NASA SBIR 2016 Phase I Solicitation

H9 Space Communications and Navigation

Space Communication and Navigation (SCaN) technologies support all NASA space missions with the development of new capabilities and services that make our missions possible. Â Communication links are the lifelines that provide the command, telemetry, science data transfers, and navigation support to our spacecraft. Â 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. Â NASA's communication and navigation capability is based on the premise that communications shall enable and not constrain missions.Â Â This topic supports development of technologies to fundamentally change the paradigm of communications and navigation.Â They include greatly increased data rates via optical communications; cognition in Software Defined Radios (SDR); advanced guidance, control, and navigation; and advanced RF systems. For more details, see:Â (http://www.nasa.gov/scan).

Subtopics

H9.01 Long Range Optical Telecommunications

Lead Center: JPL

Participating Center(s): GRC, GSFC

The Long Range Optical Communications subtopic seeks innovative technologies in free-space optical communications for increased data volume returns from space missions in multiple domains [1]:

- >100 gigabit/s cis-lunar (Earth or lunar orbit to ground).
- >10 gigabit/s Earth-sun L1 and L2.
- >1 gigabit/s per A.U.-squared deep space.
- >100 megabit/s planetary lander to orbiter.Â

Proposals are sought in the following specific areas (TRL3 Phase I to mature to TRL4 to 5 in Phase II):

- *Low-mass large apertures for high-EIRP laser transceivers [2]* - 30 to 100 cm diameter laser communications telescopes massing less than 65 kg/square-meter with wavefront errors less than 1/25th of a wavelength at 1550 nm and a cumulative wavefront error andÂ transmission loss of <3dB in the far field that can survive direct sun-pointing. Operational range of -20Â° C to +50Â° C without active thermal control is desired.
- *High-gigabit/s laser transmitter and receiver optical-electronic subsystems* - space qualifiable 1550 nm laser transmitter and receiver optoelectronic modulator, detection, and Forward-Error-Correction assemblies for

data rates from 1 gigabits/s to >200 gigabits/s with power efficiencies better than 10W per gigabit/s and mass efficiencies better than 100 g per gigabit/s. Radiation tolerance better than 100 Krad is required. Technologies for efficient waveform modulation, detection, and synchronization and on-board low-gap-to-capacity forward-error-correction decoding are of interest; also of interest are hybrid RF-optical technologies. Integrated photonic circuit solutions are strongly desired. Highly efficient (>20% DC-to-optical, including support electronics) and space qualifiable (including resilience to photo-darkening) multi-watt Erbium Doped Fiber Amplifier with high gain bandwidth (> 30nm, 0.5 dB flatness) concepts will also be considered. Detailed description of approaches to achieve the stated efficiency is a must.

- *Waveform signal processing technologies [3]* - **CCSDS White Book, "High Photon Efficiency Optical Communications -- Coding & Modulation," March 2015,** http://www.nasa.gov/directorates/heo/scan/engineering/datastandards/index.html - 100 Mb/s and higher hardware/firmware implementation of the coding and synchronization layer of the proposed Consultative Committee for Space Data Systems (CCSDS) high-photon-efficiency optical signaling waveform, including transmitter and receiver functions. Supported features are to include CCSDS Transfer Frame ingestion and slicing; attached frame sync markers; CRC; serially concatenated convolutional coding with accumulate pulse position modulation (SCPPM), including a constraint length 3 convolutional code of rates 1/3, 1/2, and 2/3, code interleaver, accumulator, and PPM of orders 4, 8, ..., 256; randomizer; 1 s channel interleaver; codeblock sync marker repeat/spreader, and guard slot insertion.

- *Large aperture ground receiver subsystem technologies [4]* - Demonstrate innovative subsystem technologies for >10 m diameter ground receiver capable of operating to within 3 degrees of solar limb with a better than 10 microradian spot size (excluding atmospheric seeing contribution). Desire demonstration of low-cost primary mirror segment fabrication to meet a cost goal of less than $35K per square meter and low-cost techniques for segment alignment and control, including daytime operations. Also desired are cryogenic optical filters for operation at 40K with noise equivalent bandwidths of a few nm in the 1550 nm spectral region, transmission losses < 0.25 dB, clear aperture >35 mm, and acceptance angle >40 milliradians with out-of-band rejection of >65 dB from 0.4 to 5 microns.

- *Superconducting magnesium diboride (MgB_2) thin films for ground receiver detectors [5]* - 5 to 20 nm thick MgB_2 films with critical temperature Tc > 35 K and critical current density Jc > 5 MA / cm^2 at 20 K The preferred substrates are SiC, Sapphire or MgO. The substrate size should be at least 4 in^2. There is also strong interest in MgB_2 films deposited on buffered Si wafers. The MgB_2 films should be passivated with SiO_2 or Au.

- *Cryogenic read-out electronics for large format superconducting nanowire arrays [6]* - 64 to 1024 channel DC coupled amplifier arrays for mounting onto a 40K cryocooler stage with 50 to 110 Ohm input impedance, <0.5 dB noise figure, DC to >4 GHz bandwidth, >40 dB gain, <1 dB compression with -47 dBm input, < 5 ps additive jitter, and less than 20 mW per channel power dissipation; strongly desired is an integrated per-channel leading-edge detect discriminator with LVDS-compatible output signal levels. Also of great interest is development of an read-out integrated circuit for direct bump-bonding to superconducting nanowire arrays operating in the 1 to 3 K range, with <0.5 dB noise figure, DC to >4 GHz bandwidth, >20 dB gain, <1 dB compression with -47 dBm input, < 5 ps additive jitter, and less than 1 mW per channel power dissipation.

- *Beaconless pointing subsystems for operations beyond 3 A.U.* - Point 20 to 100 cm lasercomm transmitter aperture to an Earth-based receiver with a 1-sigma accuracy of better than 100 nanoradians with an assumed integrated spacecraft micro-vibration angular disturbance of 150 micro-radians (<0.1 Hz to ~500 Hz) without requiring a dedicated laser beacon transmission from Earth; lowest subsystem mass and power is a primary selection factor.

- *Low mass / low power / cold survivable optical transceivers for planetary lander to orbiter links [7]* - Bi-directional optical terminals with data rates from >100 megabit/second at a nominal link range of 1000 km, with an individual terminal mass <5 kg and operational power < 25W, including a pointing system for at least full hemisphere coverage. Terminals shall be capable of operationally surviving >500 cycles of unpowered temperature cycling from -40° C to +40° C and a 100 krad TID. Discussion of acquisition and tracking con-ops and requirements is a must.

Research must convincingly prove technical feasibility (proof-of-concept) during Phase I, ideally with hardware deliverables that can be tested to validate performance claims, with a clear path to demonstrating and delivering functional hardware meeting all objectives and specifications in Phase II.

References:

- [1]Â - (http://ssed.gsfc.nasa.gov/IPM/PDF/1010.pdf).
- [2]Â - W. Farr, W, et al. â€œOverview and Design of the DOT Flight Laser Transceiver,â€ IPN Progress Report 42-185, (2011).
- [3] - CCSDS White Book, "High Photon Efficiency Optical Communications -- Coding & Modulation," March 2015.
- [4] - Birnbaum, K., et al.,Â â€œDOT Ground Laser Receiver: Overview and Major Trades,â€ IPN Progress Report 42-182, (2010).
- [5] - Wolak, M. A. et al., IEEE Trans. Appl. Supercond. 25, 1-5 (2015).
- [6] - Dauler, E., et al., â€œReview of Superconducting Nanowire Single-Photon Detector System Design Options and Demonstrated Performance.â€ Opt. Eng 53 (2014).
- [7]Â - Biswas, A., et al., â€œFuture Planetary Optical Access Linksâ€, 2011 International Conference on Space Optical Systems and Applications.

H9.02 Advanced Space Communication Systems

Lead Center: GRC

Participating Center(s): GSFC, JPL

NASAâ€™s future systems require increased levels of adaptive, cognitive, and autonomous system technologies to improve mission communication capabilities for science and exploration.Â Goals of this capability are to improve communications efficiency, mitigate impairments (e.g., scintillation, interference), and reduce operations complexity and costs through intelligent and autonomous communications and data handling.Â These goals are further described in the TA05 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems Roadmap, Sections 5.1, 5.2, 5.3 and 5.5.

Over the past 10 years software defined radio platforms and their applications have emerged and demonstrated the applicability of reconfigurable platforms and applications to space missions.Â This solicitation seeks advancements in cognitive and automation communication systems, networks, waveforms and components.Â 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 capabilities and situation for the mission.Â Cognitive systems naturally lead to advanced multi-function RF platforms; platforms that serve more than one user or function and are reconfigurable, on-demand, either autonomously or by the user for arbitrary applications. NASA can leverage these systems, techniques, hardware, algorithms and waveforms for use in space applications to maximize science data return, enable substantial efficiencies, reduce operations costs, or adapt to unplanned scenarios.Â While much interest in cognitive radio in other domains focuses on dynamic spectrum access, this subtopic is primarily interested in much broader ways to apply cognition and automation.Â Areas of interest to develop and/or demonstrate are as follows:

- *System wide intelligence â€"* 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.Â Areas of interest include (but not limited to) -cognitive architectures considering mission spacecraft, relay satellites, other user spacecraft, and ground stations, system wide effects to decisions made by one or more communication/navigation elements, handling unexpected or undesired decisions, self-configuring networks, coordination among multiple spacecraft nodes in a multiple access scheme, cooperation and planning among networked space elements to efficiently and securely move data through the system, and automated link planning and scheduling to optimize data throughput and reduce operations costs. Capabilities may include interference mitigation, maximizing data throughput and efficiency, and intelligent network routing (best route) and disruptive tolerant networking over cognitive links. The focus here is on a cognitive understanding of, and adaptation to, temporally or spatially non-contiguous communications paths.
- *Advanced waveform development in the digital domain. Specifically -* The foundation has been laid through prior NASA investments in the area of generating the infrastructure for software-based algorithms. These investments led to the development and demonstration of the Space Telecommunication Radio System (STRS) architectural standard for software-defined radios. STRS based advanced backend platforms generate (for transmission) or process (from reception) the appropriate waveform at a common Intermediate Frequency (IF) for transmission to, or reception from, an appropriate RF front-end. In addition, the backend processor is reconfigurable, by the user, for a specific application at a given time (radar vs.

- *Flexible and adaptive hardware systems -* Signal processing platforms, wideband and multi-band adaptive front ends for RF (particularly at S-, X-, and Ka-bands) or optical communications, and other intelligent electronics that advance or enable flexible, cognitive, and intelligent operations. Â The development and demonstration of advanced RF Front-Ends that cover NASA RF bands of interest; specifically S-Band, X-Band and/or Ka-Band. These RF front-ends may support time-multiplexed waveforms such as radar or (digitized) half-duplex voice transmissions as well as frequency duplexed waveforms such as full-duplex two-way navigation and data communications. Â Specifically, these front-ends are expected to leverage state-of-the-art RF materials (e.g., GaN, SiC, CMOS, etc.), packaging (e.g., MIC, SMT, etc.), device (e.g., MMIC, MEMS, etc.) and component techniques to minimize mass, volume and energy resource usage while supporting multi-functionality
- *Autonomous Ka-band and/or optical communications antenna pointing -* 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. Â To maximize the use of this capacity, user spacecraft will need to point autonomously and communicate on a coordinated, non-interfering basis along with other spacecraft using these same space- and ground-based assets. Included here are electronically steered antennas, especially at Ka-Band. Applications include large, high-performance electronically-steered antennas required for a dedicated communications relay spacecraft with multiple simultaneous connections, advanced multifunction antennas to support science missions that utilize a multifunction antenna to both communicate and conduct science, and small, lightweight antennas for communications only that provide moderate gain without the use of mechanical steering. Â Antennas that are reconfigurable in frequency, polarization, and radiation pattern that reduce the number of antennas needed to meet the communication requirements of NASA missions are desired.

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, reduction in operations staff or costs) and show a path towards Phase II hardware/software development with delivery of hardware or software product for NASA. Â Â Proposals should demonstrate and explain how and where cognitive and automation technologies could be applied to NASA space systems and be discussed in the proposal.

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). Â Early development and delivery of the simulation and prototype software and platform(s) to NASA. Â Plan for further development and verification of specific capabilities or products to be performed at the end of Phase II.

Phase II Deliverables - Working engineering model of proposed product/platform or software delivery, along with documentation of development, capabilities, and measurements (showing specific improvement metrics). Â User’s guide and other documents and tools as necessary for NASA to recreate, modify, Â and use the cognitive software capability or hardware component(s). Â Opportunities and plans should also be identified and summarized for potential commercialization or NASA infusion.

Software applications and platform/infrastructure deliverables for SDR platforms shall be compliant with 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).

H9.03 Flight Dynamics and Navigation Systems

Lead Center: GSFC

Participating Center(s): GRC, JPL

NASA is investing in the advancement of software algorithm/stools, systems, and devices to enhance and extend 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. Efforts must demonstrate significant risk or cost reduction, significant performance benefit, or enabling capability. Â

Proposals can support mission engineering activities at any stage of development from the concept-phase/pre-formulation through operations and disposal. Applications in low Earth orbit, lunar, and deep space are in scope for

this sub-topic. Â 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.Â 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:

Guidance and Control

- Advanced optimal control methodologies for chemical and electric space flight guidance and control systems.
- Numerical methods and solvers for robust targeting, and non-linear, constrained optimization problems.
- 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 guidance and control techniques that support autonomous, on-board applications.

Navigation

- 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 employ data fusion.
- Advanced autonomous navigation techniques including devices and systems that support significant advances in independence from Earth supervision while minimizing spacecraft burden by requiring low power and minimal mass and volume.
- Advanced time and frequency keeping and dissemination Â

Software

- 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 that provide significant cost or performance benefits

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.Â 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.