Lunar Rover Communication Modeling

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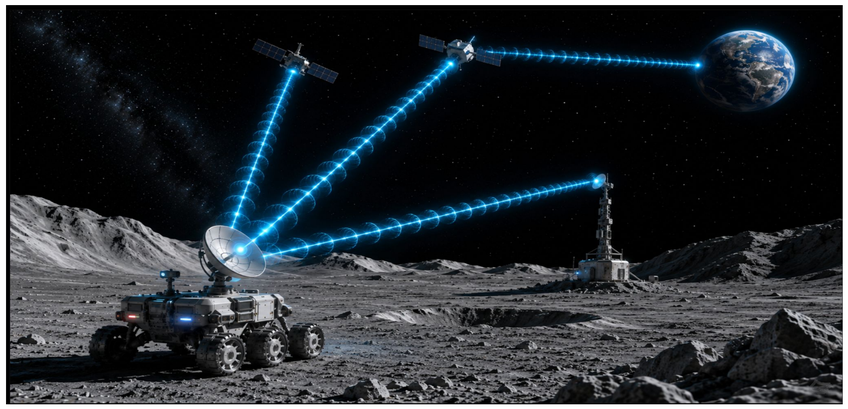
Motivation

➢ Lunar rovers need reliable communication to transmit data, receive commands, and navigate autonomously. However, terrain, long distances, orbital motion, and limited visibility can disrupt communication. This project explores how a rover can detect available links, including a base station, orbiter, relay satellite, and Earth, and automatically select the best option.

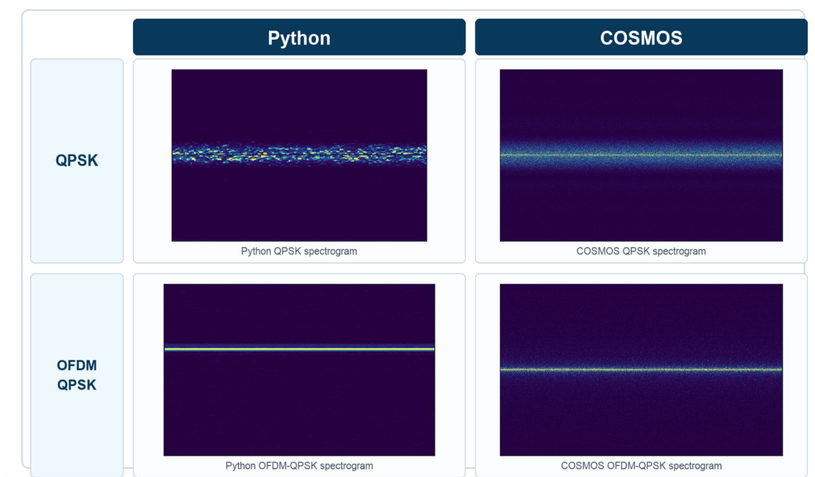
System Architecture



➢ The Rover has the four different communication options as shown above

Fig. 1. Adaptive Lunar Communication System

COSMOS Waveform Validation



➢ QPSK and OFDM-QPSK signals were generated in Python and transmitted using the COSMOS testbed at 3.5 GHz. Both signals remained centered at the intended frequency. Compared with the ideal Python plots, the COSMOS captures showed more noise and frequency spreading due to real hardware and channel effects.

Fig. 2. Python vs. COSMOS Spectrograms

Communication Oppertunity Window

➢ Communication opportunity windows show when each link is available to the rover over time. The base station remains continuously accessible, while the orbiter, relay satellite, and Earth links become available periodically. As visibility changes, the rover can switch to the best available communication mode.

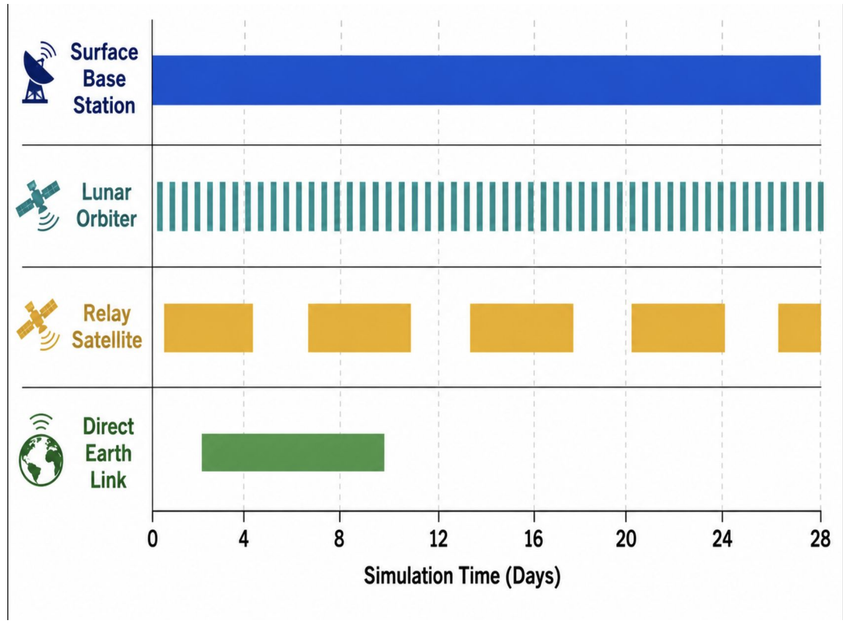


Fig. 3. Communication Oppertunity Window

Sionna Ray-Tracing Coverage

➢ Ray tracing was used to estimate base-station coverage over uneven lunar terrain. The resulting radio map illustrates how distance, craters, and elevated terrain affect predicted signal strength.

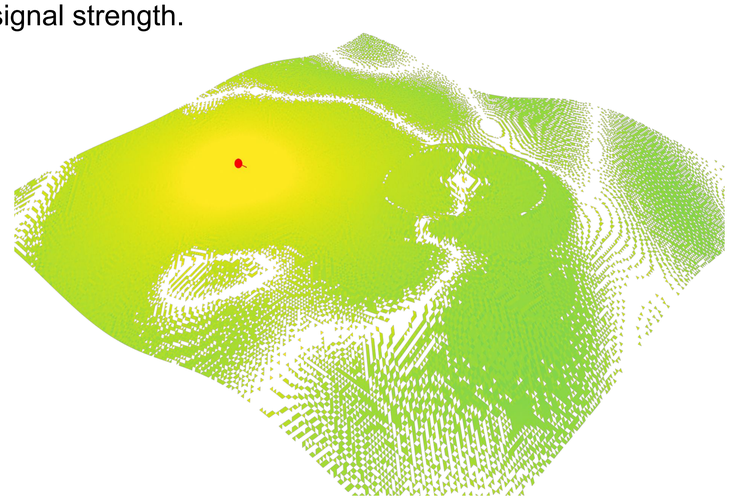
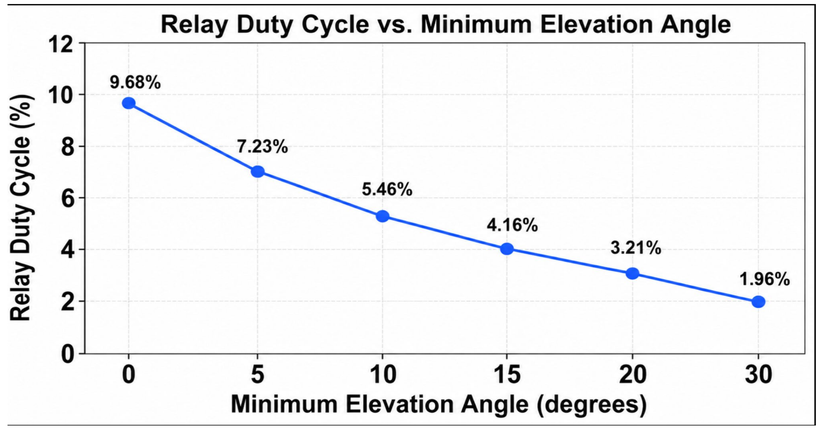


Fig. 4: Sionna RT Lunar Base-Station Coverage Map

Duty Cycle Results



➢ As the minimum elevation angle increases, the relay satellite is available for less time. The duty cycle decreases from 9.7% at 0° to 1.9% at 30°, showing the tradeoff between stronger link conditions and shorter communication windows.

Fig. 5. Duty Cycle graph

Key Findings

➢ Python waveforms were successfully transmitted and captured on COSMOS.
➢ Real testbed signals showed more noise and frequency spreading than ideal simulations.
➢ Communication links had different availability windows over the lunar cycle.
➢ The rover switched between available links to maintain communication.
➢ The continuously available base station was selected most often, while satellite and Earth links provided periodic alternatives.

Future Work

➢ Expand the lunar communication model in ns-3.
➢ Connect the project with machine learning
➢ Evaluate the system over longer and more complex lunar communication scenarios.

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