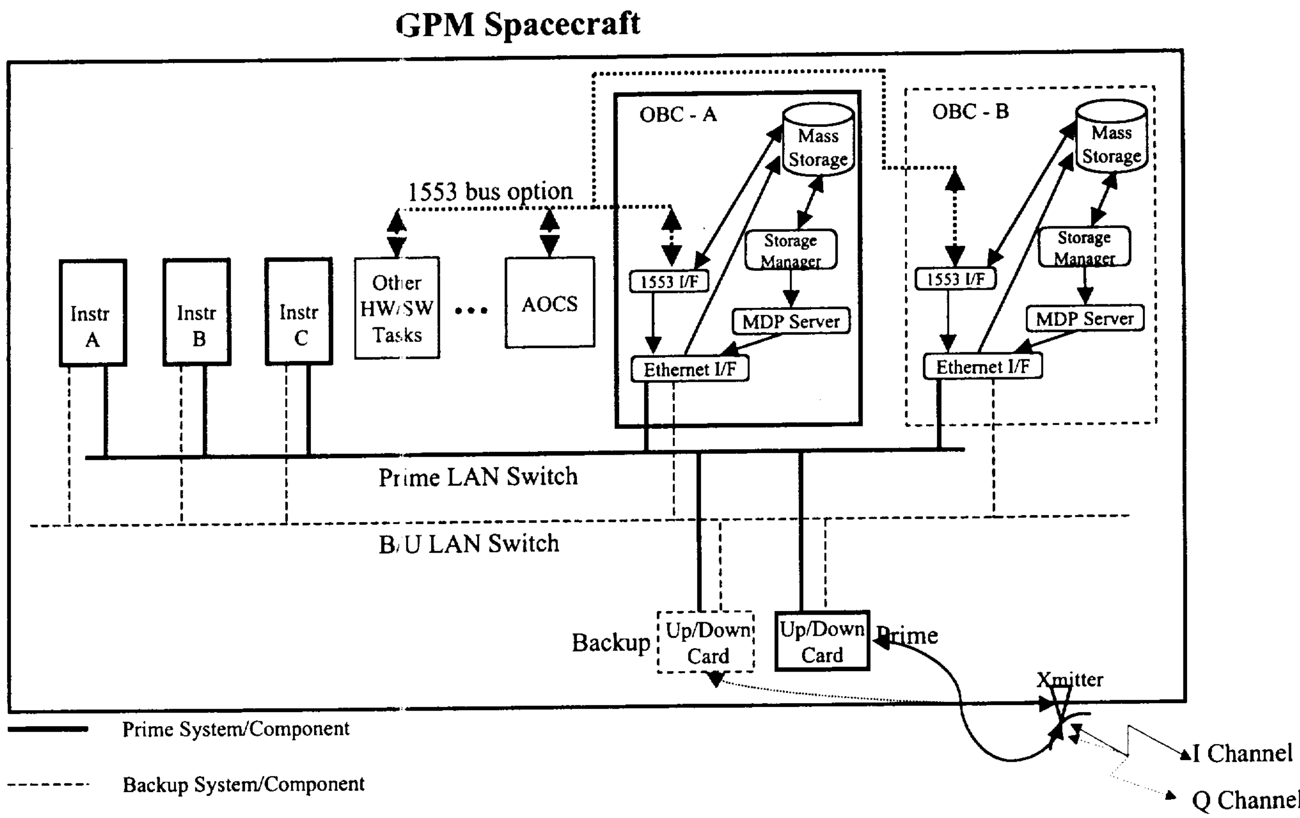

Fig 3 Proposed Architectural Concepts for GPM Spacecraft

of HDLC as a link framing technique on noisy space links; including a study completed by ITT Industries on the use of HDLC framing compared to CCSDS framing. These studies and results can be found on the OMNI web site[2].

The OMNI Project also proposed that the GPM mission use a standard router at the ground station with the corresponding IP mobility and security protocols enabled. These capabilities would assist the GPM mission to pass a NASA/GSFC security audit and would support the ability to more freely automate the commanding functions when an uplink pathway is needed to command the spacecraft.

The data transfer mechanisms were further refined with the following application controls:

- On-board science data transport using UDP/IP packets
- Data downlink, including the real-time spacecraft housekeeping data (in UDP/IP packets) and science data file transfer using the multicast dissemination protocol (MDP) application [3],
- TCP/IP for reliable real-time commanding and ack/nack confirmations
- UPD/IP for commanding in the blind

[2] http://ipinspace.gsfc.nasa.gov/documents/

On-board science data transport concepts

The science instruments format their data into UDP/IP packets for transport to the OBC via the Ethernet LAN; the real-time housekeeping data are sent to the OBC via the MIL-STD 1553 bus. In the OBC, the science data are removed from the UDP packets and stored into files. These files normally contain one minute's worth of science data; but the OBC can be commanded to use different time slices to handle different situations, like a TDRSS handover. The OBC contains a storage management (SM) task, which provides file management for the spacecraft. It opens new files, adds the data from real-time UDP packets into the files and then closes the files when the maximum time limit, usually one minute, is reached. The SM task then moves the file into the "hot directory" for MDP to begin the associated processing to downlink the file. In this example, MDP acts as the initiator of the file transfer to the ground.

Data downlink from spacecraft to ground station

The data downlink consists of both real-time housekeeping data in UDP/IP packets and the science data files downlinked using an MDP server task on the spacecraft.

These application data, both real-time and science data are inserted into UDP/IP packets with the appropriate header formats, including the Ethernet, IP, and UDP headers. The data are transferred to the up/down card/router. The up/down card throttles the data to the I and Q channels at an average rate of 150 kbps. When required, the mission operations center (MOC) can schedule an S-band single access (SSA) pass to provide an increase to the downlink rate and provide the capability of downlinking a large volume of data in a short period of time. The MOC would schedule an SSA pass in the event that there is a backlog of science data on-board the spacecraft occurring from a long TDRSS outage (over thirty minutes in duration). Shorter outages resulting from TDRSS handovers, or DSN zones of exclusion, will be handled by the excess bandwidth within the multiple access (MA) link.

The router or up/down card extracts the application data from the Ethernet header and checks the UDP/IP header fields and determines that the data are external to the local network. The up/down card is responsible for adding the link layer header/trailer artifacts. The data are inserted into a new packet using an HDLC header frame and "bit stuffed" to mask any application data patterns that could match the HDLC one-byte flag pattern; this bit stuffing ensures that the HDLC flag byte can be used as a frame delimiter. An OMNI Project study using three current NASA missions (WIND, POLAR, and SOHO) concluded that the bit-stuffing overhead averaged approximately 1% for the set of sample science data. Additional details are presented in the OMNI paper [4] HDLC Link Framing for Future Space Missions.

The data are converted into a serial stream for transmission by the antenna to the ground site. At the ground station antenna, the data are received as a serial stream and transferred to a local router. The router strips and processes the HDLC frame header/trailer fields (e.g., the frame sync and the CRC information), checks the UDP/IP header information to determine the next destination for the data and begins the routing process for an eventual transmission of the data to that address. On the ground, the standard protocols are used to route the spacecraft's housekeeping data to the control center or any other desired location. On the ground, the routers continually monitor the data quality by checking the HDLC/Ethernet CRC information as well as the IP checksum and UDP checksum fields. The checks using these fields ensure that only "good quality" data are transmitted; no "bad quality" data would be transmitted to the end-user.

The GPM spacecraft may use the Multicast Dissemination Protocol (MDP) applications task, which guarantees reliable data file delivery over a variety of link types, either infrequent return links or full duplex links.

MDP is a reliable file transfer application built upon UDP and is one of many current applications used to support a reliable multicast transport (RMT) protocol. The Internet Engineering Task Force (IETF) has chartered a working group, the RMT WG, to standardize reliable multicast transport protocols for "one-to-many bulk data" transport. This working group is currently defining three protocol instantiations, which can be used to support a reliable multicast:

- NORM, the Nack Oriented Reliable Multicast protocol, which uses NACKS for reliability
- TRACK, TRee ACKnowledgment based protocol, which uses a tree for controlling feedback and repairs
- ALC, Asynchronous Layered Coding, which uses FEC based techniques and does not require any feedback

The OMNI group is currently using the MDP based approach for a reliable file transfer to support a space to ground transfer of the on-board files. However, the OMNI group is working with the RMT and will use one of the three defined approaches listed above, whenever they become standardized within the working group. Additional details on the roles, responsibilities, and charters of the reliable multicast transport working group are contained on the IETF web site [3].

With MDP, minimal, or no, operator intervention is required to downlink stored files. The OBC contains a storage management (SM) task, which acts as the initiator of the data transfer when a file is complete with its allotted science data. The SM task will put the science data file into the MDP's "hot directory", which triggers MDP to begin processing this file for downlink to the ground station. The MDP application will segment the science files into one Kbyte packets; MDP sends these 1-Kbyte packets to spacecraft's up/down card where the identical processing as discussed in the previous sub-section is done.

Once on the ground, the data are routed using the original destination information, as sent from the spacecraft. The real-time spacecraft data are forwarded to the MOC and used to monitor and trend the health and safety of the spacecraft and instruments. At the ground station, a variety of options are available to disseminate the science data, including file storing and forwarding, forwarding data as UDP packets to one central location, or multicasting these UDP science packets to many users, or any combination of these options.

File Store and Forward

As one of the scenarios, the data initially could be transferred to a client MDP task on the ground station. This MDP client task reassembles the 1-Kbyte packets into a copy of the original file and maintains the responsibility for ensuring data completeness by transmitting the necessary acknowledgments or negative acknowledgments. This MDP client task provides a post-processing option that enables this file to be transferred to any required user or group of users.

Real-time UDP packet transfer

As an alternative example, the real-time science data initially bypass the MDP client and are automatically routed to all science users who need the data for real-time displays. The data also are routed to the MOC (or any other central location) where an MDP client task reassembles the 1-Kbyte packets into the copy of the original file. This MDP client task performs the necessary acknowledgments or negative acknowledgments to ensure data completeness.

These data routing alternatives are examples of the ways in which the mission engineering trade space is opened up through the use of standard networking technologies and protocols.

Real-time TCP/IP commanding

Under the proposed approach, the spacecraft becomes a mobile node on a network and becomes attached to that network successively at different locations, i.e., the different ground stations. Advanced groups in private industry are

[3] http://ietf.org/html.charters/rmt-charter.html

currently addressing a similar issue in relation to wireless networking for cars, laptops, personal digital assistants (PDAs), and a multitude of other electronic devices that will be mobile and require IP network access. The IETF is currently working to establish the standards, practices and applications for wireless networking for mobile nodes.

GPM is considering the proposed use of standard mobile IP protocols to support the forward link required for a TCP/IP connection for real-time command delivery. The router located at the station will have both mobile IP and IP security protocols enabled to support the GPM mission. The router will act as the foreign agent and advertise its availability; this agent advertisement will be scheduled to occur several seconds before the actual time that the forward link is scheduled to begin. The spacecraft will respond to this advertisement and return authorization packets, which are routed to the MOC for authentication. Within a matter of seconds and with a minimum of 2-3 packets, the spacecraft and the MOC have established a tunnel by which data from the MOC can be uplinked to the spacecraft. This uplink data consists of command data, the MDP ACK list and the MDP NACK list. The command data are used to continue spacecraft and instrument operations and to maintain the health and safety of the mission. The NACK list is used to request retransmission of missing data while the ACK list is used to confirm the successful receipt of the data file at the MOC.

UDP/IP for commanding in the blind

The non-reliable data transport for command data is accomplished using a connectionless UDP session. This is similar in concept to what is done to support current mission with CCSDS blind commanding. In this scenario, no mobile IP routing is established since by definition, mobile IP implies a two-way connection. For blind commanding, it is necessary to establish a forward link to the spacecraft to uplink some type of data (commands).

Instead of mobile IP and the agent advertisement that would be performed by the ground station routers, the MOC manually establishes a tunnel to a specific ground station router; this would be analogous with the approach that the MOC's currently use to establish a session with a specific station/antenna as part of the pre-pass setups. The process can be automated to occur several minutes before a station contact, or, in the event of a critical spacecraft problem, the FOT can command it to occur when a station can communicate with the spacecraft. Once the tunnel is established between the MOC and the ground station, the command data are transmitted to the station in UDP packets, not a TCP byte stream as was done in the previous scenario.

Fail-over and recovery scenarios

GPM has considered the use of backup ground stations to support the mission in the event of a failure of the GPM-TDRSS communications link. In the event of this contingency situation, the data delivery requirements will be relaxed because of the somewhat infrequent station contacts. To fully support this scenario, the ground site(s) would only need to have a standard router that can support both IP security and IP mobility protocols. However, in this failure scenario, the real-time data would not always be flowing to all science users. The MOC would still be capable of providing the files for the complete set of science products. In the event of this failure scenario, a ground station would have approximately 4- to 8-minutes of spacecraft contact, with an average of approximately 7-minutes. During the contact, the MOC would command the spacecraft to downlink the data at a rate up to 4 Mbps, depending upon the station supporting the ground contact. The downlink rate needs to be sufficient to allow transmission of all science and housekeeping files and real-time spacecraft data and to ensure that NACKs/ACKs can be sent to the spacecraft before the end of the contact. Whatever data are not successfully transmitted during the contact will be resent at the next available station contact.

In this scenario, the GPM instruments continue to create the science data and the OBC will create the files corresponding to the data and put these files into the "hot directory". These files will reside on-board the spacecraft until the spacecraft establishes a downlink with the MOC. When the spacecraft has a downlink established, the MDP server automatically begins transmitting the files at the commanded downlink rate.

FUTURE EFFORTS

Complete security studies

Before any new mission is allowed access to the GSFC closed IP Operational Network (IONet); the project must first complete a Risk Assessment document that identifies the possible risks associated with adding this control center to the network, as well as the mitigation efforts to ensure data integrity and facility security. In addition to this standard risk assessment document, any mission using a full-up IP implementation would be required to complete an IP-in-Space Risk Assessment, as required by the NASA/GSFC IT security organization. The OMNI Project is actively working with the IT security organization and several of the security studies are currently under way.

Each new mission at NASA that plans to use an IP-in-Space architecture approach will be required to complete a corresponding risk assessment security study and document their risks and mitigation activities. The mission would submit these studies and documents to the NASA/GSFC IT security organization for ratification and acceptance.

Prototyping issues

The OMNI Project is tasked to complete several trade studies and prototyping efforts over the next year to provide additional input on how GPM could be designed to use the full IP implementation approach.

The OMNI Project has another effort underway to support a flight-based MDP system, which is scheduled to be tested in the summer of 2002 on the Communication and Navigation Demonstration on Shuttle (CANDOS) mission. This mission is part of a 16-day Shuttle flight, and has its own independent transceiver, which will be used to directly contact either ground stations or TDRSS, independent of the Shuttle communications system. CANDOS will demonstrate basic IP connectivity on the space link, mobile-IP routing, and reliable file transfer using MDP. The CANDOS mission is discussed in more detail in the paper "Space

Communications Demonstration Using Internet Technology"[5].

Another prototyping effort, by a separate group that develops flight hardware, is in the planning phase to develop a space qualified onboard LAN, including the up/down card/router; OMNI currently has scheduled this activity to be completed later this year.

CONCLUSIONS

As previously described in this paper, the full use of an IP implementation for a space mission can be done with minimum risk. A full end-to-end IP approach provides simple and flexible communications that manages all mission requirements.

Technically, IP works fine in space; there are no showstoppers. The only remaining concern is simply the application of a standard engineering process with the engineering solution space enlarged.

Organizationally, IP can enable a new way of doing business. IP enables advanced mission concepts (e.g., collaborative science) and allows better alignment with industry standards and products. IP supports a simpler, yet more capable, overall mission design and enables a simpler operations solution.

The OMNI Project has successfully completed prototyping and demonstration activities using a total end-to-end IP-based architecture. The OMNI Black Sea mission to test the prototype IP mission during a solar eclipse took place in 1999 [6], followed by the UoSat-12 mission [7], and the laboratory OMNI Flatsat development [8]. The OMNI Project is currently supporting the CANDOS mission. These approaches and results are documented on the OMNI website [4]. The OMNI Project has shown that a complete IP system not only can be done but also has been done. The next generation solutions are on the drawing board. The vision will include a full end-to-end IP solution that will evolve to support advanced mission concepts and profiles as depicted in Fig. 4, with levels of interoperability for future missions that have not been available in a cost-effective manner up to this time.

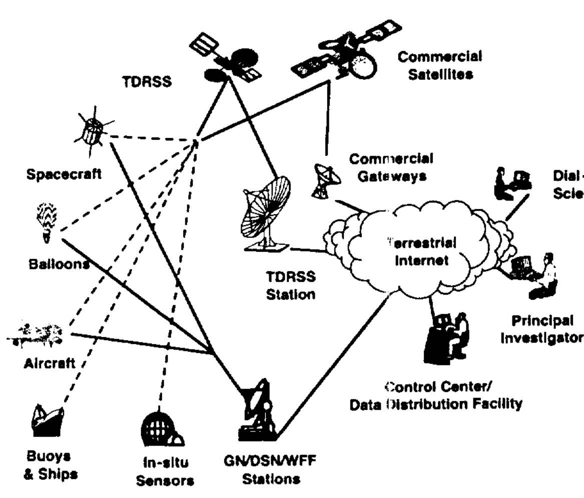

Fig 4. Evolutionary Vision of IP for Mission Applications

4 http://ipinspace.gsfc.nasa.gov/

This approach will make it easier for a constellation of satellites to directly communicate with one another, transferring data directly between the spacecraft rather than downlinking data, processing it on the ground and then uplinking the data. The use of commodity-level standard transport and routing protocols will reduce development costs, shorten schedules, and allow for earlier integration and test activities, thereby maximizing science return per dollar invested.

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Biographies

James Rash – Goddard Space Flight Center – Mr. Rash currently manages the Operating Missions as Nodes on the Internet (OMNI) Project in the Advanced Architectures and Automation Branch at NASA's Goddard Space Flight Center. He also leads development of formal methods capabilities with respect to agent-based systems. Previous assignments have included development of systems applying artificial intelligence and evolutionary programming techniques.

Keith Hogie – Computer Sciences Corporation – Mr. Hogie has an extensive background in designing and building satellite data processing systems, control centers, and networks at GSFC. He has developed ground data processing systems and control centers for over 14 spacecraft over the last 25 years at NASA/GSFC, and led the development of the NASA Internetworking Laboratory Environment in 1990. He is the technical leader of the OMNI Project at GSFC where he is applying his networking and satellite background to develop and demonstrate new communication technologies for future space missions.

Ralph Casasanta – Computer Sciences Corporation – Mr. Casasanta has been involved in ground system engineering for the SMEX and Triana missions since 1994; he is currently supporting the OMNI Project by developing mission specific documentation for the use of IP for total spacecraft and ground transport. Over the course of his 26-year career with Computer Science Corporation, he has been involved in software development, test and systems engineering projects for both NASA and the Federal Aviation Administration.