A COMMUNICATIONS NETWORK ARCHITECTURE FOR FUTURE MARS MISSIONS. R. Gilstrap[1], R. Alena[1], and T. Stone[2], [1]NASA Ames Research Center, [2]Computer Sciences Corporation.

Introduction: Future Mars surface exploration missions will require a new communications infrastructure to support mission operations. Robotic missions will generate many different types of data, including science data from large instruments and small sensors, command and control, and telemetry. Human missions will incorporate additional data, including voice, video, and astronaut health data. The mission data must be distributed among a variety of entities both on Mars and on Earth. Key requirements of a communications network to support this distribution of mission data include:

- N-way communications between surface and orbital assets on Mars and a distributed mission operations center and science teams at various institutions on Earth
- Prioritization of data streams on limited-bandwidth links
- Reconfigurability in response to changing requirements
- Simple upgradeability as new technologies or protocols emerge
- Multiplexing of diverse applications, such as real-time sensor information and multimedia data, over a single channel
- Automatic reconfiguration in response to a failure of a component
- Robustness with respect to temporary outages of both surface and Earth-Mars links
- Resource sharing with commercial and international partners

Architecture and Technologies: To address these requirements, we propose a comprehensive communications network architecture (Figure 1) incorporating several key technologies: the Internet Protocol, small communications relay satellites, laser communications, delay tolerant networking, mobile ad hoc networking, and wireless sensor networks.

The Internet Protocol (IP) is the software standard underlying the Internet, providing a robust and scalable mechanism for computer systems and other devices to identify and route traffic to each other. IP can be run over a large number of physical link technologies. The overall architecture includes laser, radio, and wired links; IP successfully unites these disparate links into a single logical network that does not require network applications to be aware of the specific underlying link technologies. The use of IP also streamlines the task of building a merged space-ground communication network, which can then support with a single protocol end-to-end communication between a science instrument on Mars and an investigator on Earth. Additionally, the ubiquitous deployment of IP makes it possible to use publicly available tools for network monitoring and administration, standard off-the-shelf hardware components, and widely available operating systems in network nodes.

Communications relay satellites can provide full-time coverage for an area of scientific interest on the surface. A small satellite approach offers a number of benefits over a large satellite approach, largely due to the less complex design of small satellites. Significant cost savings can be achieved due to several factors, including shortened development time, simpler implementation, lower launch weight, reduced power requirements, and potential economies of scale from

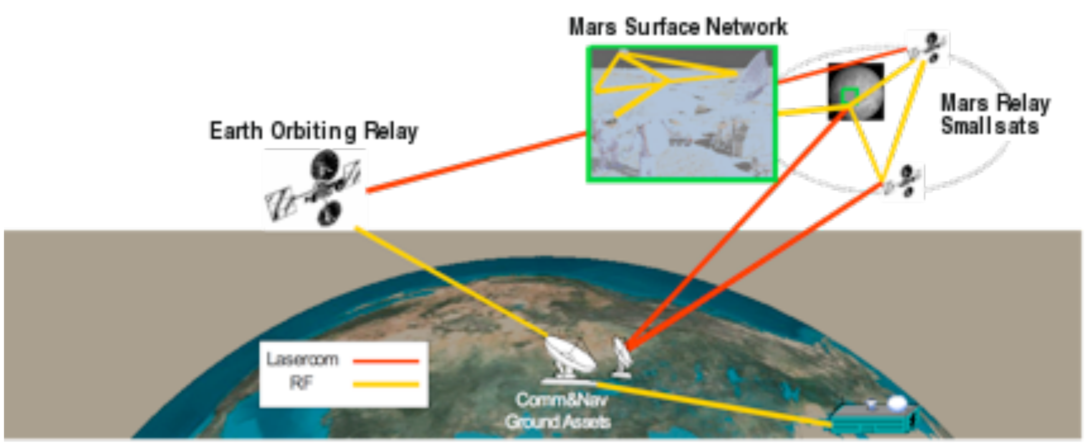

Figure 1. Mars-Earth Communications Architecture.

manufacture of multiple units. A constellation of satellites can be deployed to provide global coverage.

Laser communication (lasercom) offers exceptionally high data rates, high electrical power efficiency, low mass, and low overall system cost. Lasercom offers much more bandwidth than traditional radio links; research undertaken through the government-funded Transformational Satellite (TSAT) program has successfully demonstrated lasercom hardware operating at 10-40 gigabits per second. With successful flight demonstrations and advances in precision pointing and jitter control systems, along with space qualification of critical components, lasercom is ready for incorporation into small spacecraft platforms. Additionally, the switch to lasercom allows for a virtually unlimited future growth path as higher performance and more efficient laser devices are developed.

Delay Tolerant Networking (DTN) is a network protocol that enables data to be transmitted even in the face of intermittent communications outages. In a DTN network, if there is no currently available path to the desired data destination, the data is stored on the local node until the path becomes available again. This capability gives DTN better reliability and support for mobility in the Martian communications environment than traditional network protocols that discard data if the destination is unavailable. As a result, DTN provides an automated way to accommodate transient network outages resulting from both node mobility on the surface and temporary obscuring of a satellite's view of its peer node.

Mobile ad hoc networks (MANETs) are wireless networks in which any node can relay data toward a destination on behalf of any other node. This relay capability enables nodes that are not in direct radio range to communicate with each other through one or more intermediaries. In conjunction with IP and DTN, MANETs can be easily be extended by simply adding additional nodes (which may include robots, vehicles, astronauts, or other equipment) reconfigured by relocating existing nodes to more optimal positions for the given terrain and mission needs.

Wireless Sensor Networks (WSNs) are low-powered wireless networks that enable data collection from a potentially large number of sensors measuring a variety of physical phenomena. WSNs are optimized for very low power consumption, enabling sensor nodes to operate for periods of months to years on a battery. A gateway can be deployed to bridge WSNs to a local MANET, enabling sensor data to be transferred to external computer systems for local analysis and/or transmission to Earth.

Benefits and Agency Experience: Each of these technologies has been both proven in commercial applications and recommended for use in NASA missions, by both individual NASA centers and the Constellation Program. Integrating them into a single communications architecture ensures interoperability among the heterogeneous assets on Mars and Earth. This interoperability will facilitate distribution of data among the assets, while yielding long-term cost savings by enabling future additional assets to take advantage of the existing network infrastructure.

The proposed architecture is an extension of an architecture developed by the Lunar Communications Working Group, a NASA Headquarters-funded partnership between several NASA centers and external organizations to examine low-cost, high-performance communications network architectures for lunar communications [1].

All three challenge areas identified for consideration in the Mars Exploration workshop present significant communications requirements. While the specific architecture presented here may evolve in response to changing mission objectives and constraints, it is nonetheless imperative that communications needs be addressed as part of the mission concept development process.

Reference: [1] T. Stone et al. "A Lunar Communication Satellite Network Architecture Employing Internet Protocol, Laser Communication Technologies and Small Satellites." *Proc. 26th AIAA International Communications Satellite Systems Conference* (2008).