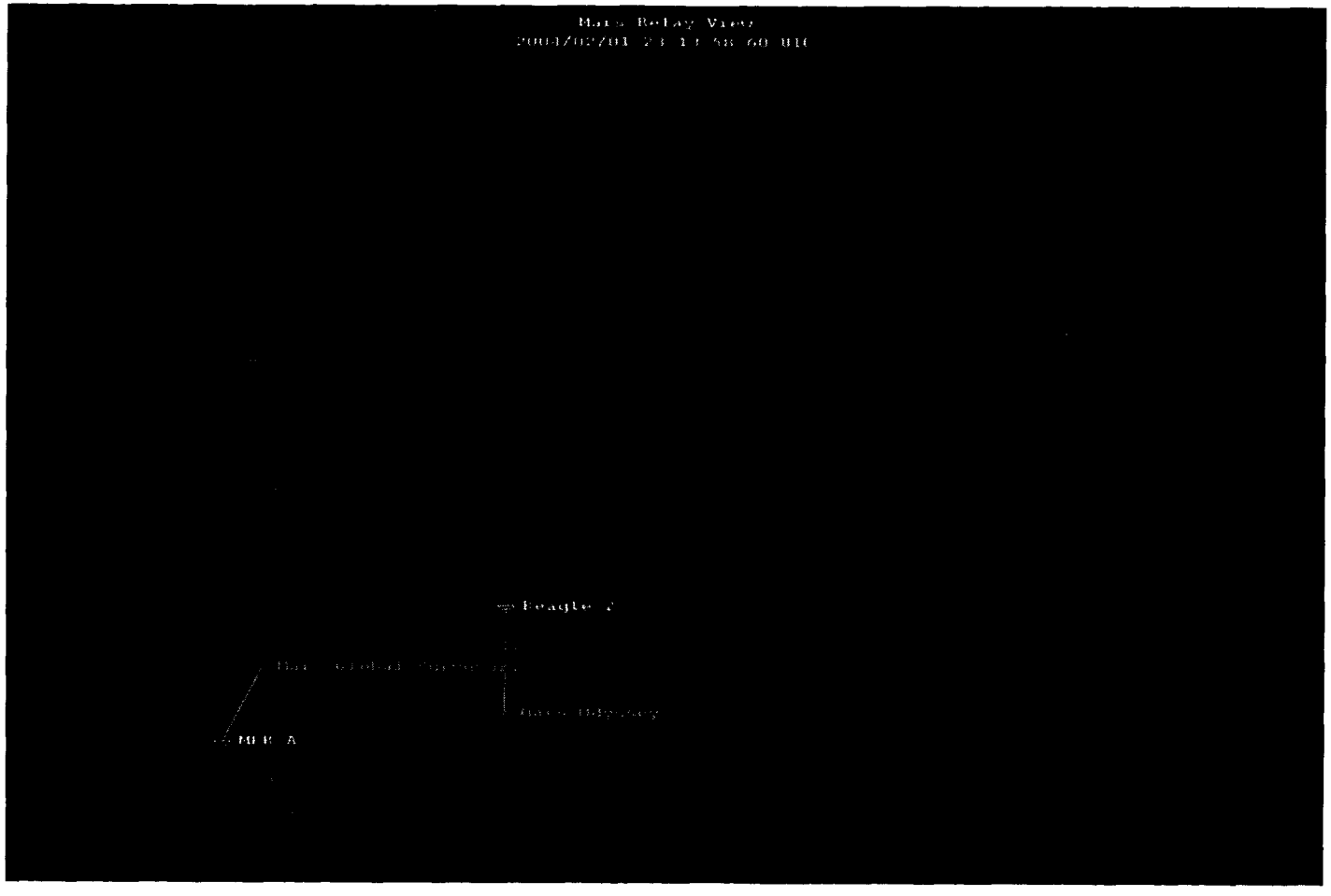
COORDINATING UHF RELAY ACTIVITES AT MARS



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INTRODUCTION

- Three Landers
  - Beagle 2 – arrives Dec 25th
  - Mars Exploration Rover A (MER A, Spirit) – arrives Jan 4th
  - Mars Exploration Rover A (MER B, Opportunity) – arrives Jan 25th

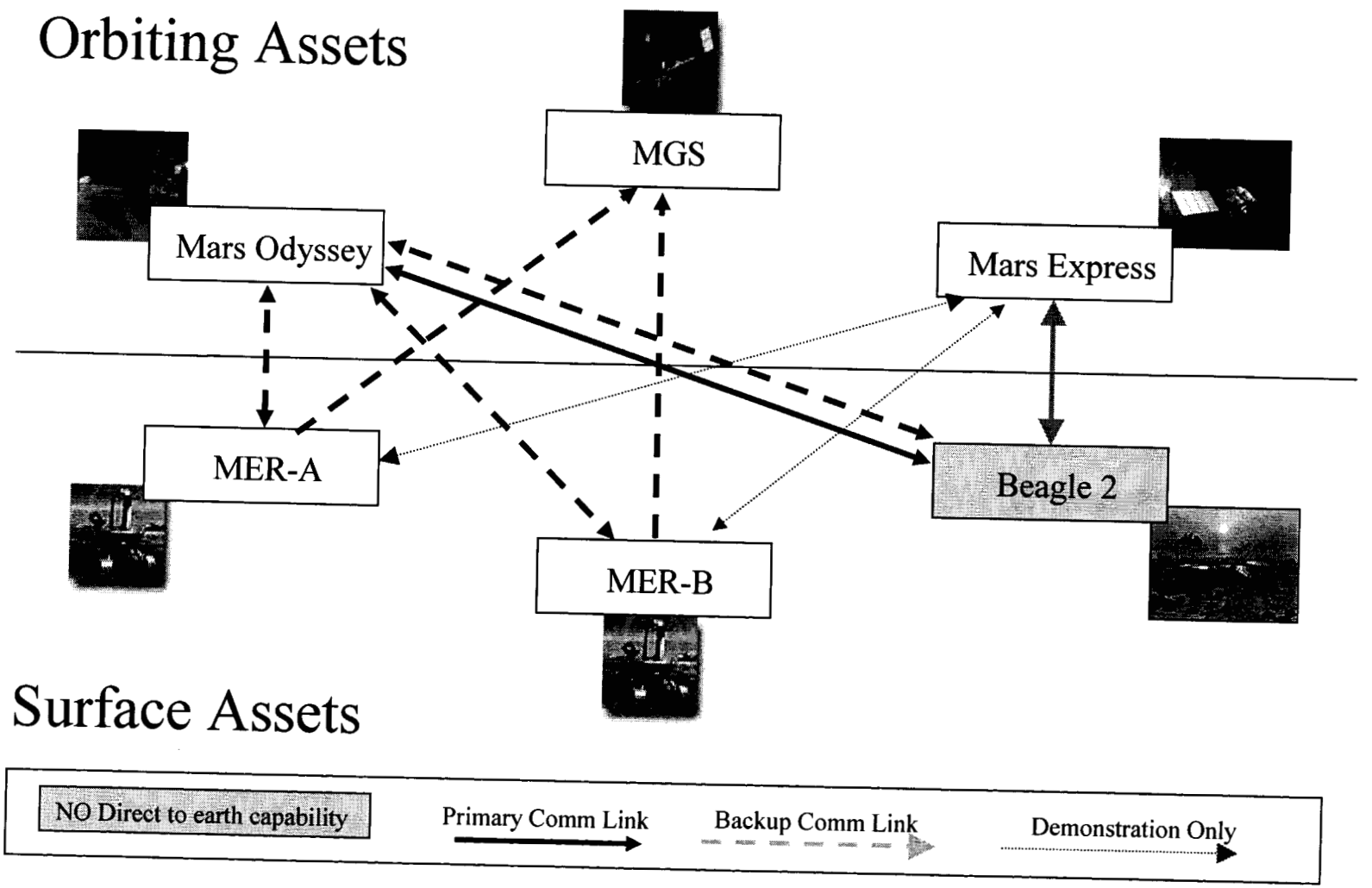
- Three Orbiters
  - Mars Express Orbiter (MEO) – arrives Dec 25th
  - Mars Global Surveyor (MGS) – In orbit
  - Mars Odyssey (ODY) – In orbit

- All three surface assets will have forward and return paths available:

  - Beagle 2
    - UHF Forward & Return via Mars Express & Mars Odyssey

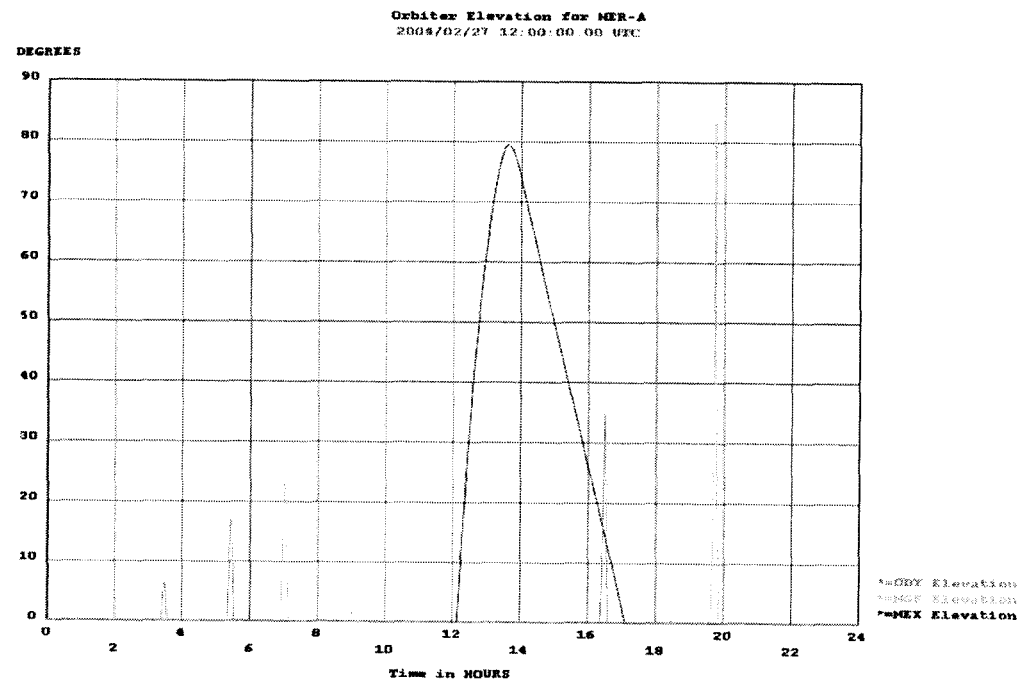
  - MER A&B
    - X-Band Forward & Return Link via X-band direct to DSN
    - UHF Forward & Return via Mars Odyssey
    - UHF Return via Mars Global Surveyor
    - UHF Forward & Return (demo only) via Mars Express

The Constellation



Technical Details

- MGS & Odyssey – high-inclination ~400 km, circular
  - 2 hour orbit
  - 2 to 5 usable overflights per day, per lander
  - 16 minutes is maximum overflight duration
- Mars Express – high-inclination ~300 km by ~10,000 km, elliptical
  - 10 hour orbit
  - 1 or 2 usable overflights per day, for Beagle 2
  - up to 9 hours overflight duration
- Forward link (Orbiters to Landers)
  - UHF @ 437 MHz
  - 8 kbps
- Return link (Landers to Orbiters)
  - UHF @ 401 MHz
  - 8, 32,128 or 256 kbps
- ARQ (Handshaking) protocol
- Doppler: ODY& MGS as reference for MER



Network Challenges

There are a variety of hurdles in architecting, implementing and operating this network:

- Shared UHF frequencies mean cross-talk
- Unknown terrain, rover position means unpredictable comm link
- Each lander requires unique UHF "settings" which change each pass
- Orbiters have primary missions to complete, they are not just relays
- Multi-national effort at coordinating day-to-day operations
- Minimal $ and staff available to build and operate relay network

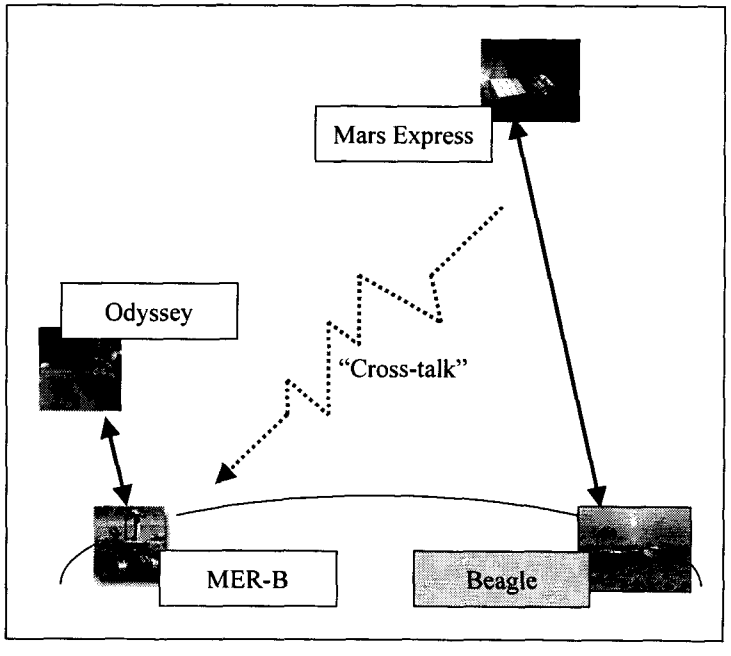
Cross-talk

Challenge: Common Uplink and Downlink Frequencies can mean cross-talk

Solutions:

- "Autogen/Apgen" tool
  - Ingests navigation (overflight) information
  - Ingests Deep Space Network coverage
  - Ingests Orbiter schedules

  - Predicts cross-talk conflicts
  - Predicts forward & return link latencies
  - Builds sequences for MGS & Odyssey



- Cross-Atlantic coordination meetings
  - Monthly – long range planning
    - what passes will be available
    - negotiation in conflict situations
  - Weekly – final negotiation of remaining conflicts
    - orbiter mini-sequences built

- Also helpful – All three Landers going to very different longitudes

Relay Operations Process

Projects	Step	Comments
MGS Odyssey	Background Sequence Development	Orbiter housekeeping activites.
ALL	Long Range Meeting	Initial understanding of relay opportunities and potential cross-talk events.
ALL	Short Range Meeting	Lander teams request over-flights. Conflict Checker runs. Relay-sequences for MGS and Odyssey built. BGL informs MEX of all overflight times.
MGS Odyssey	Relay-Sequence development	Relay-sequence prepared for uplink. Relay-sequence activities checked for interference with orbiter housekeeping activities.
BGL MER	Build commands	Lander teams build commands to forward to Odyssey. Uplink commands to Odyssey.
ALL	Overflight	Odyssey forwards commands to landers. Data returned to earth via MGS, MEX and Odyssey.

Management of Relay + Orbiter Activities

<u>Challenge:</u> Relay is a primary function, but not the only thing the Orbiters are doing

<u>Solution:</u> Landers are treated as another science payload

- Lander commands are sent through an autonomous ground processor
  - These commands are non-interactive with Odyssey
    - It simply stores and forwards to payload or lander
  - Uplink of lander commands to Odyssey can occur at anytime
    - Files are tagged with unique overflight number
    - Mini-sequence directs Odyssey to grab files with a given overflight number and forward them

- Lander data is higher priority downlink than orbiter instruments data but the required bandwidth is small

- Lander data stored on-board orbiters
  - 15 Mb for each MER, 2 to 9 Mb for Beagle 2 on Odyssey
  - 10 Mb for both MERs on MGS

Rapid Response Changes in UHF settings

Challenge: Predicting daily lander comm requirements is impossible

- Non-symmetrical UHF antenna patterns, variable topography and rover motion make UHF link unpredictable
- Variable quantities of data to return each day
- Variable quantities of commands to send each day
- Orbiter and Landers work on different schedules
  - Orbiters planning horizon:
    - 2 days ahead – Mars Express
    - 1 week ahead – Mars Global Surveyor
    - 4 weeks ahead – Odyssey
  - Landers plan: day-to-day

Solution: A compromise was reached:

- Landers will plan overflight use & non-optimum data rates 1 week in advance
- Orbiter teams will build weekly sequences to overlay background sequences
- Landers may or may not use all overflights – Orbiters robust to Lander quiescence.

Low Cost Operations

Challenge: Performing relay operations with a small staff

Solutions:

- Very automated relay sequence building tools
  - ½ person additional for MGS and ODY each, over normal operations
  - Nominal orbiter ops already use these same tools & processes
- Automated forward link commanding to Landers
  - Lander teams provide own commands, ship them to a special directory and a tool prepares commands for uplink.
- Automated handling of return link data from Landers
  - All spacecraft data parsed, dropped into communal bin where the engineers, science teams or lander teams can retrieve their own data
- MSPA (Multiple Spacecraft Per Aperture) - Several spacecraft seen by one Deep Space Network Antenna
  - Signals are separated on ground
  - Allows doubling up – any two of MER-A, MER-B, MGS, ODY

Status & Future

Status

- Ground Software (sequence builds, command system, telemetry)
  - Three tests successfully completed for MGS & ODY to MER
  - Two tests successfully completed for ODY to Beagle 2
- Odyssey & MGS relay-specific flight software, hardware successfully tested in August using 46 m Stanford station as a "Lander"
- Currently focusing on contingency scenarios

Future

- Mars Reconnaissance Orbiter ('05) and Phoenix Lander ('07) being added to the network.

Lessons Learned & Conclusion

Lessons Learned

- Cross-talk problem (and development work to avoid) could have been eliminated by having UHF radios with different channels

- Orbiter housekeeping and relay-specific commanding should be separate
  - Allows quick response to daily lander activities
  - Allows smaller orbiter staffs

- Landers should initiate contact and specify data rates, other parameters
  - This would eliminate some coordination work for Orbiters
  - Would've allowed better responsiveness to Lander's shorter planning horizon

- MSPA is a smart use of resources.

Conclusion

A simple, low-cost network to forward commands to and return data from Beagle 2, Spirit and Opportunity is being established at Mars.