NASA SBIR 2018 Phase I Solicitation

Z8.02 Communications for Distributed Small Spacecraft Beyond LEO

Lead Center: GRC

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

Technology Area: TA5 Communication and Navigation

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. DSM configurations include widely dispersed configurations of spacecraft, constellations, free-flying swarms, formation flying swarms clusters, swarms of common elements, and disaggregated science mission elements, all operating in the space environments beyond low Earth orbit (LEO).Â The term, â€œswarmâ€ refers to a configuration of spacecraft that communicate and exchange data and location information with each other andact a one controllable entity.Â In contrast, â€˜constellationsâ€™ are loosely grouped spacecraft which may communicate with other but are flown individually.Â A swarm of dozens to hundreds of spacecraft located 10s to 100s km apart must be able to act as one unit. Small distributed spacecraft acting in cooperation can execute science and exploration missions that would be impossible by traditional large spacecraft, and offer the potential for new concepts in mission design. 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.Â The goal of this subtopic is to develop DSM-enabling technologies for communications, relative and/or absolute position knowledge, and control of small spacecraft (or other directly related technologies) for configurations of small spacecraft operating over large distances beyond LEO. This subtopic is a direct enabler of deep space distributed spacecraft science missions.

DSM Communications

Communications among spacecraft in the DSM configuration and between the 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. The communications links to/from DSM spacecraft beyond LEO distances are closed via either NASAâ€™s near-Earth network (NEN) or deep space network (DSN) ground station infrastructure, depending on the distance of the spacecraft from Earth (i.e., NEN for < 2 million km, DSN for > 2million km).Â

The DSM communications portion of this subtopic invites innovative system level communications architecture and concepts of operation and an integrated communications payload design taking into consideration the following capabilities:Â

- *DSM configuration control â€“* For distributed operations of the DSM configuration and of individual small spacecraft. Identify alternatives, provide rationale for selection, and develop proposed approaches for: 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.

- *Inter-satellite links (space-space) â€“* For coordinated exchange of science instrument data and spacecraft telemetry and command (T&C) data among small spacecraft in the DSM configuration. Identify alternatives and provide rationale for selection of proposed: frequency band(s) of operation or optical communications; multiple access and addressing techniques; minimum and maximum data rates; expected link bit error rate, maximum expected range between spacecraft, maximum spacecraft field of regard; and pointing stability requirements.
- *Uplinks (Earth-space*) *and Downlinks (space-Earth) â€“* For coordinated command and control of the DSM configuration and individual small spacecraft from Earth and return of science and telemetry data to Earth. Identify alternatives and provide rationale for selection of proposed: frequency band(s) of operation or optical communications; ground terminal network; coordination with other users of the band(s); multiple access and addressing techniques; minimum and maximum data rates; expected link bit error rate, maximum expected range between spacecraft, ground terminal and maximum spacecraft field of regard; and pointing stability requirements.
- *Integrated communications payload*â€“ For the common and unique capabilities of each small spacecraft in the DSM configuration. Identify proposed hardware and software designs of the small spacecraft communications payload(s) required to implement the proposed communications links and operational controls.Â

In addition *to* the system level concepts of operation and integrated communications payload design, innovations and advancements in technology readiness in one or more of the following constituent small distributed spacecraft technologies is also requested:Â

- *Small Spacecraft Antennas* â€“Â 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 NASAâ€™s space communications infrastructure [1] and Government exclusive or Government/non-Government shared frequency spectrum allocations is required. [See References for applicable Government frequency spectrum allocations in the near Earth and deep space regions].Â
- *Optical Communications* â€“Â Point-to-point communications are the most common approach for optical communications. This focus area seeks innovations that enable optical communications among many spacecraft simultaneously operating in a distributed spacecraft network. Technologies and integrated solutions for beaconless one-way and/or bidirectional two-way optical communications from beyond LEO to Earth-based optical terminals are also sought. Technology advancements in integrated solutions are sought that increase the data rate or availability of optical communications for small spacecraft, or reduce mission risk, pointing requirements, complexity or cost at a minimally-acceptable Quality of Service.
- *Transceivers and Radios* â€“Â This area includes but is not limited to: multiple access techniques; radio frequency (RF) transmitters; amplifiers; low noise receivers, full duplex frequency selectable RF front-ends, integrated navigation and communications receivers, software defined or reconfigurable radios, or integrated transceivers and radios for inter-satellite links among distributed spacecraft and/or uplink/downlink via the NEN or DSN. Small satellites are particularly constrained in terms of power, mass and volume, therefore significant improvements in these areas are highly effective. In addition to reductions in mass, power consumption, volume and cost, increases in power and bandwidth efficiency, operational flexibility and frequency select-ability are sought. Small spacecraft transceivers and radios must be compatible with the operations of NASAâ€™s space communications infrastructure. [1] [See References for applicable NASA near Earth and deep space infrastructure guidelines and specifications].Â
- *Networking Protocols and Processing* â€“Â Standard Internet protocols donâ€™t work well over communication links that are subject to the frequent, transient service outages and/or long signal propagation delays that are characteristic of missions beyond LEO. Innovations or advancements are sought in networking protocols and distributed data processing (routing/switching) and storage systems that enable secure, low-power networked communications among small spacecraft within the DSM configuration and/or between the configuration or individual spacecraft and network service users and operators on Earth

and/or on the surfaces of other Solar System objects. Implementation of NASAâ€™s delay/disruption tolerant networking (DTN) standards to support scalable, robust and secure mission communications for small spacecraft links from beyond LEO to Earth are also invited. Interoperability between spacecraft operating with NASA and commercial space networks is an additional opportunity for innovation. [See References for applicable NASA and commercial networking standards].Â

Low mass, power, volume, cost and complexity are overarching goals. Leverage of commercial technologies or best commercial standards and practices (e.g., DVB-S2 standard, CubeSat form factors, 5G wireless technologies) that can demonstrably improve performance and be applied or adapted for use in Government, non-Government or commercial networks is also desirable.Â

Note: *Proposed Earth-Space and Earth-Space communications links must be designed to operate in and comply with the frequency spectrum bands implemented by the NEN and/or DSN and/or comply with other frequency spectrum bands allocated by the U.S. National Telecommunications Information Administration (NTIA) tables of frequency allocations for space research. Links among distributed spacecraft must use frequency spectrum allocated by the NTIA in the U.S. for inter-satellite communications service (e.g., ~23 GHz, ~24.5 GHz, ~26 GHz, ~60 GHz).*Â

Finally, small spacecraft communication systems operating beyond LEO must be robust, flexible and diverse to support a wide variety of interconnected configurations of spacecraft used by NASA to conduct space science, Earth science and exploration of the universe. Communication system components need to be able to operate over a range of environmental conditions, such as those imposed by launch vehicles and operations in space with appropriate levels of radiation tolerance in the space environment beyond LEO. A clear path to space qualification for potential operation in those regions of space is required of all proposed technologies.

DSM Position Knowledge and Control

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.Â Global navigation satellite services like the U.S. global positioning satellites (GPS) provide very limited services beyond GEO distances and no practical services in deep space. Autonomous navigation capabilities are fundamental to DSMs to ensure topography of the configuration is known at the time of data acquisition.Â 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.Â

The navigation portion of this subtopic solicits methods for determining and maintaining spacecraft position within a configuration of small spacecraft. DSM navigation solutions may be addressed via hardware or software solutions, or combinations of the two. Innovations and advancements in technologies for determining relative and absolute position knowledge include but are not limited to:Â

- *Radiometric measurements* **-** Exploitation of intersatellite communication links allows for measurements via one-, two-, or three-way ranging and/or Doppler shift measurements. Such measurements may allow for accurate estimation of the relative satellite position and velocity vectors in certain DSM topographies. Alternatively, solutions may adapt the proven signal designs of the Global Navigation Satellite Systems (GNSS, i.e., GPS, GLONASS, Galileo) for the purpose of deep space relative navigation. Novel estimation techniques that are feasible for small satellite processing platforms are also opportunities for innovation.Â
- *Laser based measurements* **-** Similar to the exploitation of radio communication systems mentioned above, an optical communication system may also provide range and/or range-rate measurements for relative orbit estimation. Innovations that leverage LIDAR technology for relative navigation of small satellites are also invited. Proposals that include satellite design enhancements for improved tracking are sought.Â
- *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. 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; this context should be described. Solutions for various mission operations concepts are of interest.Â
- *Other novel navigation methods* **-** Stellar navigation aids, such as navigation via quasars, X-rays and

pulsars, may provide enabling capabilities in deep space. Earth-based navigation aids, such as systems detecting radio beacons or terrestrial landmarks, are invited.Â

Methods for autonomous position control are also of interest. Note: Small spacecraft propulsion technologies are not included in this subtopic as those are addressed in subtopic Z8.01, Cubesat Propulsion Systems. 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.

Phased Development Guidance to Proposers

A typical approach to advance the technology readiness level (TRL) leading to future flight hardware/ software demonstration of any of the DSM small spacecraft communications and navigation technologies intended for the beyond LEO environment would include:Â

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 components offer potential advantages over the state of the art, demonstrate their technical feasibility, and show a path towards a hardware/software infusion into practice. Bench-level or lab-environment level demonstrations or simulations are anticipated deliverables. 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.Â

Phase II - Emphasis should be placed on developing and demonstrating the candidate integrated communications payload and/or selected technologies under simulated constellations or swarms of small distributed spacecraft in the relevant beyond LEO environment. A demonstration unit for functional and environmental testing is an anticipated deliverable at the completion of the Phase II contract. Some of the products resulting from this subtopic may be included in a future flight opportunity for on-orbit testing or application demonstration.

All integrated communications systems and constituent technologies developed under this subtopic area should be compatible with existing NASA space communications infrastructure [1], frequency spectrum allocations, and applicable standards. However, applicability or adaptability to non-Government and commercial use as well is desirable.Â

[1] NASAâ€™s space communications infrastructure includes the Near-Earth network (NEN) of ground stations, the Space Network (SN) of tracking and data relay satellites in geostationary Earth orbit, and the Deep Space Network (DSN) of ground stations.Â

*References:*Â Â Â Â Â Â Â Â Â Â Â Â Â Â Â Â Â Â Â

- National Telecommunications and Information Administration Frequency Allocation Chart: https://www.ntia.doc.gov/page/2011/united-states-frequency-allocation-chart.
- National Telecommunications and Information Administration Tables of Frequency Allocations: https://www.ntia.doc.gov/legacy/osmhome/alloctbl/alloctbl.html.
- NASA Spectrum Policy:Â http://www.nasa.gov/directorates/heo/scan/spectrum/policy_and_guidance.html.
- Spectrum Guidance for NASA Small Satellite Missions: http://www.nasa.gov/sites/default/files/atoms/files/spectrum_guidance_smallsats_cubesats_2015.pdf.
- Near Earth Network (NEN) Users Guide:Â https://sbir.gsfc.nasa.gov/sites/default/files/453-NENUG%20R2.pdf.
- Space Network Users Guide (SNUG):Â https://evt.grc.nasa.gov/rfp-industry-briefing-2016/wp-content/blogs.dir/52/files/sites/10/Space-Network-Users-Guide-SNUG-Rev-10.pdf.

- Deep Space Network (DSN):Â http://deepspace.jpl.nasa.gov/advmiss/missiondesigndocs/.
- Delay/Disruption Tolerant Networking (DTN):
    - NASA DTN:Â http://www.nasa.gov/content/dtn.
    - InterPlanetary Networking Special Interest Group (IPNSIG) DTNÂ www.ipnsig.org.