Enabling International Data Relay at Mars

SpaceOps 2016
Daejeon, South Korea
2016 May 16

Daniel Wenkert, Roy Gladden, Chad Edwards

Jet Propulsion Laboratory, California Institute of Technology

Peter Schmitz, Michel Denis

ESA European Space Operations Center

Alistair Winton

ESA European Space Research and Technology Centre

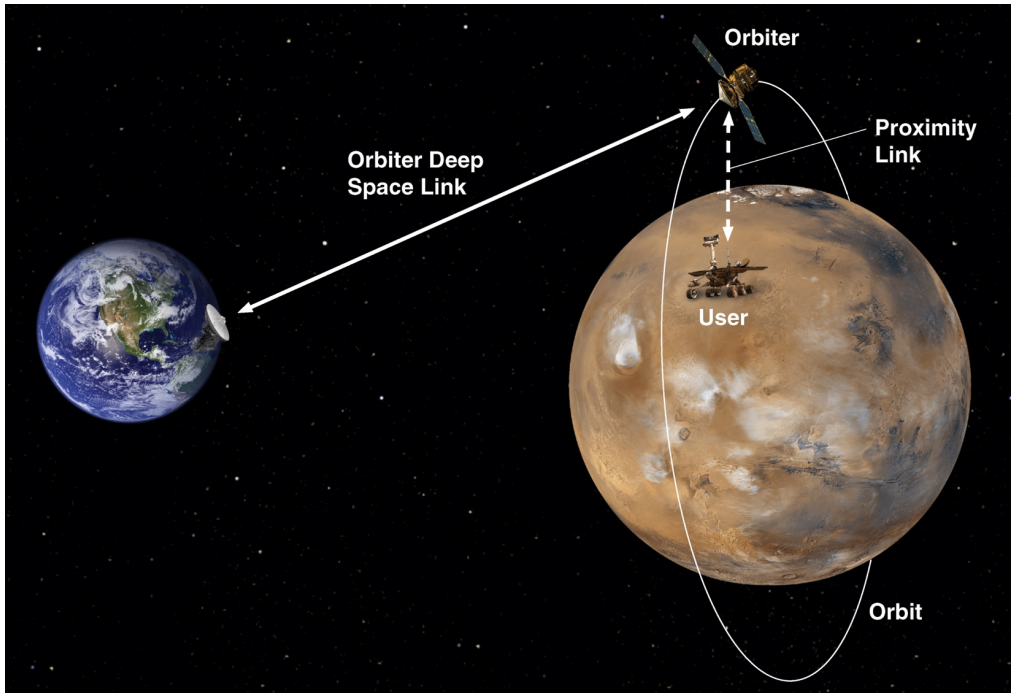
Outline

- Overview
- Modes of communication - protocols
- Inter-project agreements
- Relay process
- Relay testing
- Future

OVERVIEW

Why data relay at Mars?

- Orbiters have more powerful antennas than landers
- UHF relay between orbiter and rover/lander enables the latter to use high-bandwidth resources of the orbiter
  - Relay is accomplished when orbiter "overflies" lander
- In Oct-Dec 2015, orbiters returned a combined average of 561 Mbit/day of data from two Mars rovers



Which orbiters provide relay?

Mission	Arrival date	End of mission
MGS	1997-09-12	2006-11-21
Odyssey	2001-10-24	ongoing
Mars Express	2003-12-25	ongoing
MRO	2006-03-10	ongoing
MAVEN	2014-09-22	ongoing
ExoMars TGO	2016-10-19	

Which landers and rovers use relay?

Mission	Arrival date	End of mission
MER-A Spirit	2004-01-04	2010-03-22
MER-B Opportunity	2004-01-25	ongoing
Phoenix	2008-05-25	2008-11-02
MSL Curiosity	2012-08-06	ongoing
ExoMars EDM Schiaparelli	2016-10-19	
InSight	2018 Q4	
ExoMars 2020 Rover	2021 Q1	
ExoMars 2020 Lander	2021 Q1	
Mars 2020	2021 Q1	

COMMUNICATIONS PROTOCOLS

Proximity-1 Space Link Protocol

- International (CCSDS) standard
  - Bi-directional space link protocol, <100,000 km range
- Details for Mars relay
  - 435-450 MHz for forward link; 390-405 MHz for return link
  - Phase-Shift Keying (PSK); data rates 1 kbps to 2 Mbps
  - Full-duplex link started when orbiter hails lander, configures link
- In standard ops, retransmit frames that have errors
  - Expedited mode is alternative (no retransmission)
- Adaptive Data Rate (ADR) allows optimum data rate use
  - Periodically update return-link data rate, based on SNR

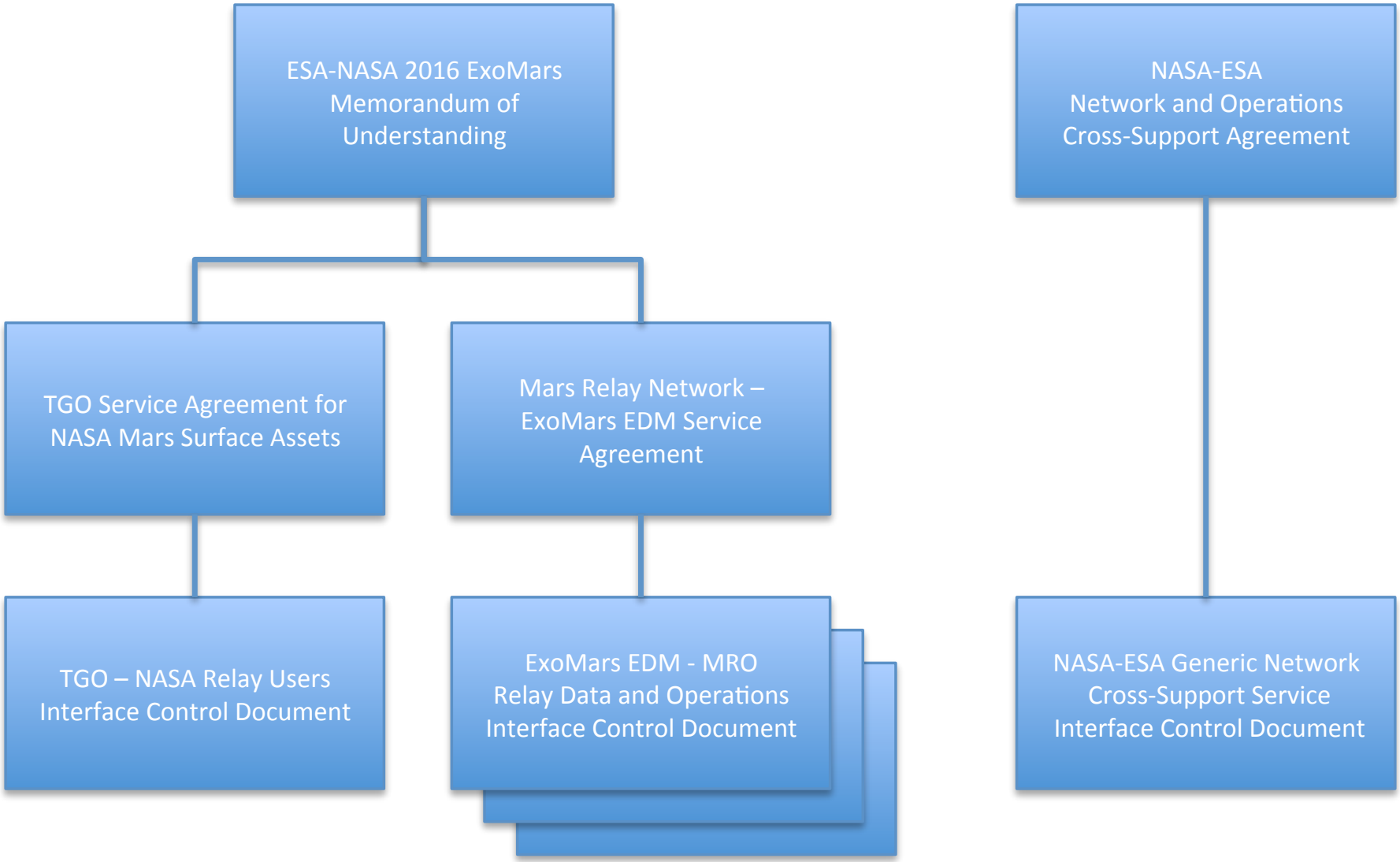
Modes used in Entry, Descent, & Landing (EDL)

- Raw data transfer of engineering data during EDL

- Open-loop recording
  - Record UHF signal from lander or rover, during EDL
  - Demodulate recorded signal on Earth
  - Not susceptible to loss-of-lock problems

INTER-PROJECT AGREEMENTS

Structure of agreements (ExoMars)



(Similar ICDs for ODY, MAVEN)

Memorandum of Understanding (MOU)

- Inter-agency agreement for ExoMars 2016
  - Signed by ESA Director General & NASA Administrator in 2014
  - Provision, testing, and support of Electra UHF radio payload for ExoMars/TGO (Trace Gas Orbiter)
  - NASA orbiters support for ExoMars/EDM Schiaparelli
  - ExoMars/TGO support for NASA rovers and landers

- Also NASA-ESA Cross-Support Agreement
  - Separate document covering DSN support for ESA missions, ESTRACK support for NASA missions
  - Important for Mars Relay because it increases opportunities to downlink relay data to Earth

Service Agreement (SA) (1 of 2)

- Project to many projects agreement, covering relationships between
  - New Mars orbiter and existing and planned landers
  - New lander and existing and planned Mars orbiters

- Describe support for entry, descent, and landing (EDL)
  - Time period for orbiter(s) to record lander's UHF signal
  - How data are returned to Earth
  - Possible imaging support by orbiter(s) before or during EDL
  - Processing of returned data and transfer to other project/agency

Service Agreement (SA) (2 of 2)

- Describe support for surface ops (most of document)
  - Time period over which support is required (e.g. life of mission)
  - Types of support to be supplied (e.g. forward/return-link Prox-1)
  - Frequency of overflight support
  - How inter-project planning is accomplished
  - Data latency, completeness, and accountability
  - Onboard data management

- Describe inter-project testing for relay operations
  - Responsibilities, personnel, documentation

- Describe anomaly resolution

Interface Control Document (ICD) (1 of 2)

- Project-to-project agreement
  - Defines interface details between single orbiter project and single lander/rover project (except for ExoMars/TGO)

- ICD defines
  - Details of UHF physical and data layers
  - Naming conventions and contents of relay session products
  - End-to-end data flow and data interfaces within and between:
    - lander and orbiter ground systems,
    - Mars Relay Operations Service (MaROS),
    - ground stations (DSN, ESTRACK),
    - orbiter and lander flight systems at Mars

Interface Control Document (ICD) (2 of 2)

- ICD defines pre-pass planning parameters
  - Return-link data rate, carrier loss timeout for rehailing, remote spacecraft ID, etc., etc., etc.
  - Lander request for emergency vs. normal communications pass
  - Response from orbiter project (supported, denied, cancelled)

- ICD defines post-pass analysis parameters
  - "Scorecard parameters" from both orbiter and lander, for example communications pass/session start time, session end time, return-link bits received, forward-link data rate
  - "Overflight Performance Assessment File (OPAF) parameters" from both spacecraft, reported as function of time

THE RELAY PROCESS

Relay process overview

- Strategic Planning: Designate relay opportunities during specific time period, implement those as baseline
- Tactical Planning: Quickly change baseline plan (hours)
- Forward-Link Commanding: Forwarding data from lander ground data system (GDS) to lander via Mars orbiter
- Return-Link Data Flow: Returning data from Mars lander to its GDS via Mars orbiter
- Relay Accountability: Measure efficiency of data transfer

Mars Relay Operations Service (MaROS)

- MaROS enables coordination of relay activities at Mars, by all missions participating in Mars Relay Network
- MaROS is central repository for planning information
- Provides standard interfaces and centralized infrastructure to current and future network participants
- Securely exchange & store relay-related planning and operations data

Strategic planning

- All the activities to plan relay in specific period of time
  - Timeline of when data needs to be exchanged between projects
  - Who is providing relay services & who is requesting

- Planning starts with orbiter project identifying:
  - Predicted geometric view periods between orbiters and landers
  - Periods during which orbiter can't support relay services

- Orbit predictions uncertain due to atmospheric variations
  - Variations perturb the orbit, making trajectory predicts longer than a few weeks difficult
  - NASA orbiter relay scheduled only few weeks in advance

Strategic planning, NASA-ESA timeline

- ESA projects design long-duration orbiter trajectories
  - Typically begin planning processes ~2 months before relay
- NASA lander projects do single relay plan for all orbiters
  - NASA orbiter trajectory means lander can't plan on ESA timeline
  - Lander projects plan relay services for ESA orbiters early & make assumptions about final integrated plan
- TGO will become increasingly critical relay asset at Mars
  - Lander projects will need to manage disparate planning horizons
  - Planning timelines will be reconciled before regular TGO relay

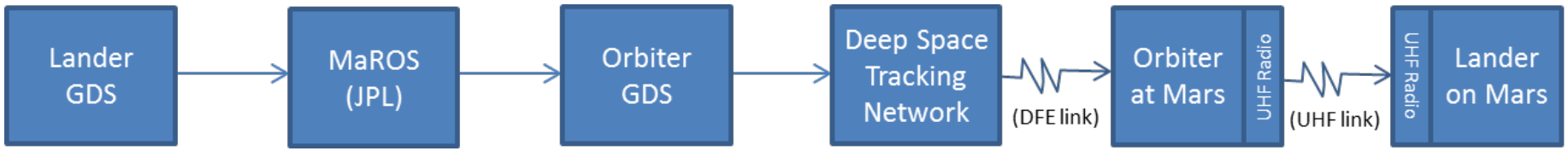
Tactical planning

- Tactical Planning enables short-term changes to relay plan developed by Strategic Planning
  - Mostly minor changes, e.g. data rate for single session
- Any change to strategic relay plan is a tactical mod
- MaROS is intermediary to manage change requests
- Lander project can submit requests as late as possible
- Negotiations for tactical changes to relay plan are similar to those used in developing initial strategic plan

Forward-link commanding (1 of 2)

- MaROS is intermediary between lander project and orbiter project to exchange lander command data
  - From lander GDS to orbiter GDS
  - Lander project passes command data to MaROS, for any orbiter
- Forward-link products are submitted to MaROS any time
- Each orbiter handles forward-link data differently
  - Orbiter project configures MaROS to identify rules for how forward-link data must be packaged by the lander projects

Forward-link commanding (2 of 2)

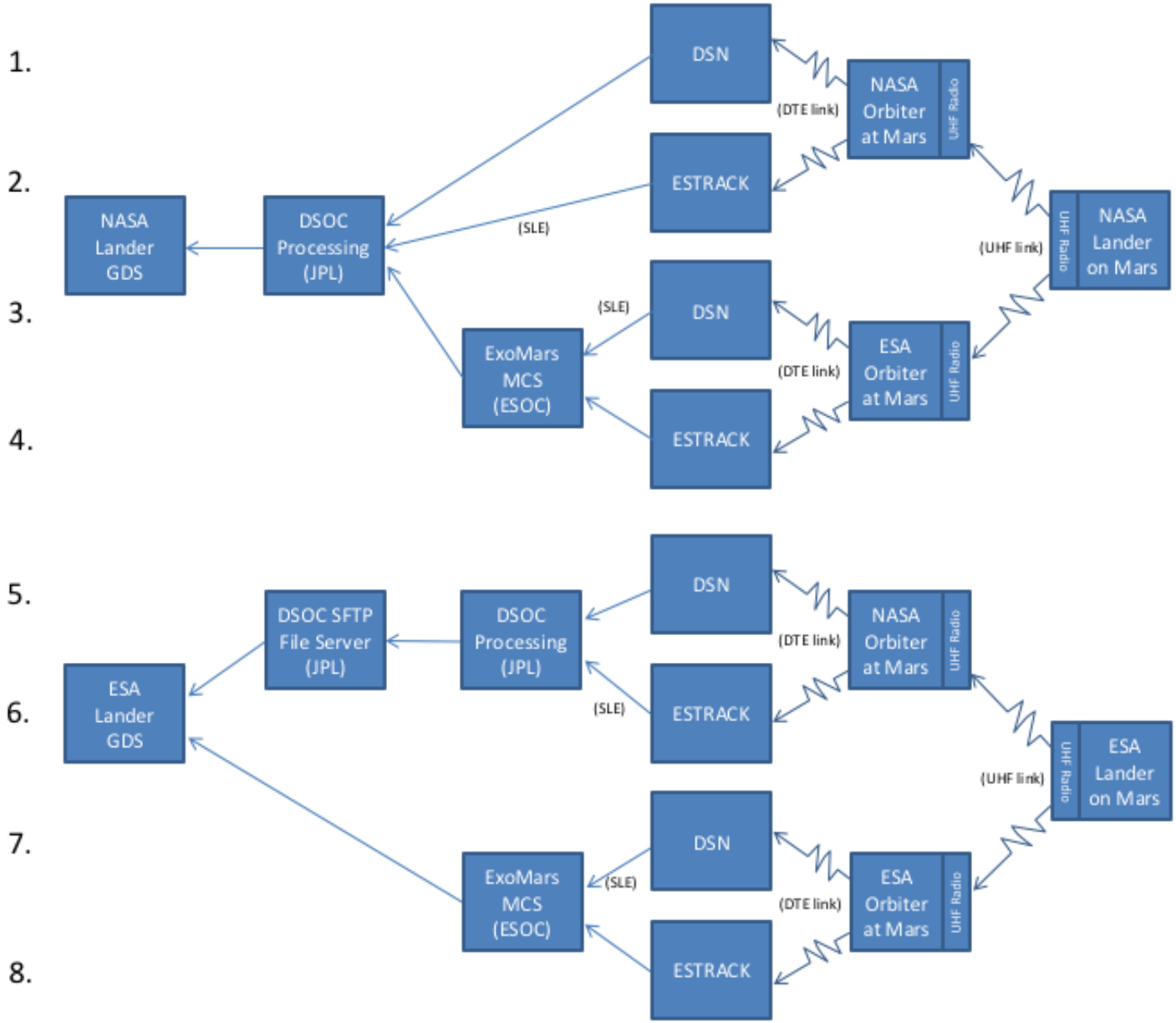


- Lander project packages commands in its own manner
  - Then is handled as file of indeterminate format ("bucket of bits")
- Orbiter project packages product as uplink product
- After transmission to orbiter, it undoes any packaging
  - So, original lander command product gets transmitted to lander

Return-link data flow (1 of 2)

- Orbiter project delivers return-link data to lander GDS
- In past, DSN has acted on NASA orbiter projects' behalf
  - DSN DSOC extracts NASA lander data from return-link product before delivers to lander GDS
- ESA support of NASA landers is new to architecture
  - ESA lander data transferred to lander GDS as data product
  - Disassembled into telemetry and other data products once there
- Data return via NASA or ESA orbiter, DSN or ESTRACK

Return-link data flow (2 of 2)



Relay accountability

- Orbiter & lander projects report relay results to MaROS
  - Number of bits transferred, signal strengths during relay, etc.
  - Both partners report similar parameters
  - Data are generally derived from spacecraft telemetry
- Data can identify where in network problems occur
- Projects submit “Scorecard” for each relay session
  - Scorecard reports fixed-value results from relay session
  - Number of bits transferred, maximum signal strength, etc.
- Also submit report of time-dependent values

RELAY TESTING

Radio compatibility testing (ExoMars/EDM)

- Tested compatibility at Lockheed Martin Denver between
  - Portable system, representative of ExoMars/EDM
  - Ground testbeds for MRO, Odyssey, and MAVEN
- Tested and analyzed commanding, file transfers, various return-link modes
- Lessons learned
  - Electra on MAVEN and MRO need extended data rate tables
  - Proximity-1 return link cannot be used with Odyssey

Readiness testing & simulations (ExoMars)

- ExoMars project testing operations interfaces between ESOC (Darmstadt) and NASA Mars orbiters & landers
- ESOC tested end-to-end flow of forward & return links through NASA orbiter testbeds to EDM testbed
  - Alongside radio compatibility testing in Summer 2015
  - Used MaROS as interface
- Testing of TGO to NASA lander missions is ongoing
  - Many forward-link interfaces already successfully tested

In-flight testing (MAVEN)

- Highest fidelity testing is done at Mars
- Recent in-flight testing has focused on MAVEN
  - Arrived at Mars in 2014
- Tested MAVEN's Electra UHF radio with MSL & MER-B
  - MSL is surrogate for EDM; both use adaptive data rate (ADR)
  - Tests have been successful

FUTURE

Future of Mars relay operations

- Accommodate long ExoMars planning timeline with short relay operations planning timeline
- Expect more orbiters
  - NASA studying possible orbiter for launch in 2022 or 2024
- Expect more landers and rovers
  - NASA, ESA, other space agencies, private sector?
- Desire to move toward delay tolerant networking (DTN)
  - Probably need orbiters designed specifically around relay