LOCAL NAVIGATION IN LUNAR POLAR REGIONS WITH COMPASS, LUNACELL AND MOBILE AD HOC GEODESY
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Introduction: With the recent expansion of plans for lunar exploration there has been increased interest in support of operations at and near the Moon (i.e., in Cislunar Space), including robotic and crewed missions to the lunar polar regions. Real time navigation and communication will be especially difficult on the heavily shadowed lunar polar regions, given the bad lighting, the frequent lack of line of sight to the Earth, the extreme Geometrical Dilution of Precision (GDOP) for any use of terrestrial GPS and the lack, at least in the near term, of continual overhead satellite coverage. Unlike the Apollo surface Extra-Vehicular Activities (EVAs), future astronauts on polar surface EVAs will need local relays to communicate with the home base, and to perform local navigation, and communication beyond the local line of sight to a central lander.

The LunaCell Network: We are developing a unified “LunaCell” system that can be deployed onto the lunar surface either with or, better yet, in advance of, a crewed or robotic new landing. Figure 1 shows an artists impression of a LunaCell network on the surface of the Moon. Upon deployment (which could be done in stages, with a penetrator deployment augmented by deployments from landers or rovers) the LunaCell system will provide the following services: terminal navigation and landing positioning, local PNT for astronauts and robots over an area surrounding the landing site, communications relay over that same area; and deployment of scientific or prospecting instrument networks.

This system is intended to be self-constructing after being deployed, using inexpensive, and low- or zero-maintenance nodes. The system should also be expandable to larger areas or to link existing areas of coverage, e.g. two separated landing sites. It should also have the ability to patch into satellite/spacecraft communications networks to augment the main-site communications capabilities. Just as the LunaCell communications network will be based on Mobile Ad hoc Networking (MANET) technology [1], which enables the combination of in near real time of a collection of network links of varying quality and bandwidth, the LunaCell PNT will be based on Mobile Ad hoc Geodesy (MAGEO), the near-real-time combination of point to point geodetic links of variable accuracy. Essential to the LunaCell will be Medium Wave (MW) communications at or below 100 MHz, which can penetrate through many meters of the dry upper lunar regolith [2], and which will provide coarse navigation and low bandwidth (audio quality) communications even when out of line of sight of any other node.

The LunaCell Penetrator: LunaCell is based on a mesh network deployed from orbit or on the surface, with the default deployment using a kinetic penetrator deployed near the surface with an impact velocity of \( \sim 100 \text{ m s}^{-1} \) or less; a prototype penetrator exists and the design is ready for impact testing. The penetrators, each of which has on-board processing, communications, and imaging and other sensors, would be carried on the host spacecraft within a carrier. The carrier would detach and then decelerate to a near standing-stop several kilometers above the lunar surface before dispersing the nodes in an appropriate pattern. Following deployment, each node would estimate direction and distance to every other node as they fall to the lunar surface and form a communications network. Following impact, and the system is designed so that the penetrators would not bury themselves too deep, the nodes would then deploy a communications mast, establish a local network, and use their onboard RF and imaging systems to determine their relative positions to each other and the lunar surface from surface features and astronomical sightings. Using COMPASS Very-Long-Baseline-Interferometry (VLBI), which can locate spacecraft to sub-meter accuracy with Earth-based radio telescopes, the nodes could then be more precisely located from Earth and their onboard timing and positioning systems calibrated to near-GPS accuracy. Once deployed onto the surface, a process that should take only a few minutes at most, the nodes would be ready to act as positioning beacons for a descending spacecraft, as well as providing location positioning, secure area communications, site security, and distributed networks of scientific instruments.

COMPASS: COMPASS (Combined Observational Methods for Positional Awareness in the Solar System) is a spacecraft navigation system being developed to provide cost-effective techniques for the accurate positioning of large numbers of spacecraft in cislunar space using Ultra-WideBand (UWB) GHZ beacons [3]. COMPASS will use UWB beacons within the 2-14 GHz range and is designed to be interoperable with the routine modes of the new VLBI Global Observing System (VGOS) [4]. COMPASS+VGOS should be able to provide rapid determination of interferometric observables (phase delay and plasma dispersion with picosecond level accuracies) during routine VGOS observing sessions. Multi-baseline phase-referenced COMPASS-VGOS observations with simultaneous calibrator obser-
Figure 1: A Penetrator deployed LunaCell network set up in advance of a crewed landings to provide mobility and communications support for astronaut EVAs. This could include terminal landing navigation plus a LunaPhone “astronaut cell phone” for communications and PNT even when out of line of sight of both the Earth and any other LunaCell node.

Figure 2: W.P. Blase of Space Initiatives with a prototype 1 meter lunar penetrator in a protective plastic shell. The metal tip on the right would enter the lunar surface, and PNT modules and antennas would be mounted on the left.

Observations should thus enable transverse positioning with 10 cm accuracy with small (credit-card sized) beacons and a few seconds of observations.

Conclusions: The LunaCell system is intended to provide communication and navigation solutions for lunar operations. The basics of differential VLBI have been developed for decades using natural and artificial radio sources [5]. Using UltraWideBand (UWB) technology to provide coherent broadband transmissions in multiple frequency bands, differential VLBI should be able to provide transverse accuracies of $\sim$0.25 nanoradians, or $\sim$10 cm at the lunar surface, and instantaneous range position of about 6 meters. Surface beacons could also provide phase reference sources for orbiting beacons in support of time-critical Lunar operations, such as during landing navigation, and will be useful for lunar science, e.g. by directly tying the Lunar Reference Frame to the VLBI-based Celestial Reference Frame.