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TOWARDS A RESILIENT AND ACCESSIBLE PNT INFRASTRUCTURE FOR LUNAR EXPLORATION

Abstract

Position, Navigation, and Timing (PNT) is a fundamental service for supporting diverse lunar missions. While the existing frameworks, such as NASA's LunaNet, aim to facilitate interoperability among space assets, including Earth-Moon relay spacecraft and orbiters, the potential for leveraging multiple lunar-oriented infrastructural assets—both within and beyond LunaNet—remains underexplored. Utilizing these assets to enhance accessible and high-quality lunar PNT services can play a crucial role in fostering open and responsible lunar development. However, the current PNT discussions are focused on using a small scale of space assets, whereas the use of a wider range of applicable assets in an open setting has not been explored. The current interoperability frameworks, such as the latest LunaNet Interoperability Specification (LNIS) published in February 2025, have not yet addressed the network protocol for interoperable lunar PNT services. Critical aspects such as comparative performance evaluation, security, and resilience as key considerations for future lunar missions also remain unaddressed.

To address these challenges, this research examines the feasibility of designing a feasible open infrastructure with the integration of multiple satellites in elliptical lunar frozen orbits, infrastructural spacecraft such as Gateway in a near-rectilinear halo orbit, and lunar surface stations. We will propose an envisioned PNT-oriented open infrastructure that incorporates a variety of interoperable space/ground PNT-related assets from upcoming lunar missions and beyond that can enable accessible, secure, and resilient lunar PNT services. These PNT assets will include lunar orbiters, high-altitude GPS, and ground facilities.

Building on this open infrastructure, we will develop an LNIS-based network protocol to support PNT services. A comparative performance analysis based on state-of-the-art lunar PNT methods and software simulations will be conducted, evaluating viable configuration options that integrate different PNT assets with a focus on service coverage and accuracy. Within these configurations, we will present a case study demonstrating how the proposed PNT-oriented infrastructure enhances resilience and security. In the end, we will discuss our findings and outline directions for future research, including opportunities for international and public-private collaboration to accelerate the development of PNT-based services on the Moon.