Geophysical Research Abstracts,
Vol. 10, EGU2008-A-11288, 2008
SRef-ID: 1607-7962/gra/EGU2008-A-11288
EGU General Assembly 2008

Evolvable lunar navigation and communication constellations

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Several international space agencies have announced plans for future lunar exploration missions, including orbiters, rovers, and the eventual build-up of a lunar outpost. Each of these missions will have certain communication and navigation requirements. Some missions will explore parts of the lunar environment that are not directly visible to the Earth, and a lunar relay element will be necessary to provide critical communication and navigation support. NASA's exploration plan begins with robotic precursor missions, followed by short human sorties progressing to a permanent base on the surface, located near the lunar South Pole. This paper presents an example of a highly evolvable, low-cost lunar relay constellation concept using small satellites in halo orbits about the Earth-Moon libration points L_1 and L_2. The initial constellation is designed to provide coverage of the lunar South Pole in support of the inaugural robotic missions and is easily expanded to provide global coverage. Two satellites in an L_2 halo orbit provide continuous South Pole coverage for the initial constellation. This constellation is expanded to provide nearly continuous global coverage by inserting two spacecraft in a halo orbit about L_1. Halo orbits offer several advantages: Halo orbit insertion costs are less than those for geostationary orbit, station-keeping costs are minimal, and the Earth is visible for 100% of the spacecraft's orbital period. The methodologies used to construct the example constellation can be tailored to design halo orbit constellations to meet the coverage needs of any lunar mission. Alternatively, the halo orbits are selected such that low energy-transfers may be used to transfer spacecraft between halo orbits for very small maneuver costs. This can allow multiple space agencies to utilize the same lunar relay constellation by reconfiguring

the spacecraft to provide optimal coverage for different missions at different times.