ARTEMIS: An Enabling Technology for Long Range or High Data Rate Microspacecraft Communications

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Ground Stations Arrays for Improved Microspacecraft Communications

- Effective improvement without incurring dramatic price increases while allowing for large aperture areas - costs scale linearly for increasing effective aperture
- Can retrofit existing assets or develop low-cost new assets
- Enables higher data rate microsatellite LEO missions (1 Mbps or more) and interplanetary microspacecraft missions
- Most flexible array design: downconvert each antenna signal to baseband, transmit to a central site, and use time correlation to align the signals in phase and time (this method is used by the DSN)
Frequency Offsets in Array

- Frequency offsets between the various local oscillators of each antenna in the array and the microspacecraft, as well as errors in Doppler shift correction must be dealt with
  - DSN uses hydrogen masers as frequency sources to give high frequency accuracy to avoid these error - expensive and difficult to obtain for general use

- SFL developed a software solution to the problem that can be used with any ground station equipment - frequency correlation
Low-Cost Alternative: ARTEMIS

- **AR**raying **T**echniques for **E**nhanced **M**ultiplexing of **I**nterferometric **S**ignals
- Uses both Time Domain and Frequency Domain Correlation to replace hardware requirements with software solutions

![Diagram of ARTEMIS system](image)

Low-Cost Ground Equipment + Time Correlation (DSN: Full Spectrum Combining) + Frequency Correlation (Orthogonal Frequency Division Multiplexing)
ARTEMIS Proof-of-Concept Hardware Apparatus

- Transmitter and Receiver / Ground Correlator are TI floating-point DSPs (optimized for I/FFT function)

IF Wired Link Between Transmitter and Receiver / Ground Correlator (digital upconversion to IF of up to 38.4 kHz)
ARTEMIS Frequency Correlation Experiments

• Example experiment:
  - No. OFDM channels vs. receiver SNR
    - Correlation will not function if digital signal SNR at any of the antennas in the array is too low (ie. the array will not function regardless of its size)
    - Adding more OFDM channels allows for frequency and time correlation to function for weaker signals.
  - Comparison to traditional “single-channel” transmission
Experimental Results

• Frequency correlation works down to -21 dB receiver SNR (at each antenna) with 4096 OFDM channels
  ▪ Equivalent “single-channel” signal at best would work down to -15 to -18 dB, and data rate has to be further reduced to get an equivalent frequency offset detection resolution as the OFDM signal

• This means that ARTEMIS will allow for higher downlink data rates on smaller array antenna assets using low-cost ground station equipment
### ARTEMIS Applications

**Microspacecraft Missions to the Moon & Mars**

<table>
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<tr>
<th>Mission</th>
<th>Antenna Type</th>
<th>Data Rate</th>
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</thead>
<tbody>
<tr>
<td><strong>Moon</strong></td>
<td>3 m Parabolic Antennas in Array</td>
<td>450 kbps data rate</td>
</tr>
<tr>
<td><strong>Mars</strong></td>
<td>6.1 m Parabolic Antennas in Array</td>
<td>2 to 80 kbps data rate</td>
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<tr>
<td><strong>Mars Global Surveyor</strong></td>
<td>6.1 m Parabolic Antennas in Array</td>
<td>300 kbps data rate avg. (DSN: 42 kbps avg.)</td>
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<tr>
<td><strong>Cassini</strong></td>
<td>6.1 m Parabolic Antennas in Array</td>
<td>60 kbps data rate avg. (DSN: 16 kbps avg.)</td>
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Next Steps for ARTEMIS

- Additional memory for DSP to allow for more OFDM channels
- Addition of an RF link between the transmitter and multiple receivers, with the receivers connected to the central correlator via a wired digital data link
- LEO flight experiment on a future SFL mission
  - OFDM transceiver in orbit
  - ARTEMIS array with central correlator site on ground
Summary

- Deep Space Communications:
  ARTEMIS as a low-cost alternative to DSN
  - For new ground stations, can use low-cost RF equipment
  - Can create ad-hoc array with existing antenna infrastructure (large or small) using low-cost equipment.

- Microspace Applications of ARTEMIS
  - High data rate LEO missions
  - Greater range for Interplanetary Microsats

- LEO flight experiment on future SFL mission
Thank You

Partners

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