A Feasibility Study of Techniques for Interplanetary Microspacecraft Communications

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Microsatellites to Microspacercraft

- Numerous successful microsatellite missions
- Dynacon, UTIAS/SFL, & UBC successfully launched MOST on June 30th
- Microsatellites limited primarily to Low-Earth Orbit (LEO)
- Many difficulties must be overcome to expand the role of microsatellites to become microspacecraft, capable of performing interplanetary missions
Microspacecraft Issues

- Launch availability
- Propulsion
- Radiation
- Power (for very long distances away from Sun)
- Communications

<table>
<thead>
<tr>
<th></th>
<th>Magellan</th>
<th>Mars Global Surveyor</th>
<th>Galileo</th>
<th>Cassini</th>
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</thead>
<tbody>
<tr>
<td>Downlink</td>
<td>1k2 &amp; 268k8</td>
<td>2k &amp; 21k33</td>
<td>134k *</td>
<td>40 bps &amp; 17k</td>
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</tbody>
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* due to high gain antenna failure, actual data rate 10 bps with no arraying, 1000 bps with arraying

- Can improve the communications system either on the spacecraft and/or on the ground
Spacecraft Radio/Antenna Improvements

- Need to increase effective isotropic radiated power (EIRP)

900 km (LEO)  385 000 km (Lunar Orbit)

Over 40 dB path loss introduced between LEO and Lunar orbit!
Spacecraft Radio/Antenna Improvements

- Better way to improve the EIRP – directional spacecraft antennas
- Eg. 30 cm parabolic dish (assume 70% eff.)

20 dBi gain at S-Band (2 GHz)
40 dBi gain at K-Band (20-30 GHz)

- Where can a dish antenna fit on the microspacecraft bus?
Earth Ground Station Solutions

- Easier to implement (power and available space are not as limiting)
- Parabolic antennas can range anywhere from 2 m to 70 m in dia. (NASA Deep Space Network)

Everyone should have one of these!
Earth Ground Station Solutions

- Problem: Ground station costs increase dramatically as the size of the antenna increases

Eg. Upwards of CAN$500 000 for a 5 m antenna ground station
Solution: Antenna Arraying

- Done by the DSN for Galileo and Voyager
- Costs scale linearly for increasing effective aperture

Ideal SNR improvement of 3 dB for every doubling of the number of identical antennas in an array
Solution: Antenna Arraying

- Cost Comparison: Array is made up of 3 m dish antennas – includes central site cost

SNR Improvement (dB)

<table>
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<tr>
<th>SNR Improvement (dB)</th>
<th>Estimated Ground Station Cost ($kCAN)</th>
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<tbody>
<tr>
<td>0</td>
<td>34</td>
</tr>
<tr>
<td>2</td>
<td>234</td>
</tr>
<tr>
<td>4</td>
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<td>8</td>
<td>834</td>
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<tr>
<td>10</td>
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- Single Dish Ground Station
- Array Ground Station
Many Different Ways to Array Antennas

- Connect the antennas up via equal length segments of cable and combine at RF/IF (all the antennas share the same local oscillator (LO))
  - Better to combine at baseband (modem frequencies) - tolerance requirements for timing and phase errors are directly proportional to the frequency of the signal being combined
- Requirement to share LO limits the sky coverage and design flexibility of the array
Many Different Ways to Array Antennas

• A more flexible array design would allow the users to locate the antennas, each with its own LO, wherever they wish
• This design would allow for the construction of a ground station array using existing ground stations located across a large surface area, increasing the sky coverage of the ground station
Very Long Baseline Interferometry (VLBI)

- Radio astronomy (1960’s): data collected at each site in an array recorded on magnetic tape. Tapes are then combined at a central correlator site to extract signals out of the noise.

- Similar techniques can be used to combine, in real time over a high speed data link, microspacecraft communication signals received by an array. VLBI can also be used to calculate cross-track information on the microspacecraft.
Array Signal Combination Techniques

Symbol Stream Combining (SSC)

Full Spectrum Combining (FSC)
Sources of Error in a Commercial FSC Array

- Must compensate time and frequency phase errors introduced by such sources as:
  - the fact that each antenna receives the signal at a different time due to their different geographic locations
  - frequency and phase shifts between the various commercial grade LOs
  - timing accuracy problems when combining high data rate signals using commercial grade radio equipment

- Array decorrelation will occur unless these errors can be detected and corrected
Array Simulations & Experiments

• Currently, simulations are being done to test the capabilities of a FSC-VLBI ground station array using commercial radio equipment. To improve its performance, the following is being done:
  • Several spread-spectrum techniques are in the process of being researched and simulated
  • A method of performing frequency-domain correlation is being developed
  • Several digital sampling and filtering techniques are also the subject of current research
Array Simulations & Experiments

- Simulations will involve communications with a microspacecraft with a low powered radio with an omni-directional antenna in LEO, Lunar orbit, and Mars orbit.
- The advantages of using an array to uplink signals to a microspacecraft are also under study.
- The next step after the simulations will be to develop laboratory hardware experiments using equipment that can simulate noise, array time differences, and LO frequency drift.
Conclusions

• The flexibility of the FSC-VLBI design would allow for the creation of an array that can communicate with microspacecraft using small, existing ground stations located over a large area.

• Though interplanetary microspacecraft missions might be years away, if hardware experiments are successful, the techniques developed can also be used to increase the data bandwidth of LEO microsatellites to 1 Mbps and beyond.
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