Reducing Cost and Complexity of Future Missions to Mars with a Microsatellite Constellation Providing a Shared Communications and GPS Service

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Introducing the Status Quo

While NASA's Mars science orbiters are all designed to relay high data rates from other missions back to Earth, they are each in imaging orbits at altitudes without significant coverage of the surface or nearby space. Because of this, as each orbiter closely circles the planet, it comes into line-of-sight radio contact with payloads on a given surface or orbital mission only rarely and intermittently.

Thus, despite the existence of these orbital relays, the status quo of robotic Mars exploration is for each mission to carry a high-powered radio to communicate directly with ground stations on Earth, sometimes more than 375 million kilometres away.

Proposing a Network of Tiny Repeaters

The lowest-cost solution for sending high data rates back to Earth is in taking advantage of this existing infrastructure. Tiny repeaters released into a higher Mars orbit would relay data at up to 128 kilobits per second to a UHF transponder on any of the growing fleet of NASA science orbiters.

Radio amateurs have been launching this kind of simple UHF repeater satellites for years, and UTIAS is developing a three-axis stabilized radio repeater, with a powerful microprocessor, measuring 10 cm cubed and weighing less than a kilogram. Clearly, a very small and very cheap microsatellite, including a straightforward monopropellant engine, is more than adequate for a low-cost repeater with store-and-forward capability.

High Potential for Gain

Interplanetary radios carry the cost, weight, and power drain of a very substantial science payload, while the need to deploy and point a high-gain antenna introduces design complexity and failure modes as witnessed by Galileo. With relays in place, a spacecraft could carry a low-powered UHF radio for its downlink—far smaller and millions cheaper than an X-band radio and dish.

Science returns are routinely limited by the data these radios can send back. While spacecraft in low Mars orbit are in radio blackout for about half of the time, surface payloads find that for part of the year, the Earth is above the horizon only at night when solar arrays are useless. This infrastructure of simple, low-cost relays provides every mission with nearly continuous radio contact with Earth.

The availability of large receiving antennas, such as the 34-metre dish used for Mars Global Surveyor, is always at their limit. Spacecraft already compete for attention from these large dishes, and while Canada can add radiotelescopes to the network, it has the most to gain by not worsening this Mars ground station problem.

Finally, a lower limit on size is placed on miniaturized spacecraft by the need to carry their own radio. Low-cost, but routine interplanetary missions are desirable both programmatically and scientifically, and easier communication helps to make regular small missions truly affordable for Canada and other middle powers.

Mars Global Positioning Service

The network of microsatellites establishes global coverage from orbit, allowing an accurate global positioning service as made familiar by GPS. The more satellites that are deployed, the faster the position can be calculated (a single spacecraft will do if you can wait for a full orbit). Besides a fixed lander, solar-heated balloons and traversing rovers would both be stopped overnight, allowing a positioning lock to average a few hours.

With just three satellites, a real-time positioning service is possible. With a bit of advance notice and choreography, they could all be simultaneously overhead to provide a moving target with an accurate, real-time positioning fix. This would be indispensable for a short aircraft flight, or for terminal navigation on a lander.

This real-time positioning service nicely complements the Mars Terminal Navigation efforts involving LIDAR and inertial systems, extending this suite of Canadian competencies to serve a broader market for Mars navigation.

System Design

There are plenty of examples of more ambitious microsatellites with only about 15 kg of systems, including some basic propulsion. A 200 kg secondary payload delivered to the common geostationary transfer orbit could deliver a cluster of four such satellites, with a 79 kg Thiokol Star 17 solid motor for trans-Mars insertion. Four fuelled vehicles of about 30 kg each separate, and using a very simple onboard monopropellant engine with 15 kg of hydrogen peroxide fuel, establish a high, long-lasting orbit around Mars.

Alternately, as even smaller repeater satellites are possible, the same 200 kg secondary launch could place seven microsatellites into different Mars orbits. Each is inserted on a Mars trajectory by a 95 kg electrodynamic momentum-exchange tether. One by one, a grapple lowers and releases the 15 kg fuelled repeaters on a direct trans-Mars insertion, and each consume 8 kg of monopropellant before entering a precise high orbit.

A small contractor could reproduce the feat of amateurs in building and launching the system, certainly at less than the cost of a typical communications system for the same volume of data. Capitalising on the systems and expertise developed through the MOST microsatellite program, this could be built cheaply and quickly using off the shelf parts.

Benefits to Science

Rational self-interest asks sponsors of science payloads to also promote infrastructure. By investing our budget for communication into patching a serious hole in the existing infrastructure, we will increase the number of payload opportunities for Canadian scientists. Given a fixed budget, every country can fly more payloads on the same missions by eliminating a major cost, weight and power driver.

By providing this relay and positioning service, Canada has added power in negotiating payload opportunities aboard foreign missions. Of course, a more effective use of funds is also an important asset when requesting an expanded exploration budget.

Finally, the tactical effect of this infrastructure is to make small interplanetary missions more accessible, helping to bring small-but-frequent missions towards the cost and complexity levels possible for Canada and other small nations to finance regularly.

This small constellation could easily accommodate small orbital payloads, providing a platform for simultaneous observation, as with the Cluster II plasma analysis mission, and allowing continuous global observation of the Martian atmosphere and surface.