NASA's Unique Networking Environment

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Networking is an infrastructure technology; it is a tool for NASA to support its space and aeronautics missions. Some of NASA's networking problems are shared by the commercial and/or military communities, and can be solved by working with these communities. However, some of NASA's networking problems are unique and will not be addressed by these other communities. This paper examines individual characteristics of NASA's space-mission networking environment, explains how the combination of all these characteristics distinguishes NASA's networking systems from either commercial or military systems, and outlines some research areas that are important for NASA to pursue.

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1. Introduction

The purpose of this paper is to explain how networking in support of NASA's space missions presents research problems that are unique to NASA. There is no single characteristic of this environment that makes it unique. Each characteristic, considered separately, applies just as well to commercial networks or to military networks. However, only the NASA space-mission networking environment has all the features listed below. Thus, from a systems perspective, NASA has unique networking problems.

2. Distinguishing characteristics of the NASA environment

There are several characteristics of the networking environment for NASA's space missions that contribute to its uniqueness.

2.1. Inaccessibility to human operators

Networks which support NASA's space missions will be located at least partially in space. This remoteness means that the network will not be readily accessible to human operators to permit them to maintain the network, to upgrade the network, or to correct faults in the communications system. This inaccessibility intensifies the need for NASA's future networks in space to rely heavily on automation. Whereas the use of automation and expert-system technologies is a desirable feature in commercial networks, it is essential to the success of NASA's space missions.

2.2. Large space-to-ground communication delays

Networks to support NASA's space missions will include both networking components in space and networking components on the ground. The space-to-ground delay is very large compared to the transmission rates available with technologies of today, such as fiber optics, which will be used for the space and ground components. The end-to-end communication system, including the space-to-ground link, must operate as a unit to support real-time applications, both to support interactive command and control of mission operations from the ground and to support interactive communication between scientists located at their home institutions and their experiments located onboard a spacecraft. Hence, the disparity between transmission rates either on ground or in space and the space-to-ground communication delay is a major element of the space networking environment for NASA.

2.3. Integration of scientific usage with support operations

In the past scientists who flew experiments as part of NASA's space missions had to plan the entire experiment in advance. Once the mission was underway, it was impossible for the scientist to make even minor adjustments. NASA is committed to changing this mode of operation, so that scientists will be able to control their spaceborne experiments interactively. At the same time, flight-critical networking functions must be isolated from scientific users, to ensure the safety of the mission. Hence, networks on NASA's spacecraft must satisfy the seemingly incompatible requirements of being open to the scientific community, yet being closed to protect flight-critical functions.

2.4. Provision of support for man's presence in space

NASA will continue to support manned missions in space. Distributed systems will be the foundation of life-support for these missions.

3. NASA environment versus commercial and military environments

This section explains how the combination of the above characteristics makes the NASA space-networking environment unique.

3.1. Comparison and contrast to commercial networking environment

Similar problems must be solved in both the NASA and the commercial networking environments. For example, both communities are interested in designing evolvable networks, and both are interested in incorporating automation in the networking environment. As another example, network management, a research area that is currently receiving much attention, is clearly important in both environments. However, solutions to these similar problems will differ because NASA must solve them for the space environment. Problems are more easily solved for commercial networks, because ground-based networks are so easily accessible. NASA's networks will not be accessible after they are placed in orbit. Hence, while some features, such as modularity, evolvability, flexibility, reliability, and incorporation of automation, are desirable for commercial networks, they are essential for NASA's space networks, to ensure the success of its missions.

3.2. Comparison and contrast to military networking environment

Clearly, the military must also provide networking in space to support its missions. However, NASA cannot rely on the military community to solve its networking problems. Military systems and NASA systems share the first two characteristics listed above. That is, space networks for both communities will be inaccessible to human operators and both will have to accommodate the large space-to-ground communication delay. However, military networks will not be accessible by the scientific community and will not support the presence of man in space. In addition, the nature of military space missions differs significantly from NASA's. Military missions are directed towards defense or surveillance. NASA's missions are more exploratory in nature; they must be able to adapt to environments, such as the Mars atmosphere and landscape, that won't be completely understood ahead of time. Finally, the emphasis in fault-tolerance differs between NASA's networks and military networks. Military systems are developed to survive attack. The military approach is to divide and replicate functionality, so that the system will be able to survive destruction of multiple components. The fault-tolerance emphasis with NASA systems is on safety and reliability. NASA simply cannot afford to launch multiple shuttles, each with its own astronaut crew, with the expectation that only a majority of the shuttles and astronauts will return to earth.

4. Implications of NASA environment

The implications of NASA's unique networking environment in space are not yet fully understood. However, it is clear that distributed intelligent agents, either expert-system based or based on other technologies, will be commonplace in NASA's future space missions. These distributed intelligent agents must be able to accommodate the large space-to-ground communication delay, they must be able to integrate scientific usage of the communications system with support operations, and they must provide a level of safety and reliability that will enable man's presence in space. Networking capabilities to support these distributed agents, including the ability to guarantee low latency to selected applications and the ability to coordinate real-time distributed activities, must be developed. The degree to which standard networking protocols are capable of supporting distributed intelligent agents is not yet known. Modifications to these protocols are likely to be necessary. Research to develop network technology to support distributed intelligent agents should go hand in hand with research to develop the the technology for distributed intelligent agents themselves. Only then will NASA have the proper networking infrastructure to support its space missions.

5. Networking research areas

The above implications of NASA's space networking environment justify NASA's pursuit of research in the following areas: real-time networking in space, modification of standard protocols, and management of the distributed enterprise.

5.1. Real-time networking

NASA requires real-time networking to support distributed intelligent agents in space. Both low-latency protocols and techniques for coordinating the activities of multiple agents are necessary components of the required capability. NASA can leverage activities that are currently being pursued by both the commercial and the military communities. Various light-weight protocols are currently being developed for layers 3 and 4 of the Open Systems Interconnection (OSI) network model. The primary intent of these new protocols is to match the speed of the newly emerging high-performance protocols at the lower layers of the OSI model, such as the 100 megabit-per-second Fiber Distributed Data Interface (FDDI) token-ring protocol. The extent to which such light-weight protocols can support distributed intelligent agents is a research issue that NASA needs to pursue. Commercially available protocols may need to be modified, or new protocols may need to be developed.

5.2. Modification of standard protocols

The second area of research that NASA needs to address is the adaptation of standard protocols to the high-bandwidth space-ground environment. NASA should use standard network protocols wherever possible, both for economical reasons and to enhance evolvability and flexibility. However, the commercial and military communities are not solving NASA's unique problems. Hence, the standard protocols they develop need not be suitable for NASA's unique networking environment. Collaboration with the military community might reduce the effort that NASA would need to devote to this project. However, NASA must work on its own to the extent that its requirements differ from those of the military.

5.3. Management of the distributed enterprise

NASA's computing systems for its future space missions will be distributed in several different ways: distributed geographically, in space, on the ground, and between space and ground; distributed user-wise, supporting operations personnel as well as scientists; and distributed as to type of information being communicated over the system, integrating voice, data, video, command and control signals, and sensor data from instruments onboard various spacecraft. Hence, NASA's space-mission computing systems, such as the Space Station Information System (SSIS), are truly distributed enterprises. Management of such an enterprise is essential to its success. Management from the perspective of the end user must be emphasized, as well as management of system components. Current standardization organizations are developing network-management standards. NASA needs to determine how to apply these standard protocols and services to manage distributed systems in its unique environment. However, NASA also needs to address the broader systems issues, including development of a methodology for management of the distributed enterprise from the perspective of the end user, and development of enabling technologies to support this methodology.

6. Benefits to NASA

Networking is an infrastructure technology; it is a tool that supports NASA's space and aeronautics missions. Hence, the benefits of devoting NASA resources to the development of networking technology must be measured in terms of the support that such technology will provide to these missions.

NASA is funding the development of new computer architectures, such as the Spaceborne VHSIC Multiprocessor System (SVMS), specifically for use in the space environment. These new computers will function as part of a distributed system. Networking research is needed to enable the effective use of these new computer architectures in a distributed environment.

Development of technologies to support real-time networking in space will enable the use of distributed intelligent agents in NASA's space missions. The use of distributed intelligent agents will, in turn, enable increased automation of mission operations and functions, reduction in manpower needed to control the missions from the ground, and increased safety and reliability for the missions. Development of technologies for management of the distributed enterprise will also lead to a reduction in ground personnel needed to manage NASA's space missions. In addition, both time and money devoted to the planning and scheduling of space missions will be saved. Effective management of the distributed enterprise will enable more efficient utilization of scarce resources during space missions.

Finally, NASA is committed to providing the scientific community with interactive access to computing resources while a mission is in progress. The networking implications of this mode of operation, called telescience, have not yet been determined. However, the benefits of telescience to the scientific community are enormous. In the past, experiments had to be completely specified before launch. If there was a mistake in programming, or if unexpected conditions arose during the mission, there was a risk that the experiment would be a total loss. The development of telescience technologies will enable scientists to adjust their spaceborne experiments to conditions in near real-time, thus reducing the risk of failure of the experiment, reducing the need to reschedule the experiment for another flight, and utilizing scarce space resources more effectively.