



Moving Toward Space Internetworking via DTN: Its Operational Challenges, Benefits, and Management

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Why Space Internetworking?

- **International space agencies are increasingly planning for collaborative sets of missions at Mars and the Moon**
- **The established model for management of communications with spacecraft – commanded data transmission over individual pair-wise contacts – has been developed in an ad hoc way, is operationally unwieldy, and does not scale well**
- **The international Inter-Agency Operations Advisory Group (IOAG) chartered a Space Internetworking Strategy Group (SISG) to define an agreed interoperable approach for space internetworking**
- **The IOAG report includes a recommendation that the space flight community adopt Delay-Tolerant Networking (DTN) to address the problem of interoperability and communication scaling, especially in mission environments where there are multiple spacecraft operating in concert**
- **There are a number of technical and operational issues that must be addressed in designing and implementing individual missions as the path toward deploying and operating DTN as part of a multi-mission, multi-agency space internetwork**

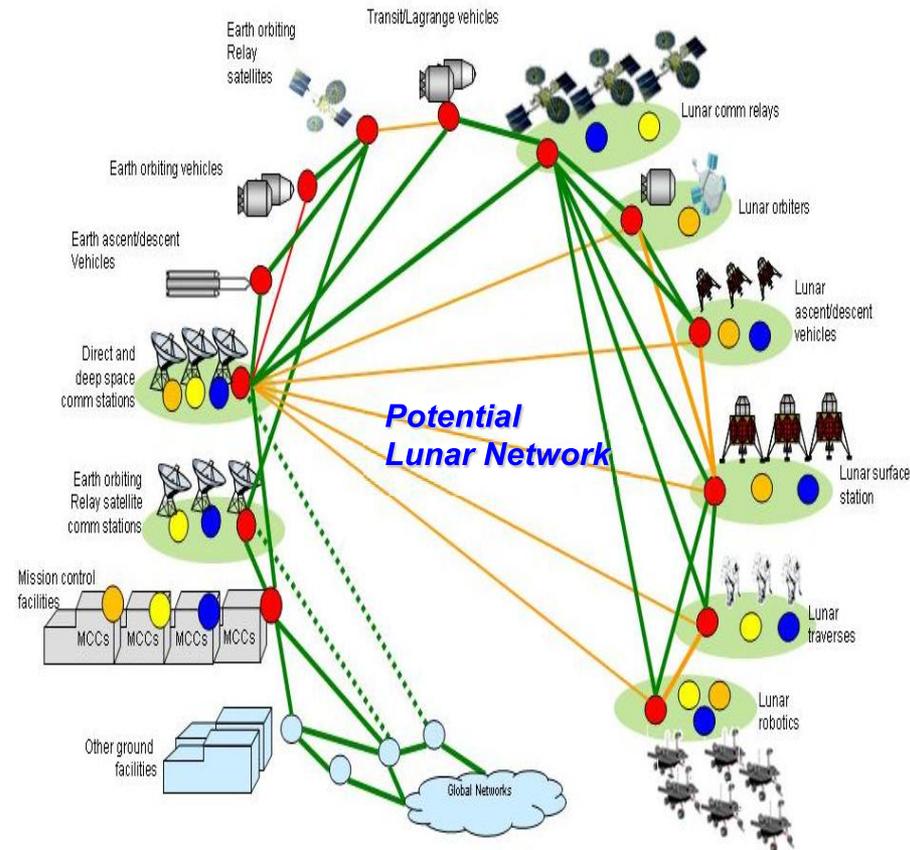
Benefits (1 of 2)

- Automation

- Reduced risk of operator error
- Reduced ops cost per vehicle
- Enables missions with larger numbers of vehicles

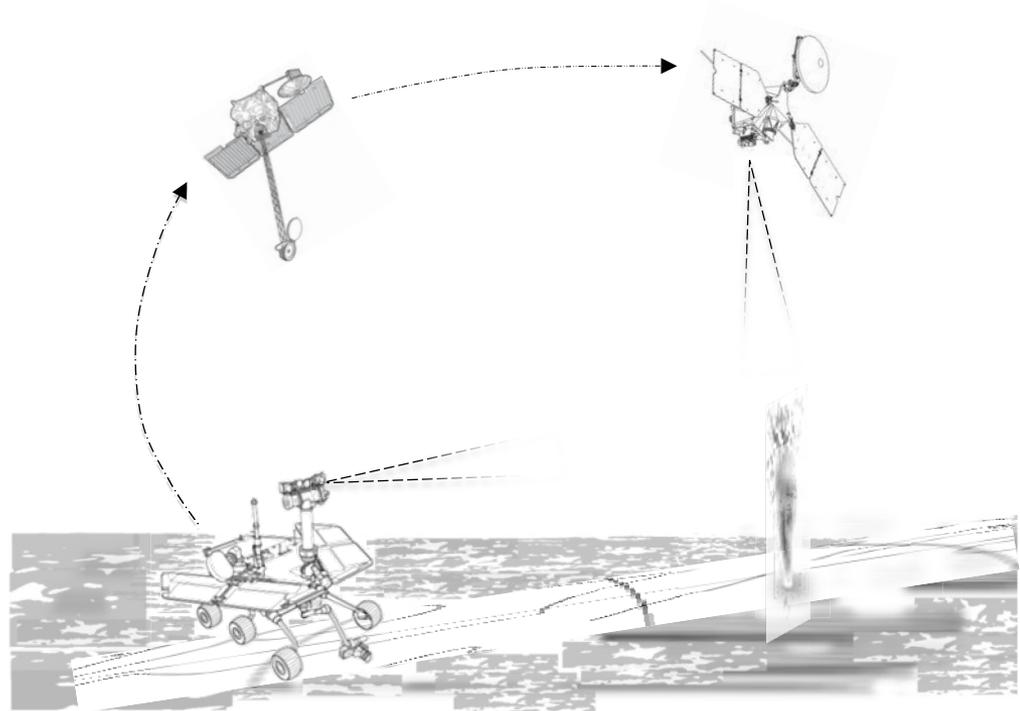
- Mission cross-support

- Multiple possible data paths
- Reduced risk of data lost due to single point of failure
- Higher data return



Benefits (2 of 2)

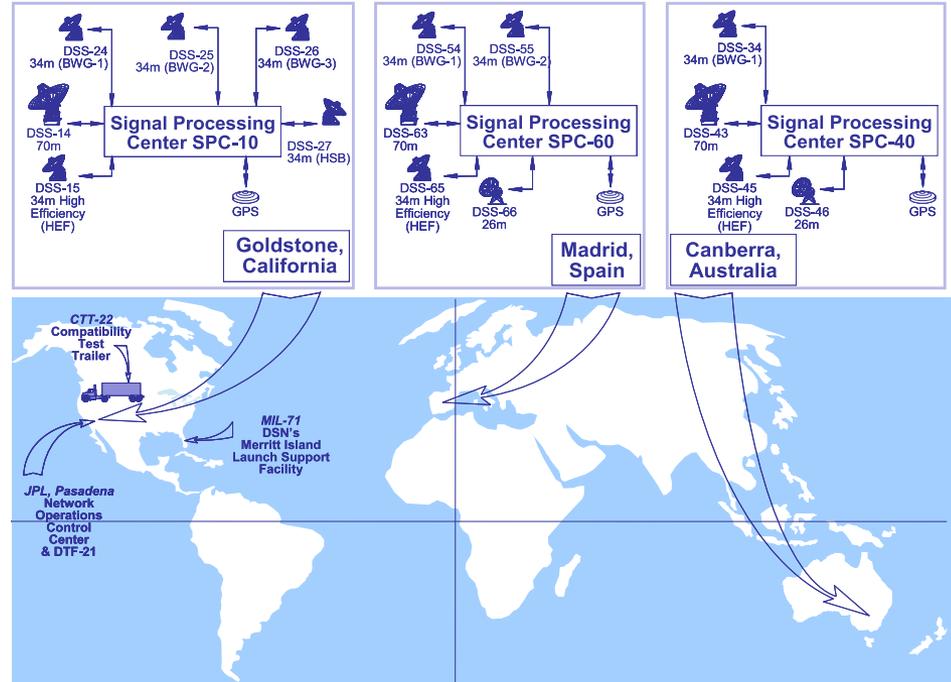
- Support for in-situ communications
 - Tight observation and retargeting loops.
 - Already demonstrated in JPL Mars Yard: autonomous detection and coordinated observation of simulated dust devils by multiple vehicles.





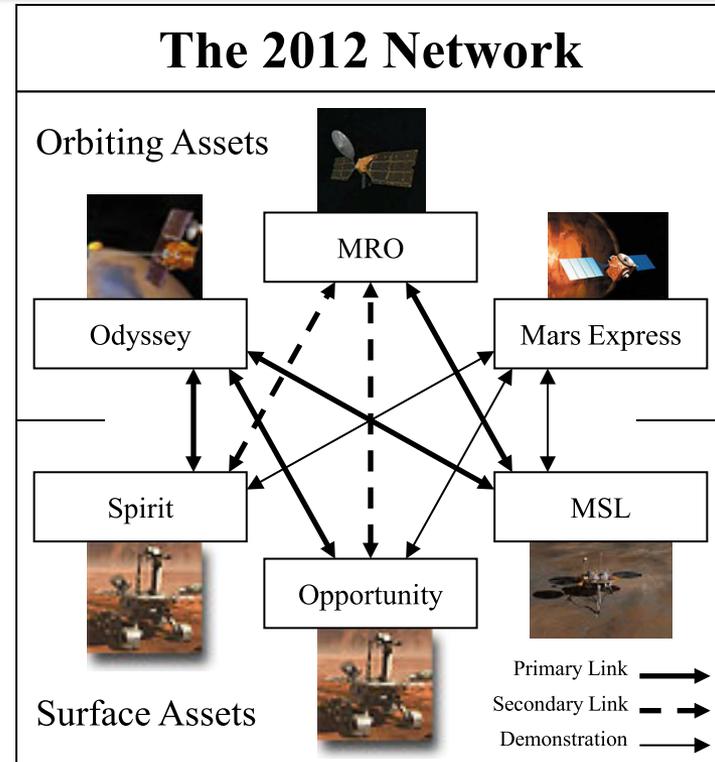
The Deep Space Network

- Composed of three Deep Space Communication Complexes around the globe provide continuous communications and navigation support for the world's deep space missions
- Provides Services to mission spacecraft including, but are not limited to
 - Command
 - Telemetry
 - Ranging/Radiometric
 - Radio Science
- Determines communication geometry between its antennas and mission spacecraft
- Maintains a schedule of services in conformance with available resources and communications geometry
- Manages space links to/from spacecraft including Doppler compensation
- Moving toward more automated mission communication support planning and scheduling
- Moving toward more automated service quality and performance assessment



The Mars Relay Network

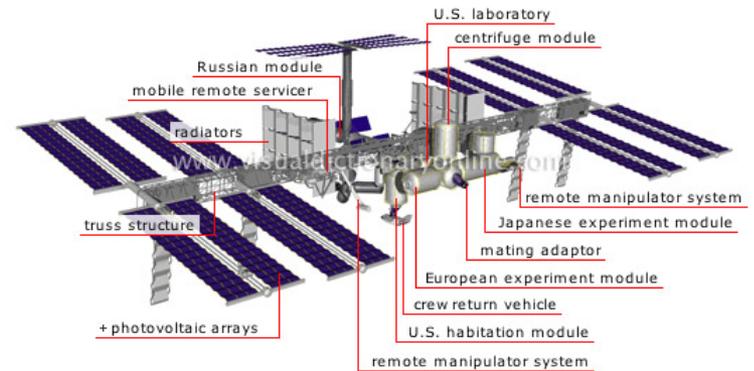
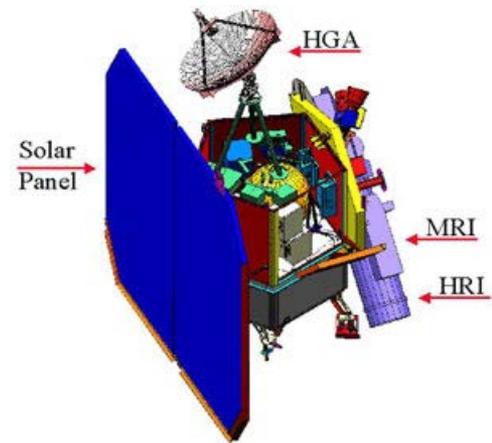
- The Mars relay network is and has been:
 - Evolving and ad hoc.
 - Focused on science acquisition, not relay support.
 - Managed by a variety of independent organizations.
 - Requires human involvement to carefully plan and coordinate relay activities.
 - Centered on “time of data insertion” rather than on minimizing transfer times and simplifying the transfer mechanisms.
 - Not “always on”, and the orbiters always initiate the relay sessions.
 - Requires unique and specific commanding to the orbiters to enable the transfer of the data.
 - Does not support “custody transfer”.
- Interfaces, both technical and human, have to be carefully negotiated.
- New software is being developed to standardize and centralize the relay planning and coordination data:
 - Intent is to provide a common interface for use by all participants.
 - This is the first step towards further automation which may lead to DTN-enabled data transfers.





DTN Experiments and Results

- Deep Impact Network Experiment (DINET)
 - 4 weeks in Autumn 2008
 - Up to 81 light seconds from Earth
- Continuous operation on ISS since May 2009
- DINET 2 ground exercise
 - EPOXI testbed exchanging bundles with ISS
 - Multiple flight LANs



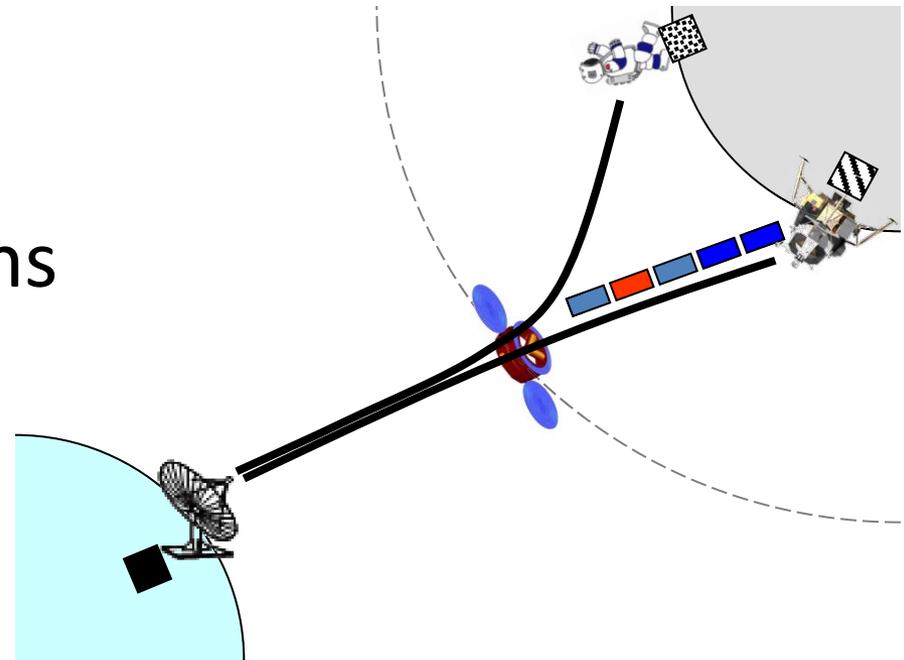


MaROS Timeline View



Future Scenarios

- Mission infrastructure accretion
- Heterogeneous missions
 - Multi-technology
 - Multi-agency
- Solar System Internet “Backbone”
- Operations during solar conjunction





Conclusions

- Current data relay operations at Mars are like the earliest days of terrestrial computer networking but are far more idiosyncratic and ad hoc.
- Increasing numbers of interacting spacecraft, low power missions that require data relaying, and interdependent mission scenarios drive requirements for an Internet in space.
- Space-based Internet must provide interoperable data transfer among elements designed and operated by different agencies and also contend with periodic connectivity, long light travel times, and a noisy operating environment.
- Internationally agreed technical approach is to adopt a suite of space internetworking protocols collectively referred to as Delay Tolerant Networking (DTN).
- Flight experiments are used to demonstrate that the Solar System Internet is feasible. Demonstrations on Deep Impact, ISS, and ground validate the protocol's functionality, demonstrate its effectiveness, and mature the current implementations.
- Next steps are to produce space-qualified radios that incorporate not just standard transceiver functions but also link layer capabilities, DTN networking capabilities, and sufficient on-board storage to manage relayed communications.
- Operationally there is the need to choreograph and orchestrate these communications services. The basic requirement is to coordinate when the involved spacecraft and ground stations will be able to see one another and when they will have resources available to perform a coordinated communications session.
- Operational choreographing activities are not new for DTN based space internetworking – they already occur – but in ad-hoc fashion, so...
- Some new multi-agency governance model, dealing with how the infrastructure is managed and moderated, will need to be developed, attempted, and refined.
- The availability of in-space networking will permit innovative new mission configurations, and this will open up new opportunities for collaborative science and exploration, whether robotic or human.



Acknowledgements

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