Mars Network: An Infrastructure to Support the In Situ Exploration of Mars

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November 17, 1999
1999 American AAS National Conference and 46th Annual Meeting
Pasadena, CA

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Telecommunications

- Communications performance decreases as the square of distance
  - Mars-Earth distance can reach over 2.5 AU (~400 million km)
  - Typical GEO Earth communications satellite is only about 40 thousand km away
  - It’s about 80 dB (or 100,000,000 times) harder from Mars!

Operations

- Large distance implies long round trip light time (RTLT)
  - RLTL varies from ~ 10 min up to ~40 min
  - RTLT >> seconds
    - No “joysticking” or “teleconferencing”
    - Need for high levels of autonomy at Mars
  - At the same time, RTLT << 1 sol
    - Sci/Eng teams on Earth can interact with Mars assets many times per sol, if infrastructure allows
The Coming Decade of Mars Exploration

- Highly diverse spacecraft (size, power, mobility, lifetime, ...)

- Globally distributed missions

- Complex surface and orbital operations

- Evolving capabilities
Key Considerations for Mars Communications

- **Increased data return for virtual presence**
  - Pathfinder: Direct-to-Earth link returned 30 Mb/sol
    - Corresponds to only 300 bps time-averaged Mars-to-Earth bandwidth
  - Future: Increased data return to enable new science and increased public outreach
    - Frequent full-resolution PANCAM images (~1 Gbit/image)
    - Streaming video (~1 Mbit/s) for long range rovers, aerobots
    - High-resolution 3-D representations of surface geology

- **More frequent contact to support complex surface operations**
  - Pathfinder direct-to-Earth link provided only few hrs/sol contact (energy-limited)
  - Polar science orbiters provide only one or two 5-min contacts/sol
  - Frequent contact allows rapid closed-loop planning with sci/eng teams

- **High-sensitivity relays for microprobes, microlanders, ...**
  - Pathfinder Direct-to-Earth link required high mass (>15 kg to surface), and high energy-per-bit (500 W-hrs/Gbit to 70m DSN antenna)
  - Relay links enable much lower mass (~1-2 kg or less) and reduced energy-per-bit (~5-10 W-hrs/Gbit) w/ UHF omni

- **Improved navigation for new mission concepts**
  - Pathfinder landing error ellipse ~ 100 km
  - Targeting future landers to specific sites of geological/biological interest will require sub-km precision landing capability
  - Sample return drives new capability for in-orbit rendezvous & docking

...all this with programmatic reliability, resiliency, flexibility, and evolvability...
Systems Engineering Approach for Mars

**Goal:** Create a virtual presence and support robust exploration at Mars

**Provide:**
- Increased data return
- Greater connectivity
- Resiliency
- Flexibility and evolvability

**Requirements:**

**Assets to be Supported:**
- Landers, orbiters, fly-by's (larger mass/power budget)
- Rovers, airplanes, aerobots, microprobes, canisters (low mass/power budget)

**Options:**

**Mars Network Common Solution**
- Enhancing capabilities for larger vehicles (increased data return and connectivity, more mass/power for science payload)
- Enabling capabilities for whole new classes of small vehicles
Mars Network Overview

Key characteristics
- Breakthrough increases in communications bandwidth
- Seamless end-to-end information flow
- IP-like protocols tailored to operate over long round-trip-light-times
- Highly efficient relay communications for energy-constrained microprobes/microlanders/aerobots
- High-accuracy navigation and timing services

Flight Elements:
- Low-Altitude Microsat Constellation
  - >1Gb/sol low-latitude data return
  - Contact every 1-2 hrs to entire planet
  - 10-100m position determination
- Areostationary MARSAT
  - 1Mb/s near-continuous contact, streaming video
  - 100 Gb/sol data return
Communications and Navigation Microsatellite

- Low cost, single-string, 3-axis stabilized design
- Common bus design, also applicable to Mars science probe/orbiter missions, to be developed by Mars Micromissions Project
- Piggyback launch on Ariane 5 Structure for Auxiliary payload (ASAP)
- 220 kg mass, 250 cm x 60 cm x 80 cm
- X-band Earth link—standard DSN link; volume-constrained 80-cm HGA
- UHF proximity link for in situ communications and navigation
Mars Micromissions Using Ariane 5

- ASAP5 secondary launch to GTO
- 6 month flexible launch period
- 45 kg payload to Mars, or 6 kg to Mars orbit
- NASA, CNES, and Arianespace cooperation
• Proposed six-satellite constellation is motivated by optimizing key figures of merit
  - data return/sol/W
  - contacts/sol
  - maximum gap times
  - navigation performance

Evolving Performance of 4Retro111 Constellation

4Retro111 Mars Network Constellation
All Spacecraft at 890km Altitude
2 S/C inclined at 172°
4 S/C inclined at 117°
Mars Network: Navigation Performance

Fixed Surface Asset

Orbiting Sample

Precision Landing

Network Orbiter (Self-Navigation)
MARSAT Spacecraft - Baseline Design

- Communications asset for breakthrough increase in bandwidth & connectivity
- Ka-band Earth link; X-band in-situ link
  - One high-rate (> 1 Mbps) link from orbiter to Earth
  - One high-rate (~ 1 Mbps) link from science element
  - Several lower data rate (20 kbps) links from science elements on Mars to orbiter
  - Landed elements use small, low power, components, e.g., 2W SSPA; 20cm, 22 dBI directive antenna
- Delta II launch
- 808 Kg mass
- 7 year life
- Deployed similar to Earth geostationary satellite; near continuous comm

- Solar Panels, each 3.5m X 1m, produce between 493W (BOL) to 354W (EOL) at Mars
- X-band Proximity Link, 2 axis gimballed, 1.3m High Gain Antenna
- Ka-band Direct to Earth (DTE) link body fixed 1.5m High Gain Reflect-array
- Two Ka-band DTE downlink LGAs and X-band DTE uplink LGA are not shown
- X-band Proximity Link, 2 axis gimballed, 25cm Medium Gain Antenna
Mars Network Proximity Link
UHF Payload Point Design

- Microprocessor-based transceiver design
  - Heritage to JPL GPS rcvr, DS3 AFF
  - Highly software-based architecture provides post-launch evolvability over s/c lifetime to accommodate new protocols, new users, ...
- 10 dBi UHF antenna for enhanced pre-aerocapture capability

Payload Block Diagram

UHF Paylaod - Physical Layout

Payload Block Diagram

UHF Low Gains 360° x 180° +0 dBm
transmit & receive

UHF High Gain 50° x 50° +10 dBm
receive only

S/X Low Gains 360° x 180° +0 dBm

Digital Transmit Channel
- PRN Gen.
- Phase Ctrl
- Data Encoding
- D-to-A

Digital Receive Channel
- Carrier
- Symbol
- Range
- Decoder
- AGC

μProcessor SubSystem
- Carrier, Symbol, Ranging, AGC Loops
- Transmitter Control & Data Formatting
- Navigation Processing
- CCSDS Protocol Stack Processing
- Command Handling
- Command & Data Packet Routing
Deep Space Communications Protocols

- **CCSDS Proximity-1 Link Protocol**
  - Specification of link layer protocol for short-range communications
  - Critical for ensuring interoperability among NASA, ESA, CNES, and ASI assets at Mars in the 2003 time frame

- **CCSDS File Delivery Protocol**
  - Provides FTP-like functionality, with reliable end-to-end file transfer over long-light-time, multi-hop relay links
Mars Network Evolution

- Aggressive technology infusion will allow orders-of-magnitude growth in communications capability, enabling radical increases in the fidelity of Mars virtual presence.