NASA SBIR 2015 Phase I Solicitation

H9 Space Communications and Navigation (SCaN)

Lead Center: GRC

Space Communication and Navigation (SCaN) technologies support all NASA space missions with the development of new capabilities and services that make our missions possible. Communication links are the lifelines that provide the command, telemetry, science data transfers and navigation support to our spacecraft. Advancement in communication and navigation technology will allow future missions to implement new and more capable science instruments, greatly enhance human missions beyond Earth orbit, and enable entirely new mission concepts. NASA's communication and navigation capability is based on the premise that communications shall enable and not constrain missions.

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Today our communication and navigation capabilities, using Radio Frequency technology, can support our spacecraft to the fringes of the solar system and beyond. As we move into the future, we are challenged to increase current data rates - 300 Mbps in LEO to about 6 Mbps at Mars - to support the anticipated numerous missions for space science, earth science and exploration of the universe. Technologies such as optical systems, RF systems including ground based Earth stations, surface networks, cognitive and adaptive systems and networks, access links, reprogrammable communications systems, advanced antenna technology, innovative, relevant research in the areas of positioning, navigation, and timing (PNT) and communications in support of launch services are very important to the future of exploration and science activities of NASA.

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This year, three major technology areas are being solicited:Â

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- Long Range Optical Telecommunications, seeks innovative technologies for significant improvement in long range (> 0.1 AU) optical telecommunications providing increased data throughput in both directions, and lower spacecraft mass and power, in support of human and robotic space missions.
- Intelligent Communications Systems, seeks advancements of cognitive system capabilities to sense, detect, adapt, and learn from the environment to improve communication and/or navigation capabilities for NASA missions. And
- Flight Dynamics and Navigation Technology for the development of software tools, ground facilities, system concepts and on-board devices to enhance capabilities for providing spacecraft position, attitude, and velocity and for advancements that enable independence from earth supervision. For spacecraft systems, emphasis is placed on size, weight and power improvements to reduce the user spacecraft burden or provide greater capability within NASAâ€™s networks. Innovative solutions centered on operational issues are needed in all of the aforementioned areas. All technologies developed under this

topic area to be aligned with the Architecture Definition Document and technical direction as established by the NASA SCaN Office.

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For more details: https://www.spacecomm.nasa.gov/spacecomm/

Subtopics

H9.01 Long Range Optical Telecommunications

Lead Center: JPL

Participating Center(s): GRC, GSFC

This subtopic seeks innovative technologies for long range (> 0.1 AU) optical telecommunications supporting the needs of space missions where human and robotic explorers will visit distant bodies within the solar system and beyond. Multi-use technologies that will also benefit high rate optical communications in cis-lunar and Earth-Sun Lagrange point domains are of particular interest. Goals are increased data-rate capability in both directions and significant reductions of telecommunications system mass, power-consumption, and volume at the spacecraft.

Proposals are sought in the following areas (TRL3 Phase I, and TRL4-5 Phase II):Â

- *Spacecraft Disturbance Isolation Platforms and Related Technologies* - Compact, low mass, space-qualifiable, vibration isolation and spacecraft disturbance rejection assemblies with included re-usable launch lock that require less than 5 W of average power and mass less than 3 kg that will attenuate an integrated spacecraft micro-vibration angular disturbance of 150 micro-radians (with a spectrum of 10E-6 rad^2/Hz below 0.1 Hz, with a 20 dB/decade roll-off), plus an assumed translational disturbance resulting from an offset of 2 m between the payload and the center of rotation of the spacecraft, to less than 0.15 micro-radians (1-sigma), for payloads massing between 3 and 25 kg. Proposed solutions may use control inputs from ground-beacon-based pointing sensor with noise of 150 nrad/sqrt (Hz). Also desired are innovative low-noise, low mass, low power, DC-kHz bandwidth inertial, angular, position, or rate sensors to assist platform stabilization, including beaconless pointing.
- *PPM Space Laser Transmitters* - Space-qualifiable, 1520 to 1630 nm laser transmitter for pulse-position modulated (PPM) with >25% DC-to-optical (wall-plug) efficiency. Transmitter must support laser pulse widths from 0.2 ns (or lower) to 16 ns (or greater) for PPM orders from 16 slots per symbol (6.25% average duty cycle) to 256 slots per symbol plus 64 slots of inter-symbol guard time (0.31% average duty cycle). Other desired parameters include: <35 ps pulse rise and fall times and jitter; <25% pulse-to pulse energy variation (at a given pulse width); single spatial mode output with near transform limited spectral width, single polarization with at least 20 dB polarization extinction ratio; amplitude extinction ratio greater than 48dB, average output power of 10 to 100W; massing less than 500 g/W. Laser transmitter to feature slot-serial PPM data input at CML, LVDS, or AC-coupled PCEL levels and an RS-422 or LVDS levels control port. All power consumed by control electronics will be considered as part of DC-to-optical efficiency. Also of interest for the laser transmitter is robust and compact packaging with >100krad radiation tolerant electronics inherent in the design. Detailed description of approaches to achieve the stated efficiency is a must. Also of interest is a space-qualifiable high power fiber switch for implementing redundant space laser transmitters.
- *PPM Ground Laser Transmitters* - >2000W average power PPM laser transmitters for nested modulation forward links to support simultaneous data rates of ~10 b/s (outer code) and at least 10 Mb/s (inner code) with an outer rate inter-symbol guard time of 50%. Operational wavelength in either 1030 - 1080 nm or 1480 - 1570 nm bands. Other desired parameters include: spectral line width of 0.5 nm or less; amplitude extinction ratio greater than 35 dB; output M-squared of 1.2 or less; projected MTTF of at least 20,000 hours; high wall-plug AC-to-optical power efficiency.
- *Photon Counting Near-infrared Detectors Arrays for Ground Receivers* - Close packed (not lens-coupled) kilo-pixel arrays sensitive to 1520 to 1630 nm wavelength range with single photon detection efficiencies greater than 90%, single photon detection jitters less than 40 ps FWHM, total active diameter greater than

500 microns, 1 dB saturation rates of at least 10 mega-photons (detected) per pixel, false count rates (intrinsic dark rate plus after-pulsing rate) of less than 1 MHz/square-mm. Also desired are cryogenic read-out integrated circuits with an operating temperature of 40K capable of time-tagging electronic pulses from 64 high-bandwidth readout channels to an accuracy of 100 ps or better and a maximum count rate of 10 MHz per channel. The approach should demonstrate scalability to >1000 readout channels Also of interest are: sub-Kelvin cryogenic systems which can support >1000 channels of high-bandwidth (2 GHz or higher) readout signals with a low-temperature hold time of 24 hours, and preferably can be tilted from vertical to near-horizontal during operations; cryogenic interconnects and vacuum feedthroughs for high-density cabling solutions capable of supporting kilochannel readouts from a 1 K detector focal plane stage to room temperature.

- *Photon Counting PPM Digital Ground Receivers* - Digital receiver and decoder assemblies for processing photon counting detector array outputs of PPM encoded data. Receiver to support PPM orders from 2 to 256, data rates to at least 1 Gb/s, and PPM slot widths down to 200 ps. Receiver shall support SCPPM or other demonstrated low-gap-to-capacity (< 1 dB) forward error correction code for PPM. Receiver shall provide signal and background photon flux estimates at kHz rates to support 2-axis control of a fine pointing mirror in a ground receiver telescope.*Â*
- *Photon Counting Near-infrared Detectors Arrays for Flight Receivers* - 128x128 or larger array with integrated read-out integrated circuit and thermo-electric cooling for the 1030 to 1080 nm or 1520 to 1650 nm wavelength range with single photon detection efficiencies greater than 40% and 1dB saturation loss rates of at least 2 mega-photons/pixel and dark count rates of <10 kHz/pixel. ROIC to provide time-stamping of each photon arrival with a precision of 500 ps or better, and an interface bus bandwidth of 125 MHz or less. Radiation doses of at least 5 Krad (unshielded) shall result in less than 10% drop in single photon detection efficiency and less than 2X increase in dark count rate.
- *Advanced Flight Opto-electronics* - Ultra-small, low-mass, low-cost, low-power, modular transceivers, transponders, amplifiers, and components for 1520 to 1630 nm optical links at GHz modulation bandwidths, incorporating integrated photonic circuits and other components such as commercially-available ASICs to provide forward-error-correction and other digital signal processing as required.
- *Ground-based Telescope Assembly* - All-weather ground station telescope/photon-bucket technologies for implementing effective receive areas of > 100 square meters at a projected production cost of < $300K per square meter. Operations wavelength is monochromatic at a wavelength in the range of 1000-1600nm. Key requirements: a maximum image spot size of <20 microradian (static error); capable of operation while pointing to within 3Â° of the solar limb; and field-of-view of >50 micro-radian. Telescope shall be positioned with a two-axis gimbal capable of <50 micro-radian pointing accuracy, with dynamic error <10 micro-radian RMS while tracking after tip-tilt correction.

Research should be conducted to convincingly prove technical feasibility (proof-of-concept) during Phase I, ideally through hardware development, with clear pathways to demonstrating and delivering functional hardware meeting all objectives and specifications, in Phase II.

References:Â

- (http://trs-new.jpl.nasa.gov/dspace/bitstream/2014/42091/1/11-1338.pdf)
- (http://ipnpr.jpl.nasa.gov/progress_report/42-183/183A.pdf)
- (http://ipnpr.jpl.nasa.gov/progress_report/42-185/185D.pdf)
- (http://ipnpr.jpl.nasa.gov/progress_report/42-182/182C.pdf)

H9.02 Intelligent Communication Systems

Lead Center: GRC

Participating Center(s): JPL

NASA seeks novel approaches to improve mission communication and navigation capabilities for science and exploration through advancements in cognitive systems and automation. Over the past 10 years software defined radios and their applications have emerged and demonstrated the potential and applicability of reconfigurable platforms and applications to space missions. The SCaN Testbed launched in 2012 demonstrated software defined radio applications capable of sensing and reacting to environment conditions. Building on this foundation, cognition and automation have the potential to improve system performance, increase data volume return, improve data transmission efficiency, and reduce user spacecraft burden to improve science return from NASA missions. Understanding how and where to apply cognitive and automation technologies is critical and should be discussed in the proposal.

This solicitation seeks advancements in cognitive and automation systems and components as applied to communication and navigation capabilities. While there are a number of acceptable definitions of cognitive systems/radio, for simplicity, a cognitive system should sense, detect, adapt, and learn from its environment to improve the communications or navigation capabilities for the mission. The goal is to improve the state of the user spacecraft system to maximize science data return, enable substantial efficiencies, or adapt to unplanned scenarios. While much interest in cognitive radio entails dynamic spectrum access, this subtopic is also interested in other ways to apply cognition and automation. Areas of interest to develop and/or demonstrate are as follows:Â

- *Cognitive engine (algorithm) and component development* - to demonstrate new capability in sensing and adapting to the radio/mission environment. Technologies may include changes in physical (PHY) layer data rate, modulation, and coding, medium access control (MAC) layers for new protocols, and cognitive engines to negotiate changes between nodes and throughout the network, learning opportunities and techniques, and networking and application layers (and across layers) to adjust to signal conditions, efficiently using links for different data types (e.g., telemetry v. video), adaptive and intelligent routing, etc.
- *System wide distributed intelligence of cognitive and intelligent applications* - while much of the current research often describes negotiations and improvements between two radio nodes, the subtopic seeks solutions to understand system wide aspects and impacts of this new technology. Areas of interest include (but not limited to) system wide effects (e.g., protocols) to decisions made by one or more communication/navigation elements, how to handle unexpected or undesired decisions, how changing data rate, modulation, or frequency between nodes effects data distribution through relay satellites, and throughout space and ground network and multiple access techniques that optimize connectivity and throughput while minimizing onboard data storage and interference.
- *Flexible and adaptive hardware systems* - (e.g., signal processing platforms, adaptive front ends for RF or optical communications, and other intelligent electronics) which directly implements or demonstrates cognitive or intelligent applications as an alternative to more general software-based intelligent systems. Systems should highlight advancements to provide needed capability while minimizing on-board resources and cost.
- *Autonomous Ka-band and/or optical communications antenna pointing on mission spacecraft within intelligent multiple access systems* - Future mission spacecraft in low Earth orbit may need to access both shared relay satellites in geosynchronous orbit (GEO) and direct to ground stations via Ka-band (25.5-27.0 GHz) and/or optical (1550 nm) communications for high capacity data return. To maximize the use of this capacity, user spacecraft will need to point autonomously and communicate with both the relays and ground terminals on a coordinated, non-interfering basis along with other spacecraft using these same space- and ground-based assets. Areas of interest include (but are not limited to): autonomous navigation and pointing techniques with sufficient precision to minimize pointing loss; techniques to coordinate multiple autonomous activities and adaptive or cognitive radio systems that can continuously maximize data return via both multiple beam GEO relays and direct to ground links.

For all technologies, Phase I will emphasize research aspects for technical feasibility, clear and achievable benefits (e.g., 2x-5x increase in throughput, 25-50% reduction in bandwidth, improved quality of service or efficiency) and show a path towards Phase II hardware/software demonstration with delivery of a demonstration unit or software product for NASA testing at the completion of the Phase II contract.

Phase I Deliverables - Feasibility study and concept of operations of the research topic, including simulations and measurements, proving the proposed approach to develop a given product (TRL 3-4). Delivery of the simulation or demonstration software and/or platform(s) to NASA. Plan for verification of specific measurements or capabilities to be performed at the end of Phase II.

Phase II Deliverables - Working engineering model of proposed product/platform or software, along with full report of development, capabilities, and measurements (showing specific improvement metrics). Userâ€™s guide and other documents as necessary for NASA to recreate and use the demonstration capability or hardware component(s). Opportunities and plans should also be identified and summarized for potential commercialization.

Depending on the status at the time, there may be opportunity to port software (cognitive engines and applications) to the SCaN Testbed software defined radio ground and/or flight system on International Space Station (ISS) for demonstration and/or test in the actual space environment. At a minimum, the SCaN Testbed ground system radio testbed will provide an ideal cognitive application test environment, as user spacecraft, relay satellites, and control centers are all emulated in hardware. Software applications and infrastructure should consider the NASA standard for software defined radios, the Space Telecommunications Radio System (STRS), NASA-STD-4009 and NASA-HNBK-4009, found at (https://standards.nasa.gov/documents/detail/3315910).Â Â Â

H9.03 Flight Dynamics and Navigation Technology

Lead Center: GSFC

Participating Center(s): GRC

NASA is investing in the development of software tools, systems and devices to enhance its capabilities for providing position, attitude, and velocity estimates of its spacecraft as well as improve navigation, guidance and control functions to these same spacecraft. Interest includes software tools, ground facilities as well as system concepts and on-board devices to support organic capabilities for its deep-space missions. Products developed under this sub-topic can be in support of any mission phase from design and development through operation and disposal. Proposals can be for either near-Earth or interplanetary missions. Specific application areas that will be considered under this subtopic are:Â

- Software that fuses and analyzes spacecraft sensor data and other spacecraft tracking data available at ground/mission operations centers (i.e., facility software). Proposals for algorithms and software for flight dynamics GNC technologies can support mission engineering activities at any stage of development from the concept-phase/pre-formulation through operations and disposal. Proposals that could lead to the replacement of the Goddard Trajectory Determination System (GTDS), or leverage state-of-the-art capabilities already developed by NASA such as the General Mission Analysis Tool (http://sourceforge.net/projects/gmat/), GPS-Inferred Positioning System and Orbit Analysis Simulation Software, (http://gipsy.jpl.nasa.gov/orms/goa/), Optimal Trajectories by Implicit Simulation (http://otis.grc.nasa.gov/) are especially encouraged. Proposers who contemplate licensing NASA technologies are highly encouraged to coordinate with the appropriate NASA technology transfer offices prior to submission of their proposals. In particular this solicitation is primarily focused on NASAâ€™s needs in the following focused areas:
  - Applications of optimal control theory to high and low thrust space flight guidance and control systems.
  - Numerical methods and solvers for robust targeting, and non-linear, constrained optimization.
  - Addition of novel guidance, navigation, and control improvements to existing NASA software that is either freely available via NASA Open Source Agreements, or that is licensed by the proposer.
  - Interface improvements, tool modularization, APIs, workflow improvements, and cross platform interfaces for software that is either freely available via NASA Open Source Agreements, or that is licensed by the proposer.
  - Applications of cutting-edge estimation techniques to spaceflight navigation problems.
  - Applications of estimation techniques that have an expanded state vector (beyond position, velocity, and/or attitude components) or that combine measurements from multiple sensor suites in a highly-coupled manner to improve upon the overall system accuracy.
  - Applications of advanced dynamical theories to space mission design and analysis, in the context of unstable orbital trajectories in the vicinity of small bodies and libration points.
- Advanced celestial navigation techniques including devices and systems, especially those that support of deep-space, planetary missions. System concepts should support significant advances of independence from Earth supervision including the ability to operate effectively in the absence of Earth-based transmissions or transmissions from planetary relay spacecraft with those that operate in the complete absence of human intervention or Earth-based transmissions are preferred. Proposed solutions should meet objectives while minimizing spacecraft burden by requiring low power and minimal mass and volume. User spacecraft impact is of significant importance and proposed solutions include assessments of mass, power, thermal impact on targeted mission spacecraft as well as identifying any requirements placed on the user spacecraft by the proposed design. Of particular interest are concepts that support pointing of high rate optical communications terminals to earth terminals that do not rely on the use of optical uplinks or beacons for achieving proper pointing of the communication beam. However, concepts which are capable

of supporting planetary missions of any type are of interest. Proposals that include re-purposing/cross-purposing of advanced sensors contemplated for future deep-space missions such as x-ray telescopes are preferred. In addition to advances in positioning, attitude estimation, orbit determination, guidance, navigation and control particular interest in the area of deep-space celestial navigation lies in the following focus topics:

- Time and frequency keeping and dissemination.
- Advanced methods and sensors for optical/IR detection of star fields (i.e., star cameras).
- Advanced methods and sensors detecting RF and x-ray pulsars.
- Methods to process celestial observations to perform Orbit Determination (OD) and precision attitude estimation.

Phase I research should be conducted to demonstrate technical feasibility, with preliminary software being delivered for NASA testing, as well as show a plan towards Phase II integration. For proposals that include hardware development, delivery of a prototype under the Phase I contract is preferred, but not necessary.

With the exception listed below for heritage software modifications, Phase II new technology development efforts shall deliver components at the TRL 5-6 level with mature algorithms and software components complete and preliminary integration and testing in an operational environment. For efforts that extend or improve existing NASA software tools, the TRL of the deliverable shall be consistent with the TRL of the heritage software. Note, for some existing software systems (see list above) this requires delivery at TRL 8. Final software, test plans, test results, and documentation shall be delivered to NASA.