NASA SBIR 2020 Phase I Solicitation

Z8.02 Communications and Navigation for Distributed Small Spacecraft Beyond LEO

Lead Center: GRC

Participating Center(s): ARC, GSFC, JPL, LaRC

Technology Area: TA5 Communication and Navigation

Scope Title

Distributed Spacecraft Mission Communications

Scope Description

Develop enabling technologies for beyond Low Earth Orbit (LEO) communications, relative and/or absolute position knowledge, and control of small spacecraft. Space communications and position knowledge and control are enabling capabilities required by spacecraft to conduct NASA Lunar and deep-space distributed spacecraft science missions. Innovations in communications and navigation technologies for distributed small spacecraft are essential to fulfill the envisioned science missions within the decadal surveys and contribute to the success of human exploration missions. To construct the lunar communications architecture, it is appropriate to consider a hybrid approach of large and small satellite assets. Primary applications include data relay from lunar surface to surface, data relay to earth, and navigational aids to surface and orbiting users. Distributing these capabilities across multiple smallsats may be necessary because of limited Size, Weight and Power (SWaP), but also to enhance coverage. Technologies for specific lunar architecture are especially needed, but considerations of extension to the Martian domain are also solicited.

References

1] International Communication System Interoperability Standard (ICSIS), found at: https://www.internationaldeepspacestandards.com


Expected TRL or TRL range at completion of the project: 3 to 5

Desired Deliverables of Phase II

Prototype hardware and/or software.

Desired Deliverables Description

Phase I - Identify and explore options for the Distributed Spacecraft Mission (DSM) configuration control, conduct trade analysis and simulations, define operating concepts, and provide justification for proposed multiple access techniques, frequency bands of operation, command and data handling and networking solutions. Also identify, evaluate and develop design for integrated communications payload(s) and one or more constituent technologies that enable distributed spacecraft operations in the relevant space environment beyond LEO. Integrated communications system solutions and constituent component deliverables should offer potential advantages over the state of the art, demonstrate technical feasibility, and show a path towards a hardware/software infusion into practice. Bench-level or lab-environment level demonstrations or simulations are desirable. The Phase I proposal should outline a path that shows how the technology can be developed into space-qualifiable and commercially available small spacecraft communications payloads through Phase II efforts and beyond.

State of the Art and Critical Gaps

Communications among spacecraft in the DSM configuration and between the DSM configuration and the Earth become more challenging beyond LEO distances. Collaborative configurations of widely distributed (10s to 100s km apart) small spacecraft (180 kg or less) will operate far into the near-Earth region of space and beyond into deep space, further stressing the already limited communications capabilities of small spacecraft. Alternative operational approaches with associated enabling hardware and/or software will be needed with the following:

- DSM configuration control: distributed operations of the DSM configuration and of individual small spacecraft alternatives need to provide: science data time and location stamping; temporary data storage; distributed network control and data planes; networking protocols; and any other considerations associated with control of the configuration. Control needs to allow a swarm to fly with the precision approaching that of one large instrument, and/or produce relative position data that allows for compensation of measurements over time.
- Uplinks (Earth-to-space) and Downlinks (space-to-Earth): alternatives for coordinated command and control of the DSM configuration and individual small spacecraft from Earth as well as return of science and telemetry data to Earth.
- Integrated communications payload: hardware and software designs for the common and unique capabilities of each small spacecraft in the DSM configuration.
- Small Spacecraft Antennas: development of antennas optimized for either inter-satellite or uplink/downlink communications are sought across a broad range of technologies including but not limited to deployable parabolic or planar arrays, active electronically steered arrays, novel antenna steering/positioning subsystems, and others suitable for use in high data rate transmission among small spacecraft over large distances. Operations compatible with NASA’s space communications
infrastructure [9] and Government exclusive or Government/non-Government shared frequency spectrum allocations is required. [6, 7, 8].

- Compatibility and interoperability with lunar communications and navigation architecture plans [1, 2, and 3]. Application of the emerging lunar standards includes frequency allocations per link functionality, modulation, coding, and networking protocol standards.

Relevance / Science Traceability

Several missions are being planned to conduct investigations/observations in the cis-lunar region and beyond. All of these missions will benefit from improved communications and navigation capabilities. For example, follow-on missions to the current Mars Cube One mission.

Scope Title

Distributed Spacecraft Mission Position Knowledge and Control

Scope Description

The navigation portion of this subtopic solicits methods for determining and maintaining spacecraft position within a configuration of small spacecraft. In addition, timing distribution solutions for the smallsats may be important. Distributed Spacecraft Mission (DSM) navigation solutions may be addressed via hardware or software solutions, or a combination.

References


Expected TRL or TRL range at completion of the project: 3 to 5

Desired Deliverables of Phase II

Prototype hardware and/or software.
Desired Deliverables Description

Phase I - Identify and explore options for the DSM configuration control, conduct trade analysis and simulations, define operating concepts, and provide justification for proposed multiple access techniques, frequency bands of operation, command and data handling and networking solutions. Also identify, evaluate and develop design for integrated communications payload(s) and one or more constituent technologies that enable distributed spacecraft operations in the relevant space environment beyond LEO. Integrated communications system solutions and constituent component deliverables should offer potential advantages over the state of the art, demonstrate technical feasibility, and show a path towards a hardware/software infusion into practice. Bench-level or lab-environment level demonstrations or simulations are desirable. The Phase I proposal should outline a path that shows how the technology can be developed into space-qualifiable and commercially available small spacecraft communications payloads through Phase II efforts and beyond.

State of the Art and Critical Gaps

Science measurements of DSMs are based on temporal and spatially distributed measurements where position knowledge and control are fundamental to the science interpretation. Current space navigation technologies are not adequate when relative or absolute position knowledge of multiple spacecraft are involved. Global navigation satellite services like the U.S. global positioning satellites (GPS) provide very limited services beyond GEO (Geocentric) distances and no practical services in deep space. Autonomous navigation capabilities are fundamental to DSMs to ensure known topography of the configuration at the time of data acquisition. Control of the distributed configuration requires robust absolute and relative position knowledge of each spacecraft within the configuration and the ability to control spacecraft position and movement according to mission needs.

- Optical navigation - Solutions are sought for visual based systems that leverage advances in optical sensors (i.e., cameras, star trackers) to observe and track a target spacecraft and perform pose and relative position estimation. In particular, low SWaP absolute attitude determination using star trackers, etc. to achieve sub-arcsecond accuracy. JPL\#128;\#153:s ASTERIA 6U CubeSat demonstrated pointing stability of 0.5 arcseconds (0.1 m\(^\circ\)) RMS over 20 minutes using guide stars might represent the state-of-the-art. Opportunities for innovation include methods that do not require the execution of satellite maneuvers are/or the design of external satellite features that enhance observability. Innovations may be appropriate for only certain regimes, such as near, medium, or far range; however, this context should be described. Solutions for various mission operations concepts are of interest.
- Long-term, high accuracy attitude determination; in particular, low SWaP absolute attitude determination using star trackers, etc. to achieve sub-arcsecond accuracy.
- Other novel navigation methods - Stellar navigation aids, such as navigation via quasars, X-rays and pulsars, may provide enabling capabilities in deep space. Surface-based navigation aids, such as systems detecting radio beacons or landmarks, are invited.
- Methods for autonomous position control are also of interest. Technologies that accomplish autonomous relative orbit control among the spacecraft are invited. Control may be accomplished as part of an integrated system that includes one or more of the measurement techniques described above. Of particular interest are autonomous control solutions that do not require operator commanding for individual spacecraft. That is, control solutions should accept as input swarm-level constraints and parameters, and provide control for individual spacecraft. Opportunities for innovation include the application of optimization techniques that are feasible for small satellite platforms and do not assume particular orbit eccentricities. NOTE: Small spacecraft propulsion technologies are not included in this subtopic.

Relevance / Science Traceability

Space communications and position knowledge and control are enabling capabilities required by spacecraft to conduct all NASA missions. The concept of Distributed Spacecraft Missions (DSM) involves the use of multiple spacecraft to achieve one or more science mission goals.

Several missions are being planned to conduct investigations/observations in the cis-lunar region and beyond. All of these missions will benefit from improved communications and navigation capabilities.