NASA SBIR 2010 Phase I Solicitation

O1 Space Communications

NASA's communications capability is based on the premise that communications shall enable and not constrain missions. Communications must be robust to support the numerous missions for space science, Earth science and exploration of the universe. Technologies such as optical communications, RF including antennas and ground based Earth stations, surface networks, access links, reprogrammable communications systems, advanced antenna technology, transmit array concepts and communications in support of launch services including space based assets are very important to the future of exploration and science activities of the Agency. Emphasis is placed on size, weight and power improvements. Even greater emphasis is placed on these attributes as small satellites (e.g., micro and nano satellite) technology matures. Innovative solutions centered on operational issues are needed in all of the aforementioned areas. Communication technologies enabling acquisition of range safety data from sensitive instruments is imperative. All technologies developed under this topic area to be aligned with the Architecture Definition Document and technical direction as established by the NASA Office of Space Communications and Navigation (SCaN). For more details, see:

https://www.spacecomm.nasa.gov/spacecomm/
https://www.spacecomm.nasa.gov/spacecomm/programs/default.cfm
https://www.spacecomm.nasa.gov/spacecomm/programs/technology/default.cfm
https://www.spacecomm.nasa.gov/spacecomm/programs/technology/sbir/default.cfm

A typical approach for flight hardware would include: Phase I – Research to identify and evaluate candidate telecommunications technology applications to demonstrate the technical feasibility and show a path towards a hardware/software demonstration.

Bench or lab-level demonstrations are desirable. Phase II – Emphasis should be placed on developing and demonstrating the technology under simulated flight conditions. The proposal shall outline a path showing how the technology could be developed into space-worthy systems. The contract should deliver a demonstration unit for functional and environmental testing at the completion of the Phase II contract. Some of the subtopics in this topic could result in products that may be included in a future flight opportunity. Please see the following for more details:

- SMD Topic S4 for more details concerning requirements for Small Satellite flight opportunities.

Note: Communications technologies for space-based range must be highly integrated with required navigation components; hence, space-based range technologies are solicited in Space Transportation Subtopic O2.03 – Spaceport Enhancements and Improvements.

Subtopics
NASA seeks advanced antenna technologies in the following areas: phased array antennas; ground-based uplink antenna array designs; large aperture deployable antennas; novel materials for next generation antennas; smart, reconfigurable antennas; and antenna concepts for harsh environments.

**Phased Array Antennas**
High performance phased array antennas are needed for high-data rate communication at Ka-Band frequencies and above as well as for remote sensing applications. Communications applications include: planetary exploration, landers, probes, rovers, EVA, suborbital vehicles, sounding rockets, balloons, unmanned aerial vehicles (UAV's), TDRSS communication, and expendable launch vehicles (ELV's). Also of interest are multi-band phased array antennas (e.g., X- and Ka-band) and RF/optical shared aperture dual use antennas, which can dynamically reconfigure active elements in order to operate in either band as required in order to maximize flexibility, efficiency and minimize the mass of hardware delivered to space. Phased array antennas for space-based range applications to accommodate dynamic maneuvers are also of interest. The arrays are required to be aerodynamic or conformal in shape for sounding rockets, UAV’s, and expendable platforms and must be able to withstand the launch environment. Potential remote sensing applications include: radiometers, passive radar interferometer platforms, and synthetic aperture radar (SAR) platforms for planetary science.

**Ground-based Uplink Antenna Array Designs**
NASA is considering arrays of ground-based antennas to increase capacity and system flexibility, to reduce reliance on large antennas and high operating costs, and eliminate single point of failure of large antennas. A large number of smaller antennas arrayed together results in a scalable, evolvable system, which enables a flexible schedule and support for more simultaneous missions. A significant challenge is the implementation of an array for transmitting (uplinking), which may or may not use the same antennas that are used for receiving. Arraying concepts that can enable a single network (i.e., DSN, NEN, and SN) at Ka-band frequencies and above are highly desired.

**Large Aperture Deployable Antennas**
Large aperture deployable antennas with surface root-mean-square (rms) quality better than 1/40 at Ka-Band frequencies and above, are desired. In addition, these antennas should significantly reduce stowage volume (packaging efficiencies as high as 50:1), provide high deployment reliability, and significantly reduced mass density (i.e., 1kg/m2). These large Gossamer-like antennas are required to provide high-capacity communication links with low fabrication costs from deep space (Mars and beyond). Applicability to Ka-Band or higher frequencies is required. Concepts addressing antenna adaptive beam correction with pointing control are also of interest.

**Novel Materials for Next Generation Antennas**
NASA is interested in exploiting novel materials approaches for next generation antennas. For example, “smart” materials such as shape memory polymers or ionic polymer metal composites to permit active shape control or beam correction are of interest. Artificial electromagnetic media for phase velocity control and impedance tuning to improve the efficiency and bandwidth of electrically small antennas is of interest. Ferroelectric based technologies as well as multiferroics and spintronics concepts leading to new antenna designs are desirable.

**Smart, Reconfigurable Antennas**
Smart, reconfigurable antennas for applications in planetary operations are of interest. The characteristics to consider include the frequency, polarization, and the radiation pattern. Low-cost approaches are encouraged to reduce the number of antenna apertures needed to meet the requirements associated with rovers, pressurized surface vehicles, habitats, etc. for planetary surface exploration. Desirable features include multi-beam operation to support connectivity to different communication nodes on planetary surfaces, or in support of communication links for satellite relays around planetary orbits. Innovative receiver front-ends or technologies that allow for the DSP to move closer to the antenna terminal furthering the impact of the aforementioned, revolutionary “game-changing” antenna technology concepts are highly desirable.

**Antenna Concepts for Harsh Environments**
Novel, “Game Changing”, robust antenna concepts that can perform optimally and reliably in harsh environments such as those imposed by the Lunar regolith/dust and Martian dust are highly desirable.
For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path towards Phase II hardware/software demonstration with delivery of a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables: A final report containing optimal design for the technology concept including feasibility of concept, and a detailed path towards Phase II hardware demonstration. The report shall also provide options for commercialization opportunities after Phase II.

Phase II Deliverables: A working proof-of-concept demonstrated and delivered to NASA for testing and verification. Exit TRL 5 is expected at the end of Phase II.

O1.02 Reconfigurable/Reprogrammable Communication Systems

Lead Center: GRC
Participating Center(s): AFRC, GSFC, JPL, JSC

This solicitation seeks advancements in reconfigurable transceiver and associated component technology. The goal of the subtopic is to provide flexible, reconfigurable communications capability while minimizing on-board resources and cost. Areas of interest to develop and/or demonstrate are as follows:

- Software/firmware for the management of waveform or functional reconfiguration. Simultaneous operation while reconfiguration takes place and an adherence to the Space Telecommunications Radio System (STRS) v 1.02.1 document is desired, which will soon be publicly available at https://www.spacecomm.nasa.gov/spacecomm/default.cfm
  - Goal: Simultaneous operation while reconfiguration takes place.
  - Goal: STRS compliance
- Methods and tools for the development of software/firmware components that are portable across multiple platforms. Standards-based approaches are preferred.
  - Goal: Tool chain and/or development processes that result in 80% portability between 2 standards-based SDR platforms.
- Dynamic/distributed on-board processing architectures that are scalable and are designed to operate in various space environments.
  - Goal: 10x processing capability increase for fixed SWaP.
- Component technology advancements in bandwidth capacity and reduced resource consumption.
  - Goal: 5x bandwidth processing increase, 2x decrease in resource consumption.
- Analog-to-digital converters or digital-to-analog converters to increase sampling and resolution capabilities.
  - Goal: 3x increase in sampling resolution capabilities.
- Novel techniques or processes to increase memory densities.
  - Goal: 5x increase in memory per unit volume.
- Novel approaches to mitigate device susceptibility to radiation effects.
  - Goal: Target payload class SEU and latch-up mitigation techniques to achieve requirements for various class payloads in the desired space environment at lowest SWaP cost.

NASA also seeks to populate a repository for STRS compliant waveforms. These waveforms may be field or ported to available STRS-compliant SDRs. The description of STRS-compliance is available in the STRS 1.02.1 document, soon to be publicly available at https://www.spacecomm.nasa.gov/spacecomm/default.cfm.

Note that NASA not only seeks reconfigurable/reprogrammable communication systems for flight applications, but also for the additional capabilities reconfigurable/reprogrammable systems may add to R&D and interoperability test labs. NASA centers have varying roles, capabilities, and R&D interests/priorities. Therefore, this year’s call will also take into consideration how the products from O1.03 (Phase I, II, and III) will contribute to the current administration’s vision for NASA and its commercial and international partners, and where these products may be relevant within our collection of terrestrial labs and/or flight systems.

The advancement of component technology for reconfigurable/reprogrammable communications systems is highly
desirable for the insertion of these systems into space missions. Further adoption of reconfigurable/reprogrammable communications systems allow NASA science and human space flight missions to reduce risk and evolve as future requirements mature. These component technologies address either the reduction of size, weight, and power of these systems, or the costs associated with development.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables: The Phase I deliverable consists of a report detailing the technical feasibility of the innovation and it’s contribution to the advancement of the state-of-the-art. The Phase I technology is expected to result in the component technology developed to TRL 2-3.

Phase II Deliverables: The Phase II deliverable consists of a demonstration of hardware and/or software prototype(s) with the intent of integration or testing in a relevant NASA laboratory, with a corresponding report detailing operating instructions for the component technology. The Phase II technology is expected to result in the component technology developed to TRL 5-6.

O1.03 Game Changing Technologies

Lead Center: GRC
Participating Center(s): ARC, JSC

NASA seeks revolutionary, highly innovative, game changing technologies that have the potential to enable order of magnitude performance improvements for space communications and navigation. Fundamental, strategic R&D is a critical element in developing innovative and superior technologies for space communication and navigation systems by addressing deficiencies in the current space communications network infrastructure to enhance performance, improve efficiency and reduce cost.

Research is geared towards emphasizing research and space technologies that are far-term focused in (but not limited to) the following areas:

- Low SWAP Transceivers: Develop novel techniques to reduce the size, weight, and power (SWAP) requirements for communications transceivers and software-defined radios for space missions. Address SWAP challenges by addressing digital processing and logic implementation tradeoffs, static vs. dynamic power, voltage and frequency scaling, hardware and software partitioning such that operational modes are effectively managed. Use of open, interoperable standards is encouraged.
- Ka-band RF Devices and Components: Investigate novel RF (especially Ka-band) communications technologies and innovative approaches for high bandwidth, Ka-band devices and components (transceivers, modulators, highly efficient amplifiers, etc.). Approaches to significantly reducing size, mass, and power requirements for these components are paramount as well.
- High Performance Ultra Low-Power ADCs and DACs: The high power consumption and lack of flexibility to reconfigure on-the-fly make off-the-shelf analog-to digital converters (ADCs) devices ill-suited for digital radio applications. To enable next-generation radios and support the ever-increasing user demands of high resolution (6 GSPS) and input bandwidths (2.5 GHz), breakthroughs in high-speed, low power ADCs are needed. Assume dynamically adjustable resolution up to 16 bits and on-board ultra-low jitter clock circuit to enhance spectral power distribution. A deep sleep mode feature is highly desirable to conserve power. Currently, state-of-the-art high rate digital-to-analog converters (DACs) are power prohibitive. To increase robustness, spectral efficiency, and compactness, NASA seeks to develop complementary DACs. For example, at a scant total power budget of 4 watts, ADCs and DACs will facilitate breakthroughs in S-band digital transceivers with fewer parts, smaller form factors, and greater design flexibility.
- Nanotechnology: High-performance, multi-functional, nano-structured materials for communications applications. Single wall carbon nano-tubes exhibit extraordinary mechanical, electrical, and thermal properties at the nano-scale level and possess exceptionally high surface area to volume ratio. The development of nano-scale communication devices and systems including nano-antennas, nano-transceivers, etc. are of interest for nano-spacecraft applications.
Quantum Entanglement: Innovative breakthroughs in quantum information physics has sparked interest to specifically address this phenomenon and the critical unknowns relevant to revolutionary improvements in communicating data, information or knowledge. Methods or techniques that demonstrate extremely novel means of effectively packaging, storing, encrypting, and/or transferring information are sought.

RF MEMS Integrated Components: RF micro-electromechanical systems (MEMS) offer exceptional RF performance and power characteristics that can lead to dramatic advantages for novel radio applications. Such as wireless filter banks, switching matrices, and instrumentation. Although low-power, high efficiency charge pumps can be integrated into advanced communication systems that employ novel MEMS devices (e.g. switches or varactors) or circuits (e.g. tunable filters or power amplifiers), there are some long-term challenges with power handling and non-linear behavior for power levels of 1 Watt. Because high-Q varactors and filters are not well understood, NASA seeks to advance revolutionary MEMS devices and architectures that are immune to bias noise.

Trans-Horizon Communications: Innovative approaches to use of medium to high frequency (300 KHz-30MHz) bands for applications benefiting future surface landing missions. Concepts, studies, development of key technologies are needed to perform non-line-of-sight communication for potential use on the surfaces of celestial bodies. For example, the lunar exosphere may have the ability to support such communications, if fully understood. Modulation and coding techniques, antennas, solid-state amplifiers, digital baseband circuitry, etc. are required to be developed and/or validated to enable over the horizon communication and communications into craters for robotic and human missions. Range of communications on the order of 10-20 kilometers at a data rate of 128 kbps is envisioned to support many of these types of surface communications links.

Navigation: In adopting any proposed game-changing technologies, the capability for provision of high-quality metric tracking observables for orbit determination and other tracking services must be considered. Proposers should recognize that NASA may not be able to adopt certain game-changers in communications and navigation technology if they do not support at least NASA’s current needs for metric tracking data services. Proposals in this area should document any potential performance enhancements, and especially any foreseeable compatibility issues associated with metric tracking data services.

Low-Power High Stability Reference Sources: Highly stable clocks and oscillators play a pivotal role in a myriad of space communications and navigation applications. Atomic (cesium) clocks used today have time measurement accuracies on the order of 2 nanoseconds per day. New research (optical, quantum) into improving time measurement accuracy, size, reliability for space communications and navigation are of interest. Highly stable clock sources for wireless communications devices can improve network synchronization and channel selection to enhance security and anti-jamming capabilities.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path toward Phase II hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables: Deliverables expected at the end of Phase I include trade studies, conceptual designs, simulations, analyses, reports, etc. at TRL 1-2.

Phase II Deliverables: Demonstrate performance of technique or product through simulations and models, hardware or software prototypes. It is expected that at the end of the Phase II award period, the resulting deliverables/products will be at or above TRL 3.

O1.04 Long Range Optical Telecommunications

Lead Center: JPL

Participating Center(s): GRC, GSFC

This subtopic seeks innovative technologies for long range Optical Telecommunications supporting the needs of space missions. Proposals are sought in the following areas:

Systems and technologies relating to acquisition, tracking and sub-micro-radian pointing of the optical communications beam under typical deep-space ranges (to 40 AU) and spacecraft micro-vibration environments, as follows:
• **Small lightweight two-axis gimbals:** Flight qualifiable, less than 2 kg in mass capable to actuating payload mass of approximately 3 kg at rates up to 5 degrees/second, less than 30 micro-radian rms error and blind-pointing accuracy of less than 35 micro-radian. Proposals should come up with innovative pragmatic designs that can be flown in space.

• **Photon counting Si, InGaAs, and HgCdTe detectors and arrays:** For the 1000 to 1600 nm wavelength range with single photon detection efficiencies greater than 60% and output jitters less than 20 pico-second, active area greater than 20 microns/pixel, and 1 dB saturation rates of at least 100 mega-photons (detected) per pixel and dark count rates of less than 1 MHz/square-mm.

• **Single-photon-sensitive, high-bandwidth, linear mode photo-detectors:** With high bandwidth (>1GHz), high gain (>1000), low-noise (<1kcps), large diameter (200 micron), HgCdTe avalanche photodiode and/or (small diameter) arrays for optical detection at 1060 nm or 1550 nm.

• **Uncooled photon counting imagers:** With >1024 x 1024 formats, ultra low dark count rates and visible to near-IR sensitivity.

• **Ultra-low fixed pattern non-uniformity NIR imagers:** With large format (1024x1024), non-uniformity of less than 0.1%, low noise (<1e- read, <1ke/pix/s dark) and high (>0.7) quantum efficiency.

• **Radiation hard photon counting detectors and arrays:** For the 1000 to 1600 nm wavelength range with single photon detection efficiencies greater than 40% and 1dB saturation rates of at least 30 mega-photons/pixel and operational temperatures above 220K and dark count rates of <10 MHz/mm. Radiation levels of at least 300 krad (unprotected).

• **Isolation platforms:** Compact, lightweight, low power, broad bandwidth (0.1 Hz -3 kHz) disturbance rejection.

• **Laser transmitters:** Space qualifiable, greater than 20% wall plug efficiency, lightweight, 20-500 pico-second pulse-width (10 to >100 MHz PRF), tunable (~0.2 nm) pulsed 1064-nm or 1550-nm laser transmitter fiber or planar-waveguide MOPA sources with greater than 1 kW of peak power per pulse (over the entire pulse-repetition rate), with Stimulated Brillouin Scattering suppression and >10 W of average power, near transform limited spectral width, and less than 10 pico-second pulse rise and fall times. Also of interest for the laser transmitter are: robust and compact packaging with radiation tolerant electronics inherent in the design, and high speed electrical interface to support output of pulse position modulation encoding of sub nanosecond pulses and inputs such as Spacewire, Firewire or Gigabit Ethernet. Detailed description of approaches to achieve the stated efficiency is a must.

• **Low-cost ground-based telescope assembly:** With diameter greater than 2-m, primary mirror with f–number of ~1.1 and Cassegrain focus to be used as optical communication receiver optics. Maximum RMS surface figure error of 1-wave at 1000 nm wavelength. Telescope shall be positioned with a two-axis gimbal capable of 0.25mrad pointing. Combined telescope, gimbal and dome shall be manufacturable in quantity (tens) for ~$3 M each.

• **Daytime atmospheric compensation techniques:** Capable of removing all significant atmospheric turbulence distortions (tilt and higher-order components) on an uplink laser beam; and/or for a 2-m diameter downlink receiver telescope. Also of interest are technologies to actively compensate for the static and dynamic (gravity sag and thermal) aberrations of 2-m diameter telescopes with a surface figure of 10’s of waves (down to less than 1-wave at 1000 nm).

Research should be conducted to convincingly prove technical feasibility during Phase I, with clear pathways to demonstrating and delivering functional hardware, meeting all objectives and specifications, in Phase II.

Phase I Deliverables:

• Feasibility study, including simulations and measurements, proving the proposed approach to develop a given product (TRL 3-4)

• Verification matrix of measurements to be performed at the end of Phase II, along with specific quantitative pass-fail ranges for each quantity listed.

Phase II Deliverables:

• Working brassboard model of proposed product, along with full report of development and measurements,
including populated verification matrix from phase II (TRL 5).

- Opportunities and plans should also be identified and summarized for potential commercialization.

**O1.05 Long Range Space RF Telecommunications**

**Lead Center:** JPL

**Participating Center(s):** ARC, GRC, GSFC

This solicitation seeks to develop innovative long-range RF telecommunications technologies supporting the needs of space missions. The ultimate objective is to maximize aggregate mission data return per unit mass, unit volume, unit cost and unit power consumed by the spacecraft telecommunications subsystem.

In the future, spacecraft with increasingly capable instruments producing large quantities of data will be visiting the moon and the planets. To support the communication needs of these missions and maximize the data return to Earth, innovative long-range telecommunications technologies that maximize power efficiency, transmitted power density and data rate, while minimizing size, mass and power are required.

The current state-of-the-art in long-range RF space telecommunications is 6 Mbps from Mars using microwave communications systems (X-Band and Ka-Band) with output power levels in the low tens of Watts and DC-to-RF efficiencies in the range of 10-25%.

This solicitation seeks proposals in the following areas:

- Ultra-small, light-weight, low-cost, low-power, modular deep-space transceivers, transponders and components, incorporating MMICs and Bi-CMOS circuits;
- MMIC modulators with drivers to provide a wide range of linear phase modulation (greater than 2.5 rad), high-data rate (10 - 200 Mbps) BPSK/QPSK modulation at X-band (8.4 GHz), and Ka-band (26 GHz, 32 GHz and 38 GHz);
- High-efficiency (> 60%), low mass Solid-State Power Amplifiers (SSPAs), of both medium output power (10 W-50 W) and high-output power (150 W-1 KW), using power combining and/or wide band-gap semiconductors at X-band (8.4 GHz) and Ka-band (26 GHz, 32 GHz and 38 GHz);
- Utilization of nano-materials and/or other novel materials and techniques for improving the power efficiency or reducing the cost of reliable vacuum electronics amplifier components (e.g., TWTAs and Klystrons);
- Ultra low-noise amplifiers (MMICs or hybrid) for RF front-ends (< 50 K noise temperature);
- MEMS-based integrated RF subsystems that reduce the size and mass of space transceivers and transponders. Frequencies of interest include UHF, X- and Ka-Band. Of particular interest is Ka-band from 25.5 - 27 GHz and 31.5 - 34 GHz.
- Ultra low mass, high gain, high efficiency spacecraft antennas using advanced light materials and structures.
- Novel, hybrid spacecraft antenna designs that can act as efficient reflectors/concentrators of both RF (X- and Ka-Band) and optical (1550 nm) electromagnetic waves.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path towards Phase II hardware/software demonstration with delivery a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

**Phase I Deliverables:** Feasibility study, including simulations and measurements, proving the proposed approach to develop a given product (TRL 3-4). Verification matrix of measurements to be performed at the end of Phase II, along with specific quantitative pass-fail ranges for each quantity listed.

**Phase II Deliverables:** Working engineering model of proposed product, along with full report of development and measurements, including populated verification matrix from Phase II (TRL 5-6). Opportunities and plans should also be identified and summarized for potential commercialization.
O1.06 Space Networking

Lead Center: GRC
Participating Center(s): GSFC, JPL, JSC

NASA’s Space Communications and Navigation Program (SCaN) is integrating its current agency networks: Deep Space Network (DSN), Space Network (SN), TDRSS spacecraft, Near Earth Network (NEN), and future Exploration Destination networks into a single Integrated Architecture circa 2018. Technologies must be adaptable to a variety of network operating environments ranging from the long-latency limited bandwidths of deep space communications to near Earth environments with traffic flow over global partner assets and the future internet. It is also important to note that NASA systems include ground-to-ground segments in addition to space-to-ground links. Solutions must keep in mind the "big picture" and be capable of seamlessly integrating with future ground systems.

Emerging space communications environments are expected to be shaped in various ways: small mobile mission clusters; traditional large spacecraft and launch vehicles; complexities of commercial and international partnering on the network and user sides; increasing threats to US space communications and navigation assets; and NASA’s need for 40% reduction in network operating costs.

NASA seeks space-networking technologies, which add network intelligence and learning capabilities to increase network efficiency; provide tailored user services; reduce network operating costs through automation; and increase security and resiliency.

Several technologies with promise to meet some of these challenges are listed below with their purpose current state-of--art, and performance metrics desired. Proposals should focus on one or two of these technologies, or for the more complex topics, single implementation aspects.

- Dynamic traffic prioritization provides a means to quickly isolate different types of traffic schemes across the space network. Current technologies allow for such features in the ground environment and the study should leverage those techniques as appropriate. The proposed approach should identify what is necessary for prioritization to be leveraged across multiple space organizations. It should also identify how decisions may impact the performance of different types of data streams.

- Adaptive autonomous network management is to enable smart network elements to make decisions within a predetermined playbook based upon awareness of local network conditions, policies and network end-to-end-objectives. Examples such as automated uplink/downlink scheduling have been demonstrated and are in operational use in limited circumstances. The concept is to shorten the time between a particular network anomaly and the resulting response by mission control allowing for more efficient utilization of the network. Studies must show how the shortened control loop yields better efficiency and how both conditions and automated responses are relayed back to a human operator.

- Cognitive networking with learning is to enable intelligent network elements to reason about reconfiguration decisions [at any layer in the protocol stack] even in unexpected conditions [whether to make decisions autonomously or to offer quantitative support to human operators] based upon situational awareness of network conditions and statistical learning about network behavior and consequences of prior interventions. Software defined and cognitive radios have been demonstrated for terrestrial use and are progressing towards broader cognitive network applications with limited and specific terrestrial demonstrations. Cognitive networking with learning is currently at the forefront of the state-of-the-art, with a multiplicity of approaches being developed for diverse applications such as Future Internet, mobile wireless, and tactical communications. Bidders are encouraged to narrow their focus to specific implementation issues in the domain and focus on adaptation for SCaN space networks. Desired performance metrics are relevant analytical estimates of potential benefits and feature cost-benefit.

- Enhanced security and trust management services for missions that have limited computational and power resources. Contact should not be assumed to be continuous and approaches should leverage proven security techniques where appropriate and provide a means to authenticate between assets and to provide a means to securely update network information (i.e. route injection). It will be important to identify how the proposed approach mitigates particular security risks while also remaining efficient in the space environment.

- Novel techniques for position determination, timing, and route computation are to provide essential services for missions that venture beyond GPS coverage and SCaN infrastructure particularly for missions limited in
equipage they can carry or in the face of intentional service disruption. Human missions develop positional uncertainty at a rate of 10 km/hr due to random accelerations. Early lunar missions like LRO are without timing service. Route computation requirements emerge with formation flight, delta-V sensitive libration point and planetary highway orbits, and robotic surface exploration. [Metrics: convergence time, overhead (number of bytes used by routing algorithm to reach steady state)].

For more information on NASA's future space communication plans, please see the Space Communications and Navigation website at https://www.spacecomm.nasa.gov/

Performance metrics are listed by technology above.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path towards Phase II hardware/software demonstration with delivery of a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables: Phase I report will analytically demonstrate technical feasibility of one or more space networking technologies identified above by characterizing:

- Technical requirements flow-down from generic objectives and summary of state-of-the-art to SCaN network-specific requirements on key performance metrics
- Identification of specific technical challenges to implementation for SCaN networks.
- Analysis of at least three alternative approaches to obtain this performance for SCaN networks.
- Assessment of cost-benefit of each (e.g. risk, complexity, added overhead)
- Selection of software or hardware concept and emphasis topics for further investigation.
- Plan for Phase II resolution of issues or uncertainties and hardware and software demonstration.
- Target TRL 3 at the end of Phase I efforts.

Phase II Deliverables: Phase II report will document:

- Updates to the technical requirements flow-down, identified technical challenges, and selected hardware or software concept based upon further investigation in Phase II.
- Analytical or experimental investigations undertaken to resolve issues and further definition of the selected approach.
- Design and test approach selected for hardware or software demonstration with detailed description of assumptions and parameters.
- Conclusions based upon test results and recommendations for further investigation including any plans for commercialization or further development.
- Target TRL of 5 at the end of Phase II efforts.