

# Multi-spacecraft Autonomous Positioning System

## Project Manager(s)/Lead(s)

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## Sponsoring Program(s)

Space Technology Mission Directorate  
Game Changing Development

## Project Description

As the number of spacecraft in simultaneous operation continues to grow, there is an increased dependency on ground-based navigation support. The current baseline system for deep space navigation utilizes Earth-based radiometric tracking, requiring long-duration observations to perform orbit determination and generate a state update. The age, complexity, and high utilization of the ground assets pose a risk to spacecraft navigation performance. In order to perform complex operations at large distances from Earth, such as extraterrestrial landing and proximity operations, autonomous systems are required. With increasingly complex mission operations, the need for frequent and Earth-independent navigation capabilities is further reinforced.

The Multi-spacecraft Autonomous Positioning System (MAPS) takes advantage of the growing inter-spacecraft communication network and infrastructure to allow for Earth-autonomous state measurements to enable network-based space navigation. A notional concept of operations is given in figure 1. This network is already being implemented and routinely used in Martian communications through the use of the Mars Reconnaissance Orbiter and Mars Odyssey spacecraft as relays for surface assets. The growth of this communications architecture is continued through MAVEN, and future potential commercial Mars telecom orbiters. This growing network provides an initial Mars-local capability for inter-spacecraft communication and navigation. These navigation updates are enabled by cross-communication between assets in the network, coupled with onboard navigation estimation routines to

integrate packet travel time to generate ranging measurements. Inter-spacecraft communication allows for frequent state broadcasts and time updates from trusted references. The architecture is a software-based solution, enabling its implementation on a wide variety of current assets, with the operational constraints and measurement accuracy determined by onboard systems.

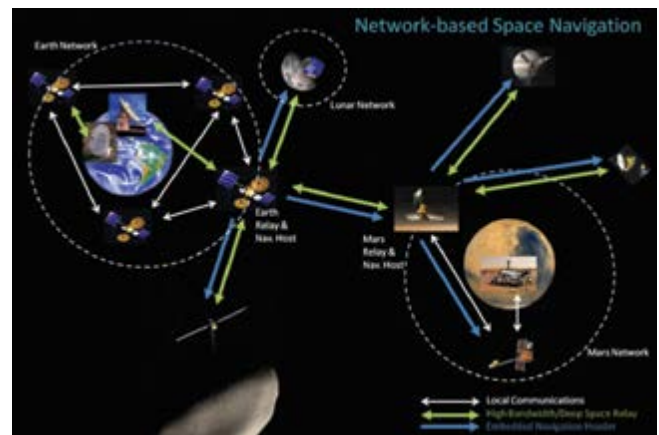


Figure 1: MAPS concept of operations.

The Martian communication network, along with deep space network support, provides an initial architecture for simulation and analysis of MAPS, providing a notional deep space implementation. This scenario is used for initial trade studies to determine capability assessments and sensitivity analysis. This architecture also serves as the mission scenario capturing the ideal initial deep space implementation of MAPS.

To support initial flight validation, a low-Earth orbit (LEO) demonstration mission concept is also being developed and analyzed. This mission scenario focuses on capturing the in-flight accuracy of the spacecraft clocks as well as in-flight packet transmission, and state estimation among a limited number of assets. To support this mission, both software and hardware simulation tools have been developed. The simulation architecture allows for analysis of link budgets and estimated performance as a function of individual asset orbits and simulated errors (such as external perturbations and timing uncertainty). To capture the effects of

real hardware, a hardware-in-the-loop system is being utilized to integrate flight quality radio and clock hardware to capture receiver delays and clock uncertainty to directly model spacecraft behavior. This framework is described in figure 2.

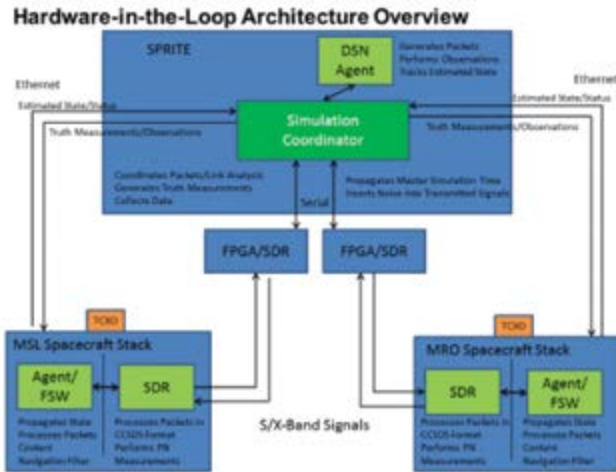


Figure 2: Simulation framework.

The capability for highly accurate timing measurements and delay modeling is enabled through the use of a truth simulation coordinator and a timing coordinator. These are both synced to high accuracy network clocks, with the timing coordinator running minimal processing to reduce any timing errors in modeling and controlling communication delays. This architecture will allow for verification and performance analysis of MAPS across a variety of mission scenarios, and provides a starting point for a full architecture simulation.

### Anticipated Benefits

This technology is well suited to providing navigation capability to spacecraft participating in the communication network. By utilization of this technology, it is possible to turn every communication pass between assets into a real-time autonomous navigation pass as well, supplementing and enhancing traditional state determination methods. This reduces the reliance and load on ground-based assets while also increasing onboard state estimation capability.

### Potential Applications

This architecture is designed to support in-space navigation for robotic and human missions. It can also serve as a backup navigation method for cases with limited

ground support availability. As onboard clocks improve in capability and multiple spacecraft implement these algorithms, MAPS can be used as a primary navigation source. Additionally, this architecture can be used to develop high accuracy navigation references throughout our solar system, integrating with interplanetary communication relays.

## Notable Accomplishments

To support mission analysis and design, an agent-based simulation tool has been developed for design space exploration, performance evaluation, and optimization of the architecture. This simulation is currently being expanded to include flight-like timing sources and radios to allow for the direct capture of hardware-based performance metrics. Current work is focused on integration with the portable hardware-in-the-loop framework to allow for detailed performance evaluation and mission analysis.

The team is also performing mission design to support a LEO technology demonstration. Initial assumptions of a CubeSat platform in LEO are being analyzed to support vehicle sizing and operations concepts. This mission concept will be the focus of the hardware-in-the-loop simulation.

## References

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- Anzalone, E.; and Chuang, C.H.: "Conceptual Design of a Communication-based Deep Space Navigation Network," AIAA Space 2012 Conference & Exposition, Pasadena, CA, September 11–13, 2012.