NASA Lunar Base Wireless System Propagation Analysis

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Abstract

There have been many radio wave propagation studies using both experimental and theoretical techniques over the recent years. However, most of studies have been in support of commercial cellular phone wireless applications. The signal frequencies are mostly at the commercial cellular and Personal Communications Service bands. The antenna configurations are mostly one on a high tower and one near the ground to simulate communications between a cellular base station and a mobile unit.

There are great interests in wireless communication and sensor systems for NASA lunar missions because of the emerging importance of establishing permanent lunar human exploration bases. Because of the specific lunar terrain geometries and RF frequencies of interest to the NASA missions, much of the published literature for the commercial cellular and PCS bands of 900 and 1800 MHz may not be directly applicable to the lunar base wireless system and environment. There are various communication and sensor configurations required to support all elements of a lunar base. For example, the communications between astronauts, between astronauts and the lunar vehicles, between lunar vehicles and satellites on the lunar orbits. There are also various wireless sensor systems among scientific, experimental sensors and data collection ground stations.

This presentation illustrates the propagation analysis of the lunar wireless communication and sensor systems taking into account the three dimensional terrain multipath effects. It is observed that the propagation characteristics are significantly affected by the presence of the lunar terrain. The obtained results indicate the lunar surface material, terrain geometry and antenna location are the important factors affecting the propagation characteristics of the lunar wireless systems. The path loss can be much more severe than the free space propagation and is greatly affected by the antenna height, surface material and operating frequency. The results from this paper are important for the lunar wireless system link margin analysis in order to determine the limits on the reliable communication range, achievable data rate and RF coverage performance at planned lunar base work sites.

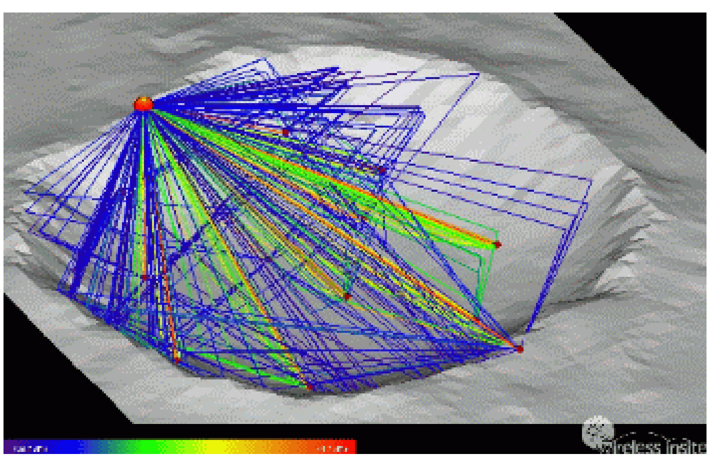

Fig. 1. Lunar wireless system propagation analysis taking into account the 3-D terrain effects.

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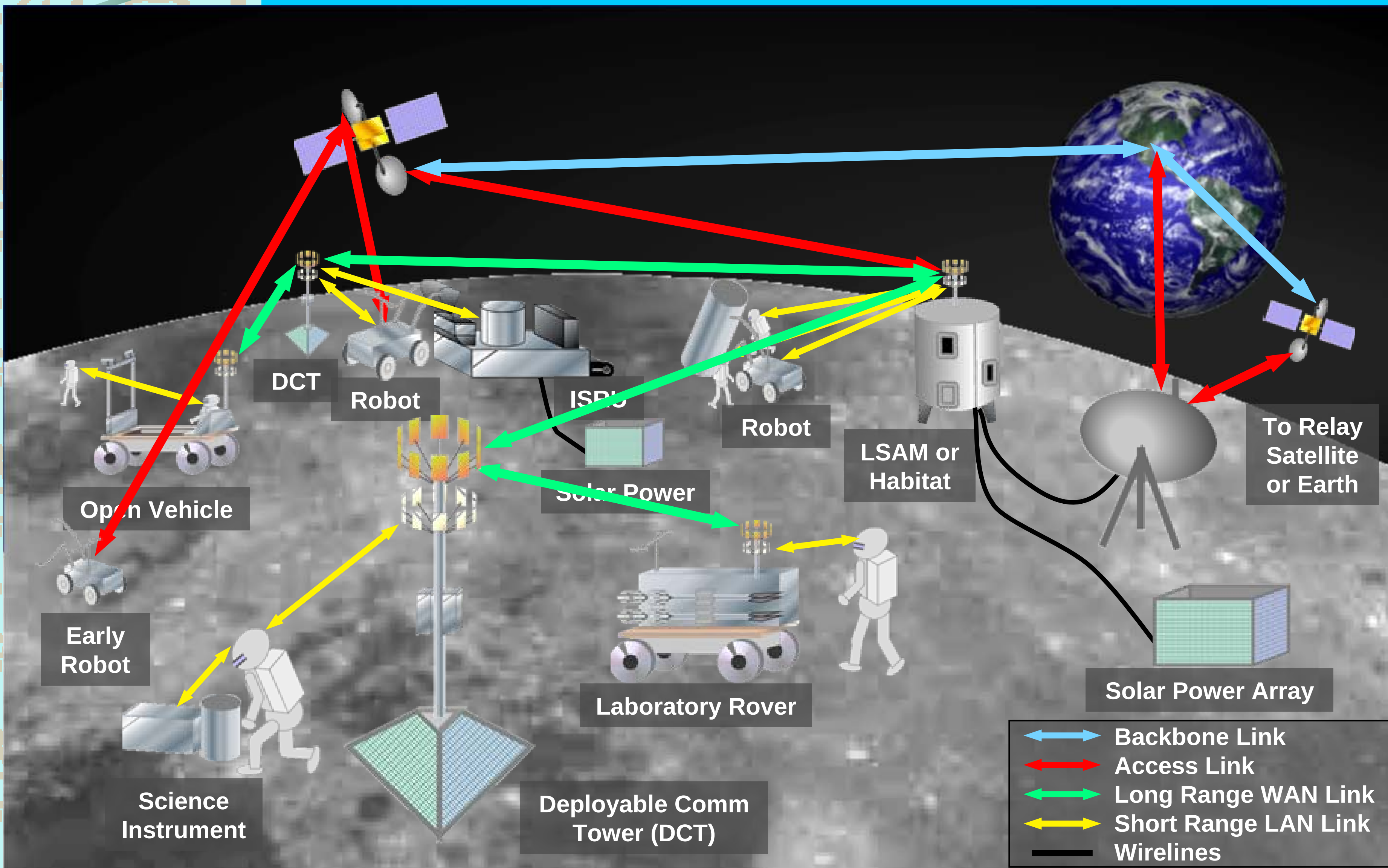
Wireless System Advantages

- Cabling:
  - To deploy an extensive number of sensors/networks in space vehicles would be prohibitive in both cost and weight because of excessive cabling.
- Mobility:
  - With wireless technology, astronauts could use laptops or PDAs at all their workstations and throughout the vehicle.
- Expandability:
  - Large arrays of sensors could be deployed to provide a more in-depth understanding of the environment inside and around the vehicle.

Lunar Surface Communications



Adapted from: Surface Communication Network Architectures for Exploration Missions, AIAA Space 2005, Bhasin, Linsky, Hayden, Tseng

Lunar Propagation Modeling

- The propagation characteristics and signal distribution are essential parameters:
  - wireless network planning
  - systems performance analysis.

- Lunar terrain was modeled with complex dielectric constant.
- Lunar vehicle and astronauts can be included in the model.
- Various types of antennas can be modeled.
- Multiple reflections and diffractions are included in the signal strength computations.
- Signal strength can be mapped in a specified region including shadow region for RF coverage analysis.
- The modeling technique in this study is computational efficient for electrical large vehicle and detail 3-D terrain model.

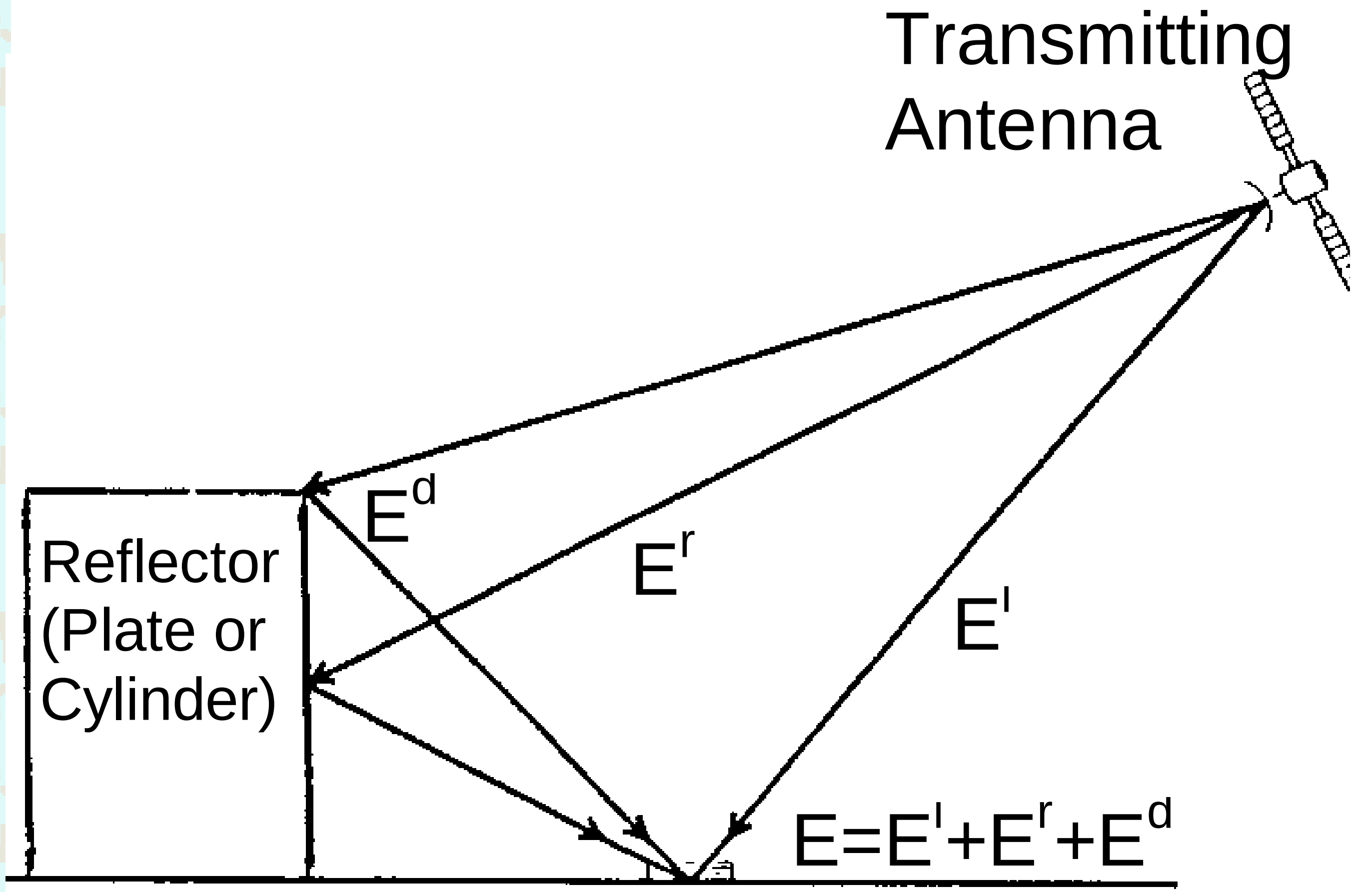
Computational Technique

- Geometrical Theory of Diffraction (GTD)
- The GTD computes direct, reflected, and diffracted fields.
- The reflected and diffracted field can be computed as

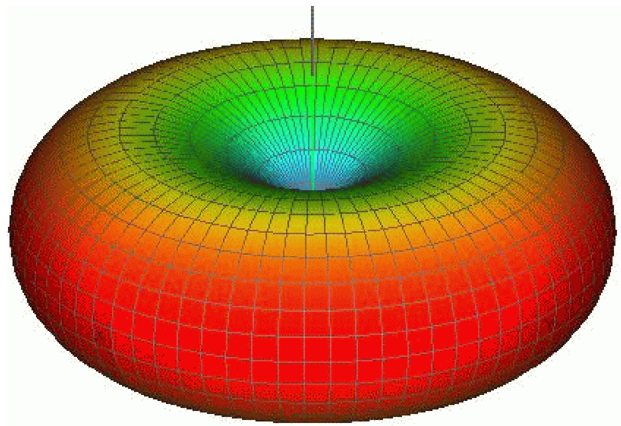
$$E^{r,d}(r') = E^{i}(r)\, D^{r,d}\, A^{r,d}(s)\, e^{-jks}$$

  - $E^{i}(r)$ is the incident field,
  - $D^{r,d}$ is reflection or diffraction coefficient,
  - $A^{r,d}(s)$ is a spreading factor.

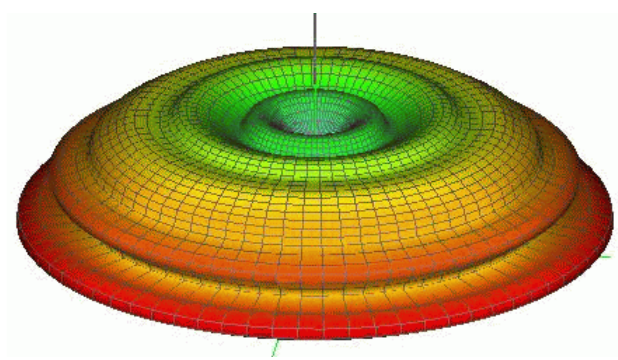
GTD Field Computations



Lunar Ground Effects
Antenna Pattern

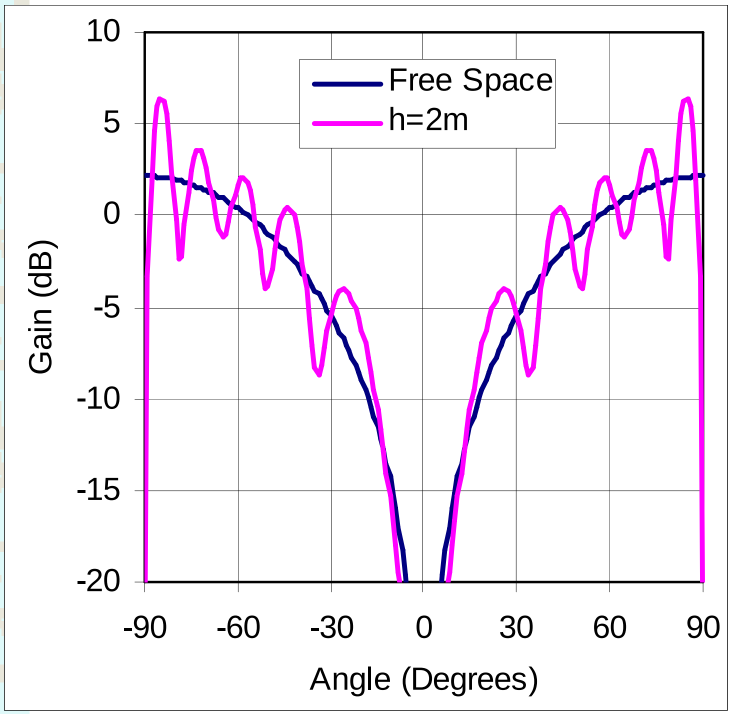


- UHF dipole antenna pattern in free space without ground.



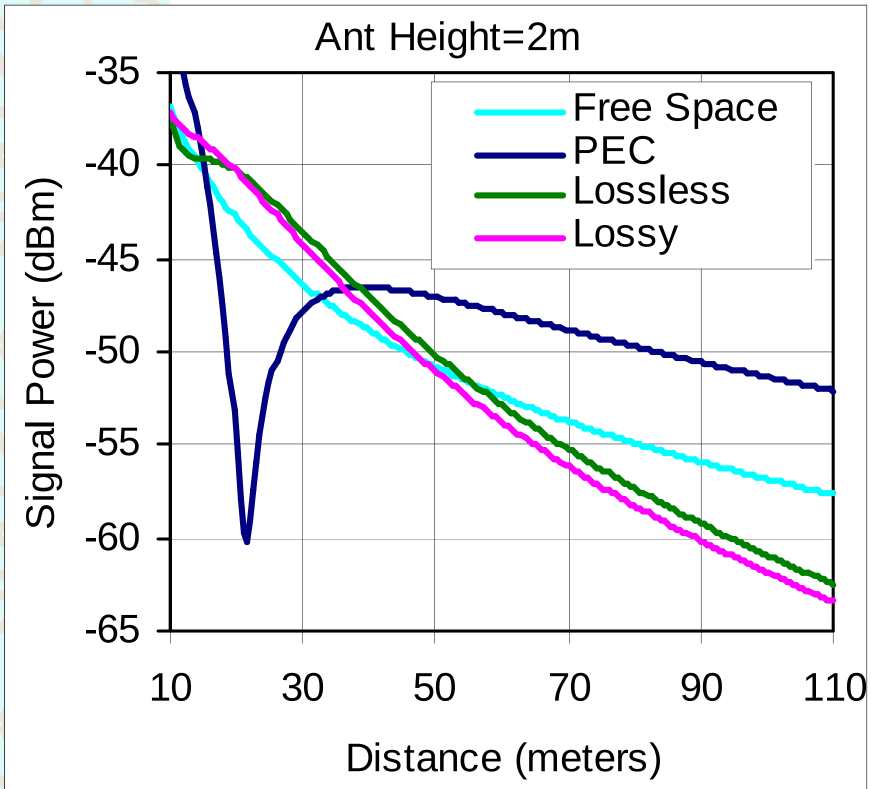
- UHF dipole antenna pattern with lunar ground effects.

Lunar Ground Effects
Antenna Pattern



- Reflection off lunar ground surface causing interferometer on antenna pattern.
- Dependent of antenna height.

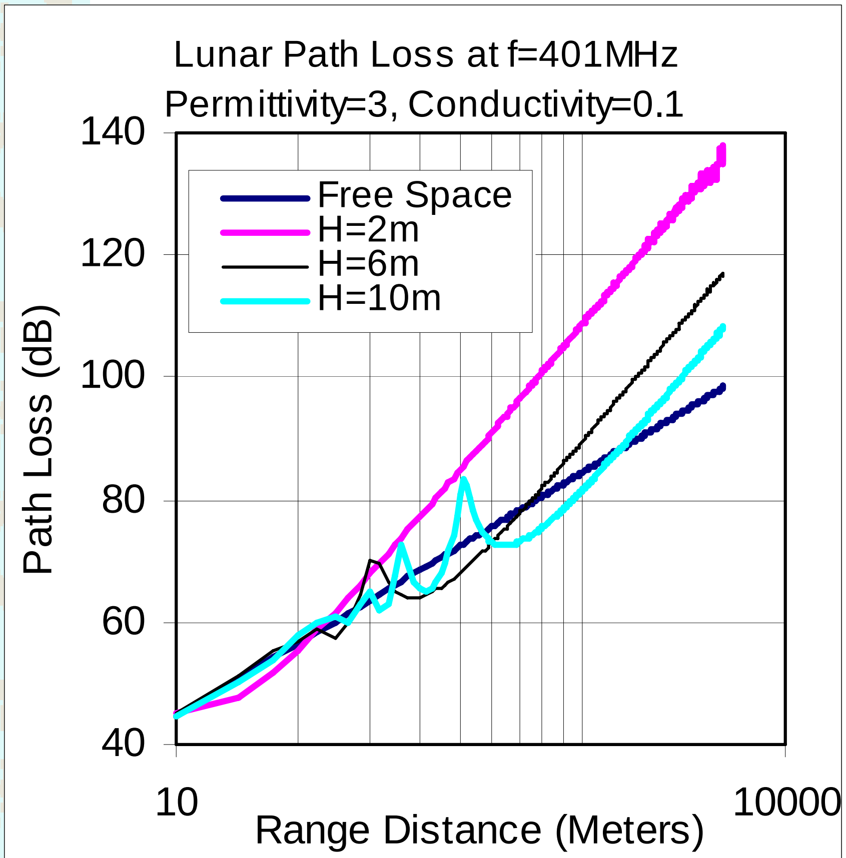
Lunar Ground Effects
Ground Materials



*PEC: Perfect Electric Conductor

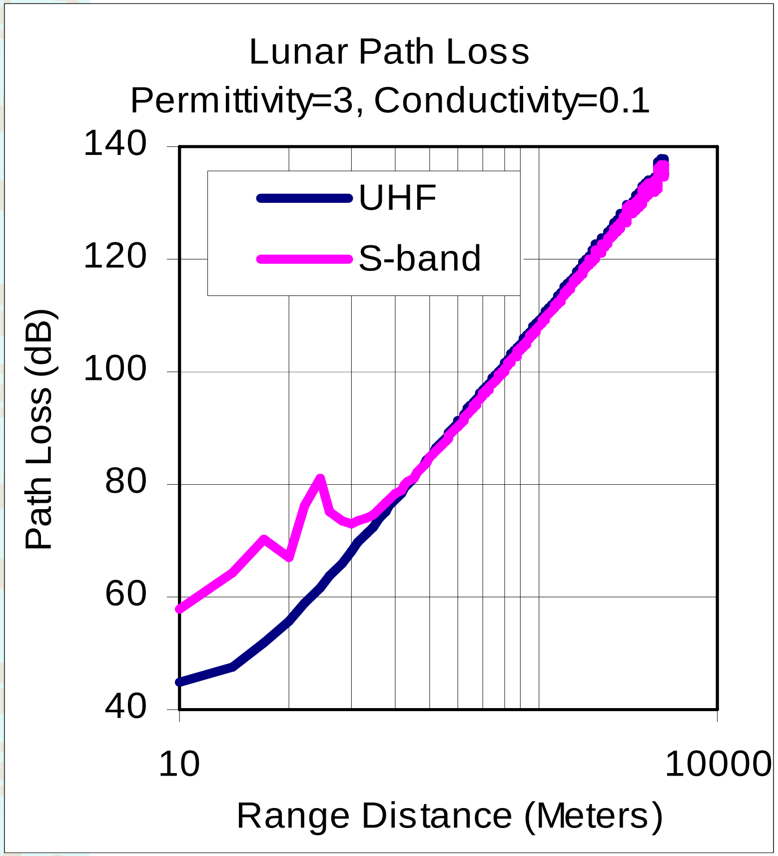
- Lunar ground causing lower signal strength.
- The UHF signal levels are 5 dB lower than free space at 100m.

Lunar Ground Effects
Antenna Heights



- Lower signal levels from systems with low antenna heights.
- Raising antenna height improves signal levels.

Lunar Ground Effects
Frequency

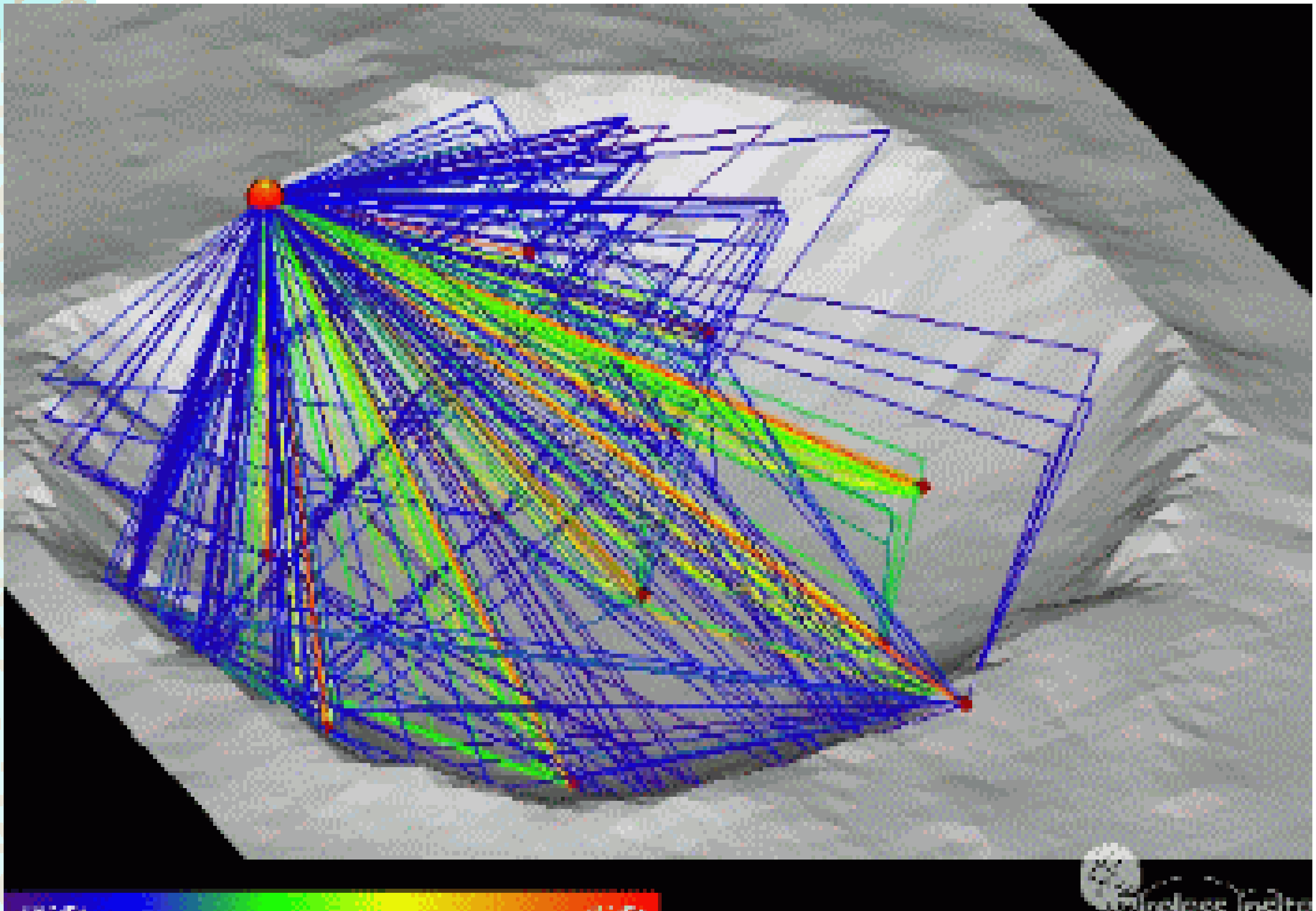


- Higher path loss for higher frequency signals at short range.
- Path loss is frequency independent at long range.

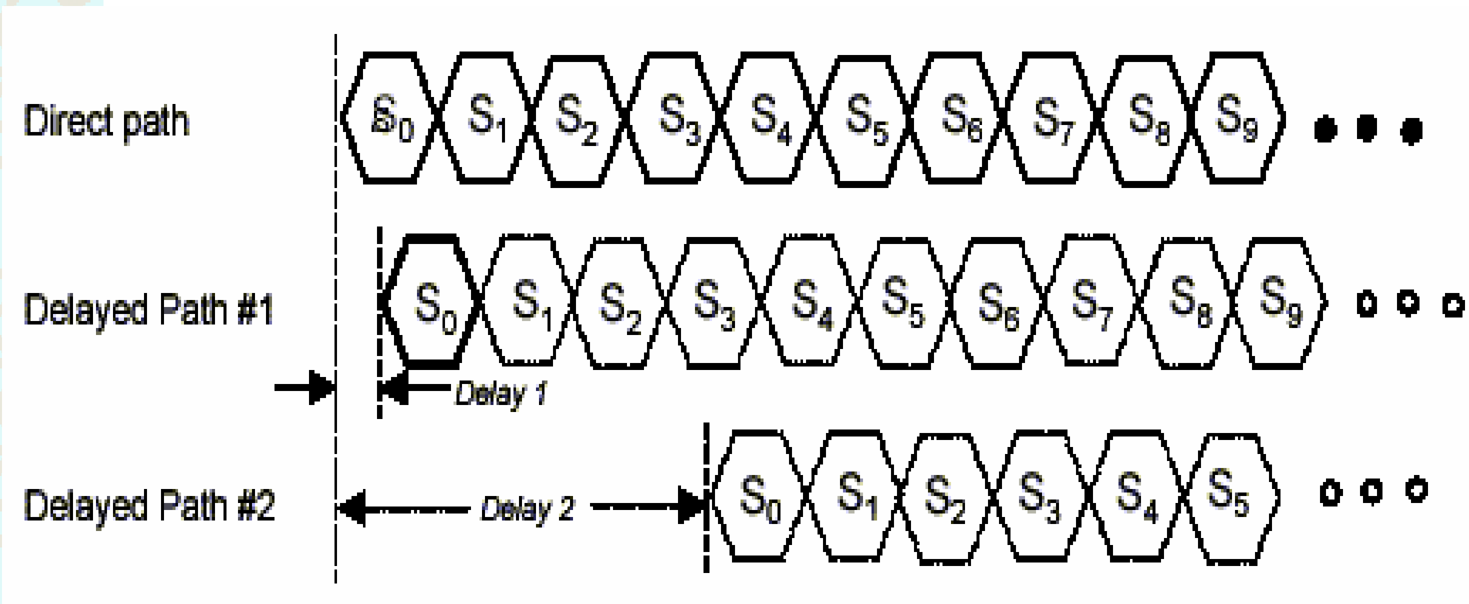
Intersymbol Interference (ISI)

- The signal delay is a major concern for a high data rate wireless system.
- Due to the reflections off the terrain, many indirect rays reach the receiver at longer travel time via longer indirect paths.
- The receiver may see a mix of delayed previous symbol and current symbol.
- This leads to intersymbol interference (ISI) at the receiver which can cause bit errors.
- The ISI problem may occur when the signal delays between direct and reflected paths arriving at a receiver exceed 10% of the symbol length.

Meteor Crater Multipath Environment



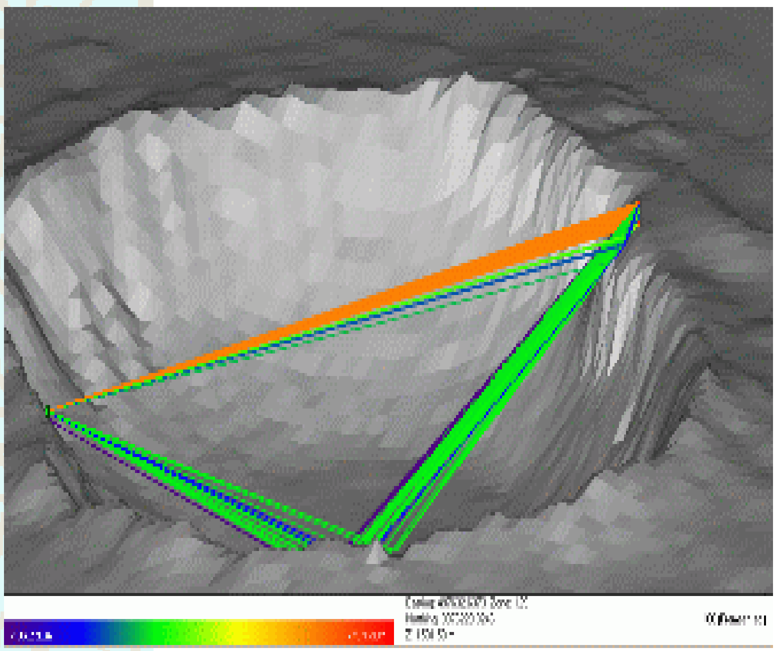
InterSymbol Interference (ISI)

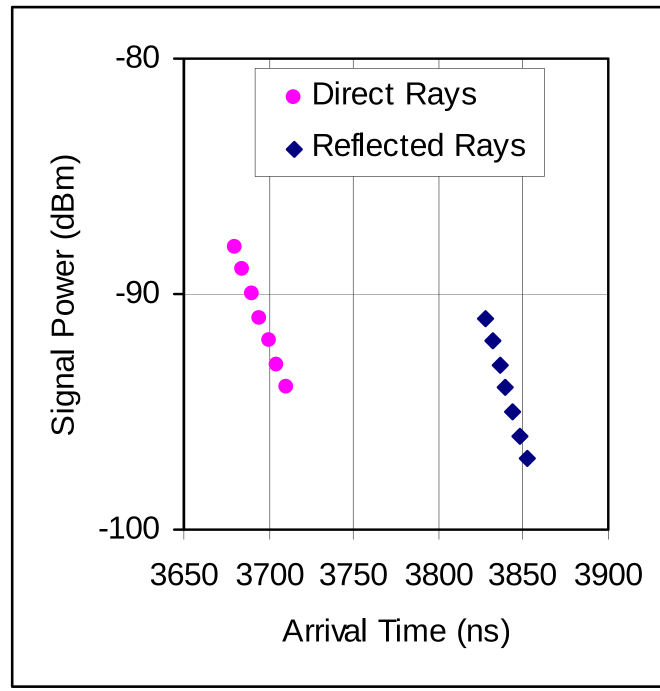


Commercial Multipath Delay Spec.

- Cisco® Datasheet
  - 802.11b : 11Mbps
    - delay spread < 130ns
  - 802.11g : 54Mbps
    - delay spread < 70ns

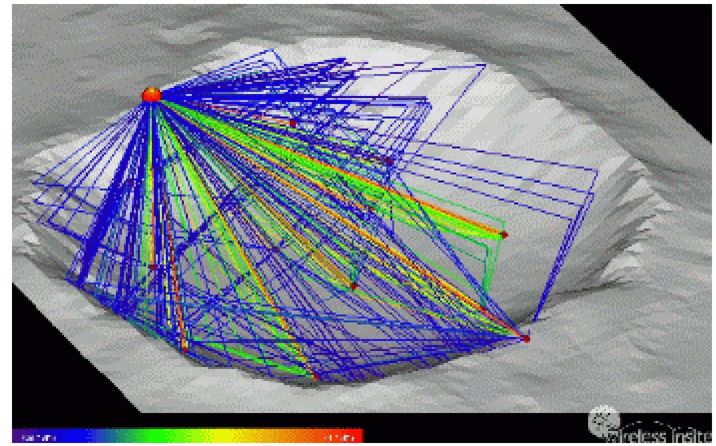
Delay due to Reflections

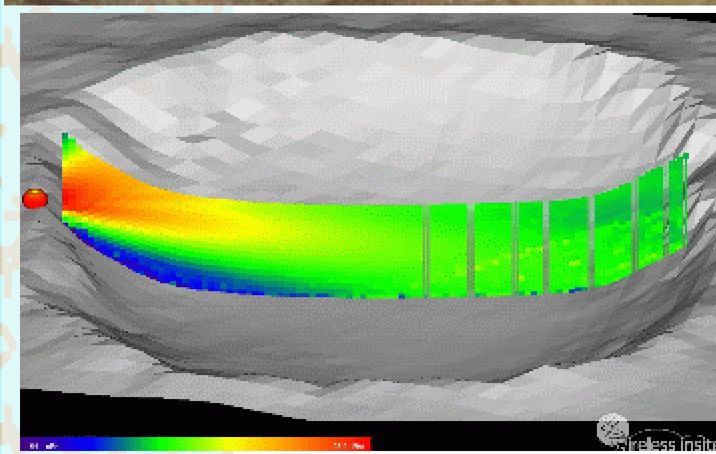


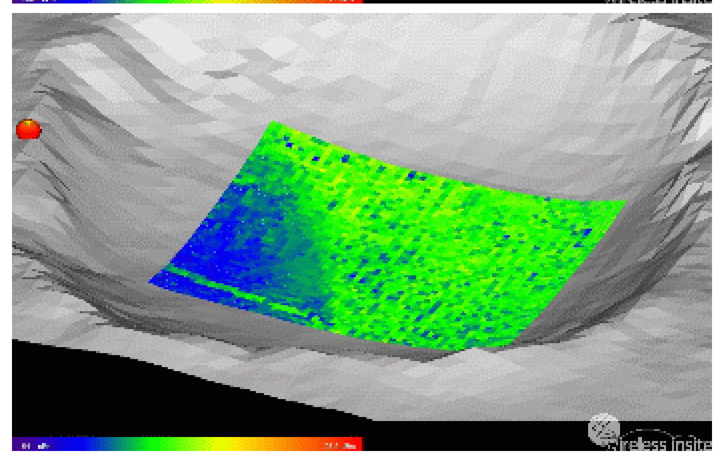


The reflected signals are delayed by about 160 nano seconds.

Meteor Crater Propagation Modeling







Conclusions

- Antenna pattern distortions due to lunar ground effects.
- Lunar ground causes higher propagation loss and lower signal strength than in free space.
- Raising antenna height improves signal levels.
- Higher path loss for higher frequency signals at short range.
- Path loss is frequency independent at long range.
- The crater terrain is common on lunar surface which can cause significant signal drop due to shadowing.
- Signal delay could be a concern in a crater environment.
- The signal delay due to terrain multipath can put a limit on the maximum data rate that can be achieved in the lunar environment.
- Test data from earth terrain may not be applicable due to foliage/vegetation effects.