USING LONG WAVE RADIO AND THE LUNAR PLASMA ENVIRONMENT FOR LUNAR EXPLORATION T. Marshall Eubanks[1], Charles F. Radley[1], W. Paul Blase[1], [1]Space Initiatives Inc , Palm Bay, Florida 32907 USA; tme@space-initiatives.com;

The Lunar Plasma Environment: Real time navigation and communication will be especially difficult in the lunar polar regions, with heavily shadowing, at best oblique sunlight and frequent lack of line of sight to the Earth or any high-altitude communications relay. Unlike the Apollo surface Extra-Vehicular Activities (EVAs), where direct line of site was maintained between astronauts and either a lander or rover in direct communication with Earth, future astronauts on polar surface EVAs will need means to communicate and perform local positioning beyond the local lines of sight to radio relays. Here we describe how these problems can be addressed through the use of low frequency radio (in this context, any usage with a radio frequency, f, with 1 Hz $\lesssim$ f $\lesssim$ 100 MHz).

It is important to realize that at the lunar polar regions astronauts will be entering a novel and relatively poorly explored plasma and radio frequency (RF) environment, quite different from the direct sunlight and solar wind encountered in Apollo EVAs. There will thus inevitably be a close relationship between the study of the physics of this environment and the study of its possible uses; it should be possible to use the same equipment for both scientific experiments and communication tests. It is also important that any solutions adopted do not interfere with astronomy from the far-side of the Moon in largely unexplored frequency regime with f $\lesssim$ 100 MHz [1].

Table 1 briefly describes the complicated and time-variable plasma environment near the lunar surface. The Moon is in the complicated plasma dynamics of the Earth's magnetotail roughly 25% of the time, and the remainder of the time will be in supersonic solar wind [2]. In the lunar wake the e^- density is substantially decreased. Thermal velocities of electrons in the solar wind are higher than the bulk wind velocity, while the thermal ion velocity is substantially below the bulk velocity. Non-neutral plasmas are thus likely to form in shadowed lunar craters [3], and possibly also in the lunar wake, in both cases on a scale that does not allow for laboratory simulation on Earth. These non-neutral electron clouds are likely to prevent grounding of astronauts and their equipment by the local plasma [4] and must be better characterized to understand this safety hazard.

The low frequency radio range can be conveniently separated into a regime between 30 and 100 MHz, where radio waves will not be affected by the near-Moon plasma and should be able substantially penetrate the regolith, allowing for direct communication "through-the-rocks," a medium-wave regime around 1 MHz where a long distance day-time ground-way propagation using the layer of photo-emitted electrons (e^-) caused by the solar UV flux should be possible, and a very long-wave band below 30 kHz where night-time reflections off the lunar wake should be possible; this very long-wave band could possibly be used for both low-bit-rate night-time communications and to monitor the entire wake environment.

The LunaCell Network: We are developing a unifed "LunaCell" system that can be deployed onto the lunar surface either with or in advance of, a crewed landing. Figure 1 shows an artists impression of a LunaCell network on the surface of the Moon. [5]. 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.

Essential to the LunaCell will be communications at f $\lesssim$100 MHz, which can pass entirely through extremely dry dielectric bodies, as was demonstrated at 90 MHz by the CONSERT bistatic radar experiment conducted by Rosetta and its lander Philae [6, 7]. The use of Mobile Ad hoc Networking (MANET) technology [8] should enables the near-real-time switching between direct line-of-site high bandwidth communications and lower bandwidth through-the-rock communications - an astronaut LunaCell phone should never be out of service!

Olhoefti and Strangway [9] describe the electrical properties of the lunar surface, which is only well characterized in the broken regolith near the surface. A LunaCell network, once deployed, could also be used as a distributed multi-static radar during EVAs, providing astronauts with an underground view of their immediate environment.

Long Range Lunar Radio: The very low frequency lunar environment is relatively unexplored. Manning [11] suggested that the photo-emitted electrons at the lunar surface would allow for long range ground-wave communications over the lunar day-time surface at f $\sim$ 1 MHz. These surface waves would of course sample the entire regolith along the raypath. If communication could be established at $\sim$ 1 MHz between stations at the two lunar poles it should be possible to determine the bulk dielectric properties of large areas of the Moon, and test this form of long range communications. Using

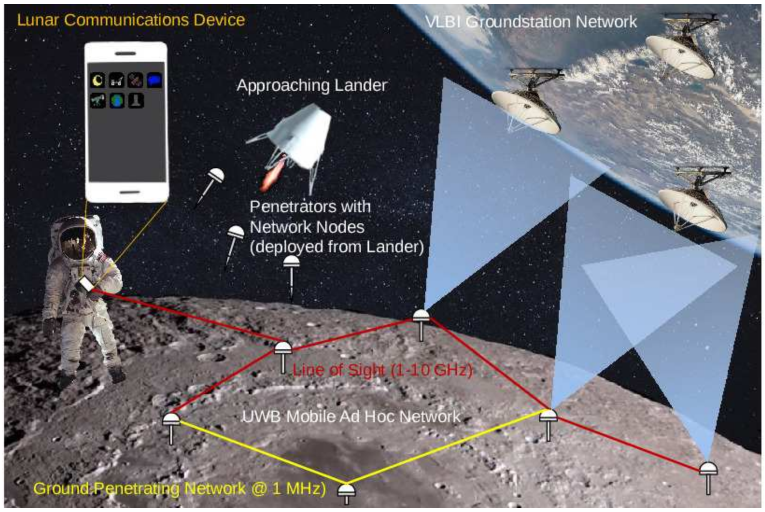

Figure 1: A LunaCell network set up to provide mobility and communications support for astronaut EVAs. This could include terminal landing navigation plus a LunaPhone "astronaut cell phone" for communications and PNT, both through a mesh radio network, and low frequency radio communications when out of line of sight of both the Earth and any other LunaCell node.

Region	e^- # Density cm^{-3}	Plasma Frequency
Solar Wind	∼7	∼ 24 kHz
Photo-Disassociated e^-	∼600	∼ 2 MHz
Earth Magnetotail	∼0.3	∼1 kHz
Shadowed Craters	∼0.01	?
Lunar Wake	∼0.01	∼30 Hz

Table 1: Different Plasma Regions Near the Moon (conditions are typical and subject to large variations). The shadowed craters (and possibly the wake) may contain non-neutral plasmas with a zero plasma frequency. References: [3, 10, 11, 12].

Software Defined Radio systems, the LunaCell network could easily be modified to support this.

At very low frequencies, roughly at or below the solar wind plasma frequency of ∼24 kHz, night-time communications should be possible using reflections off of the lunar wake, which of course would also provide a novel means of monitoring conditions in the wake. Even very low bit rate communications would find use on the Moon, both as a means of distributing alerts and for emergency communications

The electron thermal speeds should allow for shadowed craters at the lunar poles to fill with non-neutral electron clouds, which may support a variety of electrostatic and cyclotron waves and a very complicated plasma environment [13]. It will be difficult to directly sample this environment (satellites cannot fly inside most of the shadowed lunar crater), but LunaCells could be used to establish a lunar ionospheric radar at frequencies between 30 Hz and 30 KHz across or inside a shadowed lunar crater, mapping crater wave phenomena in real time.

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