



NASA SBIR 2009 Phase I Solicitation

Space Operations

Space Communications Topic O1

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, communications systems for EVAs, 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 are needed which are centered on operational issues associated with the communication capability. 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/> [1]

<https://www.spacecomm.nasa.gov/spacecomm/programs/default.cfm> [2]

<https://www.spacecomm.nasa.gov/spacecomm/programs/technology/default.cfm> [3]

<https://www.spacecomm.nasa.gov/spacecomm/programs/technology/sbir/default.cfm> [4]

A typical approach for flight hardware would include: Phase 1 - 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 2 - 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 2 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:

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

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2. Facilitated Access to the Space Environment for Technology Development and Training (FAST): http://ipp.nasa.gov/ii_fast.htm [5]
 3. International Space Station payload opportunities: http://www.nasa.gov/mission_pages/station/science/experiments/Discipline.html [6]
 4. Terrestrial analogs (Desert Rats, Haughton Field): <http://science.ksc.nasa.gov/d-rats/> [7], http://ti.arc.nasa.gov/projects/haughton_field [8]

NOTE: Communications technologies for space-based range must be highly integrated with required navigation components; hence, space-based range technologies are solicited in Navigation Subtopic O4.05.

Sub Topics:

O1.01 Coding, Modulation, and Compression

Lead Center: JPL

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

This subtopic aims to develop innovative technology in three key areas of space communications: modulation, forward error-correction (FEC) coding, and data compression. The objective is to provide the best possible trade-off of coding gain, bandwidth efficiency, complexity (mass or power), and rate-distortion, so that the total science/engineering value can be maximized while using the smallest amount of spacecraft energy possible. This will enable NASA to meet a wide range of requirements for its future space missions at near Earth, lunar, and deep space distances.

These future missions will use many link types (direct-to-Earth, TDRS relay, lander-to-orbiter relay, and short-proximity links), frequencies (S-, X-, and Ka-bands), and application-specific performance requirements (latency, complexity). The state-of-the-art in the three areas addressed by this subtopic is summarized here:

- Modulation: BPSK and QPSK for deep space, and BPSK, QPSK, SQPSK, and 8-PSK for near Earth (TDRS) applications; GMSK for bandwidth efficient applications
- Coding: CCSDS turbo codes and LDPC codes (See <http://public.ccsds.org/publications/archive/131x0b1.pdf> [9] and <http://public.ccsds.org/publications/archive/131x1o2e2.pdf> [10])
- Compression: the CCSDS standard (<http://public.ccsds.org/publications/archive/122x0b1c2.pdf> [11])

Technology development is needed in the following areas:

Modulation

There is a need for the implementation and demonstration of ground receivers and flight receivers that exhibit very low implementation loss for 8-PSK and GMSK (in addition to BPSK, QPSK, and SQPSK) for operation ranges from 8 bps (emergency) through 100 Mbps (high rate Ka-band). Emphasis is placed on minimizing implementation loss (

Phase 1 tasks should target completion of a fixed-point design whose performance can be verified by simulation (in, e.g., Simulink or SPW). Phase 2 technology target is a hardware demonstration at TRL 5.

Coding

There is a need to interface a receiver as above with a high-performing LDPC decoder. Government licensing of LDPC decoding technology (Verilog source) is available. What is needed here is the development of the following:

- FPGA simulations of all 10 CCSDS LDPC codes down to a bit error rate of $1e^{-10}$ and a codeword error rate of $1e^{-9}$, and with a goal of identifying the "error floor" of each of the codes.
- Improved decoding algorithms that reduce the observed error floor. It is known that observed error floors for these codes are a characteristic of standard belief propagation (BP) decoding, and not because of the minimum distance properties of the codes. Variations of standard decoding may not be susceptible to the same trapping sets, thereby improving error floor performance. These methods include (a) optimally decoding the 4-cycles, (b) converting 4-cycles to equivalent trees, (c) BP decoding with damping, and (d) using min in place of min* in the later iterations of the decoder. These and other variations should be tested particularly on the k=1024, r=4/5 code, which is expected to exhibit the highest error floor.

The target is a finished product at TRL 5.

Data Compression

Development of a radiation-tolerant high-speed (over 100 Msamples/sec) lossless compression component conforming to CCSDS 121.0-B-1, "lossless data compression" (www.ccsds.org [12]) allowing input dynamic range to over 24-bit/sample. Options should include user-supplied external predictor, as well as providing potential applications to hyper-spectral data by taking advantage of the spectral correlation in such data sets.

Development to TRL 5 is desired.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration and deliver a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

The proposer to this subtopic is advised that the products proposed may be included in a future small satellite flight opportunity. Please see the SMD Topic S4 on Small Satellites for details regarding those opportunities. If the proposer would like to have their proposal considered for flight in the small satellite program, the proposal should state such and recommend a pathway for that possibility.

O1.02 Antenna Technology

Lead Center: GRC

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

NASA seeks advanced antenna systems in the following areas: phased array antennas; ground-based uplink antenna array designs; high-efficiency, miniature antennas; smart, reconfigurable antennas; large aperture inflatable/deployable antennas; antenna adaptive beam correction with pointing control; parallelized numerical solvers for antenna modeling and design; and communication antennas with improved performance.

Phased Array Antennas

High performance phased array antennas are needed for (1) high-data rate communication and (2) remote sensing applications. The frequencies of interest are P-, L-, C-, S-, X-, Ku-, Ka-, and W-band. Potential communications applications include: lunar and planetary exploration, landers, probes, Lunar Relay Satellites, lunar rovers, lunar habitats, lunar surface EVA, suborbital vehicles, sounding rockets, balloons, unmanned aerial vehicles (UAV's), TDRSS communication, and expendable launch vehicles (ELV's). Potential remote sensing applications include: radiometers, passive radar interferometer platforms, and synthetic aperture radar (SAR) platforms for planetary science.

Multi-band phased array technology such as S- and Ka-band phased array antennas, which can dynamically reconfigure active element coupling in order to operate in either band as required in order to maximize flexibility, efficiency and minimize the mass of hardware delivered to the moon for lunar surface system operations, are of interest. The goal is to maximize flexibility and capability to share lunar communications infrastructure and therefore minimize mass of radio components that must be delivered to the lunar surface.

There is also a high interest in developing phased array antennas for space-based range applications to accommodate dynamic maneuvers.

The arrays are required to be aerodynamic or conformal in shape for sounding rockets, UAV's, and expendable platforms. They must also be able to withstand the launch environment. The balloon vehicles communicate primarily with TDRS and can tolerate a wide range of mechanical dimensions.

The main challenges/tradeoffs to be addressed are achieving low mass, low cost, high power efficiency, thermal stability of active array electronics, and coverage area (i.e., highly steerable arrays). Active arrays with features such as T/R module self-calibration for thermal stability, true time delay (TTD), low-cost highly-integrated MMIC-based T/R modules (e.g., SiGe/GaAs technology), multiple beam-forming capability, low-loss feeds for radiometer applications are also of interest. Advances in digital beam-forming techniques, including those based on superconducting digital signal processing methods, are also desirable.

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. Some concepts currently under consideration are the development of medium-size (12-m class) antennas (hundreds of them are expected to be required) for transmit/receive (Tx/Rx) ground-based arrays. 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. The uplink

frequency will be in the 7.1-8.6 GHz range (X-band) in the near term, and may be at higher frequencies in the future; it will likely carry digital modulation at rates from 10 kbps to 30 Mbps. An EIRP of at least 500 GW is required, and some applications contemplate an EIRP as high as 10 TW. A major challenge in the uplink array design is minimizing the life-cycle cost of an array.

Other challenges for ground-based antennas include the development of low cost, reliable components for critical antenna systems; advanced, ultra-phase-stable electronics, and phase calibration techniques; improved understanding of atmospheric effects on signal coherence; and integrated low-noise receiver-transmitter technology. Phase calibration techniques needed to ensure coherent addition of the signals from individual antennas at the spacecraft are also required. It is important to understand whether space-based techniques are required or if ground-based techniques are adequate. In general, a target spacecraft in deep space cannot be used for calibration because of the long round-trip communication delay.

Design of ultra-phase-stable electronics to maintain the relative phase among antennas is also needed. These will minimize the need for continuous, extensive and/or disruptive calibrations. A primary related effort currently underway is understanding the effect of the medium (primarily the Earth's troposphere) on the coherence of the signals at the target spacecraft. Generally, turbulence in the medium tends to disrupt the coherence in a way that is time-dependent and site-dependent. A quantitative understanding of these effects is needed. Consequently, techniques for integrating a very low-noise, cryogenically cooled receiver with a medium power (1-200 W) transmitter, are desired. If transmitters and receivers are combined on the same antenna, the performance of each should be compromised as little as possible, and the low cost and high reliability should be maintained.

High-Efficiency, Miniature Antennas

High efficiency, low-cost, low-mass, broadband or dual-band miniaturized antennas (UHF or X-band) that radiate circular polarization with full hemispherical coverage are desirable. These antennas must be able to withstand launch and re-entry environments and must be low profile/conformal.

The emergence of frequency-agile radios increases emphasis of antenna capable of bidirectional communications across multiple bands. Accordingly, emphasis on small size, high efficiency and low cost of ownership is desirable. Miniaturization of L-, S-, and C- band for Micro Air Vehicles is also of interest.

Miniaturized antennas that are wearable or can be highly integrated into the host structure/entity, are also desirable. Examples include EVA's space suits made with textile antennas, fractal antennas, or visor mounted antennas. These miniaturized antennas should also be multi-directional to support astronaut mobility, support multi-band operation, and/or possess a broad bandwidth. Antennas should be low/self-powered, small, and efficient, and compatible with communication equipment that can provide high data rate coverage at short ranges (~1.5 - 3 km, horizon for the Moon for EVA).

Smart, Reconfigurable Antennas

NASA is interested in smart, reconfigurable antennas for applications in lunar and planetary operations. 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 lunar and planetary surface exploration (e.g., rovers, pressurized surface vehicles, habitats, etc.). Desirable features include multi-beam operation to support connectivity to different communication nodes on lunar and planetary surfaces, or in support of communication links for satellite relays around planetary orbits. The antenna shall also be

highly directive, multi-frequency and compatible with the Multiple Input Multiple Output (MIMO) concept.

Large Aperture Inflatable/Deployable Antennas

Large aperture inflatable/deployable membrane antennas to significantly reduce stowage volume (packaging efficiencies as high as 50:1), provide high deployment reliability, and significantly reduced mass density (i.e.,

Novel materials (including memory matrix materials), low fabrication costs and deployment and construction methods using low emissive materials to enable passive microwave instrument application are also beneficial. Structural health monitoring systems are needed to support pre-flight integration, and test activities to determine in-flight system health, are of interest. The ability to incorporate structural considerations for mission applications is also desired (e.g., aero-braking for deep space planetary missions).

Membrane materials for large inflatable membrane antennas for remote sensing applications for earth and planetary science missions are of particular interest to the Science Mission Directorate. The current state of the art for mechanical deployable antennas is reaching limits on packaging efficiencies. Reflectors manufactured from polymer films could enable greater packaging efficiencies due to their low mass, high packaging efficiencies, solar radiation resistance, and cryogenic flexibility. However, most polymer films, including polyimide polymer films, have many challenges that limit their usefulness in practical space applications. Active membrane control system concepts, developed to reduce shape errors, often add unwanted bulk and mass to the antenna system. While other concepts will be entertained, specific membrane material technology innovations of interest are listed below:

- Polymer membrane (0.5 mil to 2.0 mil) material exhibiting zero or near-zero Coefficient of Thermal Expansion (CTE).
- Polymer membrane material exhibiting durability to the space environment, including atomic oxygen, VUV, solar particulate radiation, and temperature extremes.
- Thin film deployment methods that deploy the antenna surface substantially free of wrinkles.
- Innovative intrinsically electroactive polymer membrane actuation mechanisms that can be used to shape-correct the antenna surface.

Additionally, composite materials for large deployable antenna reflector structures for remote sensing applications for earth and planetary science missions with high specific stiffness composite materials that can be packed compactly and deployed multiple times for ground evaluation of the antenna structure prior to launch and deployment in space are of interest. Investigators should consider materials that can be folded and deployed on the order of 5 to 10 times with up to 180 degree bends that retain their structural integrity and shape accuracy upon final deployment. The deployment of these materials should require low energy. Rigidizable materials (Shape Memory Polymers, Shape Memory Composites, UV Activated Composites, etc.) could be considered to obtain the appropriate structural stiffness and post-deployment precision.

Prospective proposers are advised to review Subtopic S1.02, Active Microwave Technologies, for additional remote sensing applications needs, and indicate applicability in their proposal(s).

Antenna Adaptive Beam Correction with Pointing Control

Antenna adaptive beam correction with pointing control that can provide spacecraft knowledge with fine beam pointing with sub-milliradian precision (e.g.,

Parallelized Numerical Solvers for Antenna Modeling/Design

Development of full 3-D electromagnetic (EM) solvers that take advantage of new software engineering approaches (e.g., object oriented programming) and parallel computing resources for fast and accurate modeling/design of antennas, antennas with feed structures, and antennas in multi-path environment are of interest. Numerical solvers offering fast and accurate synthesis via search algorithms (e.g., genetic algorithm) of patch arrays and waveguide slot arrays, to reduce design time, are also of interest. All solvers must aim toward experimental validation of actual antenna concept being simulated.

Communication Antennas with Improved Performance

High performance, low-cost antennas are needed for a variety of missions for communicating with TDRSS, GPS (L1, L2, and L5 bands), or the Deep Space Network (DSN). The frequency bands of interest are L-, S-, X-, Ku-, and Ka-band. Antenna concepts that offer significant improvement in cost and performance (e.g., mass, gain, efficiency, VSWR, axial ratio, bandwidth, power handling, vibration tolerance, etc.) over existing off-the-shelf antennas would be of interest. Novel isoflux antennas at S- and X-band would also be of interest. Antennas must be able to withstand launch environments.

Deliverables and Development Timeline

After a possible Phase 3 development activity, these technologies are expected to ready for insertion at TRL 6 by 2015. Therefore a TRL progression from an entry TRL of 1 - 2 for Phase 1 in January 2010 followed by an exit TRL of 3 - 4 after Phase 2 is reasonable.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward Phase 2 hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

Phase 1 Deliverables

A final report containing optimal design for the technology concept including feasibility of concept and a detailed path towards Phase 2 hardware and/or software demonstration. The report shall also provide options for potential Phase 3 funding from other government agencies (OGA).

Phase 2 Deliverables

A working proof-of-concept demonstrated and delivered to NASA for testing and verification.

O1.03 Reconfigurable/Reprogrammable Communication Systems

Lead Center: GRC

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

NASA seeks novel approaches in reconfigurable, reprogrammable transceiver systems for Space Operations, Exploration, Science, and Aeronautics research. Exploration of Lunar and Mars environments will require advancements in radio communication systems to manage the demands of the harsh space environment on space electronics, maintain flexibility and adaptability to changing needs and requirements, and provide flexibility and survivability due to increased mission durations. NASA missions can have vastly different transceiver requirements (e.g., 1's to 10's Mbps at UHF- and S-band frequency bands up to 10's to 1000's Mbps at X- and Ka-band frequency bands.) and available resources depending on the science objective, operating environment, and spacecraft resources. For example, deep space missions are often power constrained; operating over large distances, and subsequently have lower data transmission rates when compared to near-Earth or near planetary satellites. These requirements and resource limitations are known prior to launch; therefore, the scalability feature can be used to maximize transceiver efficiency while minimizing resources consumed. Larger platforms such as vehicles or relay spacecraft may provide more resources but may also be expected to perform more complex functions or support multiple and simultaneous communication links to a diverse set of assets.

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. Topics of interest include the development of software defined radios or radio subsystems which demonstrate reconfigurability, flexibility, reduced power consumption of digital signal processing systems, increased performance and bandwidth, reduced software qualification cost, and error detection and mitigation technologies. Complex reconfigurable systems will provide multiple channel and multiple and simultaneous waveforms. Areas of interest to develop and/or demonstrate are as follows:

- Enable advancements in bandwidth capacity, reduced resource consumption, or adherence to the Space Telecommunications Radio System (STRS) standard and open hardware and software interfaces. Techniques should include fault tolerant, reliable software execution, reprogrammable digital signal processing devices.
- Reconfigurable software and firmware which provide access control, authentication, and data integrity checks of the reconfiguration process including partial reconfiguration which allows simultaneous operation and upload of new waveforms or functions.
- Operator or automated reconfiguration or waveform load detection failure and the ability to provide access back to a known, reliable operational state. An automated restore capability ensures the system can revert to a baseline configuration, thereby avoiding permanent communications loss due to an errant reconfiguration process or logic upset.
- Develop dynamic or distributed on-board processing architectures to provide reconfigurability and processing capacity. For example, demonstrate technologies to enable a common processing system capacity for communications, science, and health monitoring.
- Adaptive modulation and waveform recognition techniques are desired to enable transceivers to exchange waveforms with other assets automatically or through ground control.
- Low overhead, low complexity hardware and software architectures to enable hardware or software component or design reuse (e.g., software portability) that demonstrates cost or time savings. Emphasis should be on the application of open standards architecture to facilitate interoperability among different

vendors to minimize the operational impact of upgrading hardware and software components.

- Software tools or tool chain methodologies to enable both design and software modeling and code reuse and advancements in optimized code generation for digital signal processing systems.
- Use of reconfigurable logic devices in software defined radios is expected to increase in the future to provide reconfigurability and on-orbit flexibility for waveforms and applications. As the densities of these devices continue to increase and feature size decreases, the susceptibility of the electronics to single event effects also increases. Novel approaches to mitigate single event effects in reconfigurable logic caused by charged particles are sought to improve reliability. New methods should show advancements in reduced cost, power consumption or complexity compared to traditional approaches such as voting schemes and scrubbing.
- Techniques and implementations to provide a core capability within the software defined radio in the event of failure or disruption of the primary waveform and/or system hardware. Communication loss should be detected and core capability (e.g., "gold" waveform code) automatically executed to provide access control and restore operation.
- Innovative solutions to software defined radio implementations that reduce power consumption and mass. Solutions should enable future hardware scalability among different mission classes (e.g., low rate deep space to moderate or high rate near planetary, or relay spacecraft) and should promote modularity and common, open interfaces.
- In component technology, advancements in analog-to-digital converters or digital-to-analog converters to increase sampling and resolution capabilities, novel techniques to increase memory densities, and advancements in processing and reconfigurable logic technology each reducing power consumption and improving performance in harsh space environments.
- Development of radio technology that allows the incorporation of Space Network (SN) waveforms and candidate Lunar Surface System (LSS) wideband waveforms such as 802.11 and 802.16 into a single multimode radio capable of supporting simultaneous communications with space and lunar network assets. Development and implementation of direct RF to digital technologies that are currently emerging and can offer significant improvements in the flexibility of software or multi-mode radios. The goal is to maximize flexibility and capability to share lunar communications infrastructure and therefore minimize mass of radio components that must be delivered to the lunar surface.
- Small, lightweight all-digital reconfigurable radios and transceivers that eliminate analog front ends that operate across multiple bands, are sought for applications that involve network enhanced telemetry, leading towards adaptive and cognitive radio applications. Application of reconfigurable systems in airborne and terrestrial systems is of interest.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward Phase 2 hardware and software demonstration and delivering a hardware demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

O1.04 Miniaturized Digital EVA Radio

Lead Center: JSC

Participating Center(s): GRC

As NASA embarks upon deep space human exploration, the next-generation EVA radio will be a pivotal technology

and integral part of lunar surface systems success. It will facilitate surface operations, enable crew mobility, and support point to multi-point communications across rovers, landers, habitat, and other astronauts. Driven by Communications, Command, Control, and Information (C3I) interoperability, tight power budgets, and extreme miniaturization, this mobile radio platform must be power efficient and highly adaptive. With a scant EVA radio power budget of less than four watts, the S-band (2.4 - 2.483 GHz) adaptive radio must deliver voice, telemetry, and high-definition motion imagery transmissions. To surmount interference, the radio must support frequency diversity over the specified S-band spectrum of 2.4 - 2.483 GHz. During nominal operations, it is designed to operate with a mobile ad hoc network (MANET) so the coverage for communications can be extended indefinitely with node additions. It will communicate to fixed and mobile nodes, including lunar base stations, landers, habitats, rovers, and other astronauts. Therefore, it must support multiple bandwidths, waveforms, and energy profiles. To achieve the overarching communication goals of small form factor, ultra-power, and reconfigurability, NASA needs to extend the state-of-the-art in two key areas:

Tunable RF Front End and Transceiver

The major impetus behind the MEMS technology stems from compactness which leads to lower power dissipation, higher levels of integration, lower weight, volume, and cost. To shrink form factor and enable efficient surface operations, one of the cornerstone radio components of this radio is the tunable filter. Recent advances in RF MEMS filters and resonator technology have permitted very high quality factors (>1000) at GHz frequencies. Achieving high and excellent tuning range (>2:1) to bandwidth ratio without cryogenic cooling is now viable for the S-band frequency. For reliability, the tunable filter should employ a contact-less tuning scheme.

Also, a new class of MEMS-based frequency synthesizers offers dramatic reduction in noise, power, and form factor. One should leverage emerging microscale resonator technologies to the maximum extent. Low phase noise synthesizers running at ultra low power levels are viable using high Q resonator technologies MEMS resonators-based phase lock loop offers compelling power and noise performance enhancements.

Power-Aware Processing

To support QoS of different applications, it's not enough to optimize power at design time, but dynamic power management must be employed to ensure power efficiency. To maximum power efficiency, it must be able to adjust power and update rates to suit diverse missions. Users should be able to specify Quality of Service (QoS) for different data streams. The radio must have the capability to scale power, select the optimum mode of operation, and minimum energy profile. During low-rate-processing intensive modes, including local processing and compression of telemetry data and voice, highly energy-efficient low-voltage, low-performance modes must be used. For high-rate-processing intensive modes, like advance signal encoding of high motion imagery, medium performance modes must be used; and during active communication modes (which may have a low duty-cycle), ultra-high-performance modes must be used. Accordingly, the digital platform must be highly agile and use-case aware to continuously minimize energy. Below are the desirable technology features.

Bear in mind, research should be conducted to demonstrate technical feasibility during Phase 1 and to show a path towards a hardware and software demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

Phase 1 Deliverables

Conduct design trade analyses between power, performance, and flexibility. Estimate mass, volume, power, max/min range, and data rates for dynamic quality of service- voice, telemetry, video- standard and high definition TV at S-band (2.4 - 2.483 GHz), backed with analyses and simulation to ensure achievable performance and power

goals.

Develop a promising MEMS-based system-on-chip radio design with the following features:

- **Variation-tolerant, performance-scalable architectures:** Hardware must sense its own limitation at a dynamically varying, performance-driven optimal energy operating point, and reconfigure accordingly. If variability is stressed at the low-voltage operating point, redundant hardware should be used to improve reliability; if throughput is stressed at the high-performance operating point, redundant hardware should be used to increase parallelism.
- **Highly agile platform components (SRAM and logic):** Circuits should use functionality assists, including selective biasing, leakage-control, routine resources, etc., that get engaged dynamically depending on the operating point.
- **Energy-aware algorithms for adaptive hardware:** Algorithms must be aware of the different hardware operating-points and associated architecture. For instance, during low-power modes targeting voice and data (for telemetry), occasional high through-put applications (like high motion imagery) should dynamically switch to algorithms employing extreme parallelism in order to support a minimum operating voltage.
- **Extreme power converters:** To minimize off-chip components, DC-DC converters should use a single reconfigurable architecture that efficiently delivers load powers ranging from micro-Watts, at low-voltages, to Watts, at high voltages.
- **High performance ultra-low power ADCs:** Exploit novel ADCs with sampling frequencies in tunable multi GHz range (preferable double digits). Variable resolution up to 20 bits or higher with ultra-low power jitters for finer resolutions at higher bits and comparators managed for higher bits with minimum power overheads. A high sampling rate is desirable. SNR optimizations and efficient signal recovery demonstration is a requirement for validating ADC capabilities.
- **Modularity and extensibility:** Enabling platform must support open architecture and accommodate rapid upgrades, multiple protocols, new technology advances, complete re-configurability of functionality, and evolution of lunar communications and network infrastructure.

One significant prerequisite to Phase 2 is the development of most promising MEMS-based transceiver system-on-chip (SoC) architecture. The offeror must demonstrate the ability to achieve significant advantage in compactness and ensure power efficiency and reliability.

Phase 2 Deliverables

Develop a reliable, intelligent, and power-efficient MEMS-based EVA digital radio prototype unit, demonstrating robust and dynamic power management. The miniaturized radio technology must reach TRL=5 at the end of Phase 2.

Demonstrate RF performance and power consumption of less than four watts, delivering voice, telemetry, and standard and high-definition video motion imagery at 2.4 - 2.483 GHz (S-band). With power constraints of under four watts, performance and reliability must be assured for multiple bandwidths and data transmissions of

telemetry, voice, and high-rate video.

O1.05 Transformational Communications Technology

Lead Center: GRC

Participating Center(s): JSC

NASA seeks revolutionary, highly innovative, transformational communications technologies that have the potential to enable order of magnitude performance improvements for space operations, exploration systems, and science mission applications.

Research emphasizing both nearer-term and far-term technologies is focused (but not limited to) in the following areas:

Near-Term Focus Areas:

- Develop novel techniques to reduce the size, weight, and power (SWAP) of communications transceivers 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. Great demands will be placed on these communication transceivers to assure crew safety and robustness in harsh deep-space environments for long duration missions. Investigate and demonstrate novel RF communication technologies to alleviate the demanding requirements on analog to digital converters (ADCs) and digital signal processors (DSPs). For software-defined radios, such requirements can result in high ADC power consumption, large form factor, and expensive components, which can pose problems for power and weight constrained deep space missions.
- Significant component-level technical advances are needed in the area of UHF/VHF filter technologies. Novel, smaller form factor, lower cost, higher performance, and lower weight than existing devices are to be demonstrated employing new technologies such as MEMS resonators (e.g., electrostatic, piezoelectric) and tunable dielectrics. Filter solutions that offer a bandwidth tunability or reconfigurability and filter banks are also sought. Fractional bandwidths of 0.1% to greater than 2% are of interest, where for narrower bandwidths, operating stability across temperature is necessary. At the conclusion of Phase 1, proposers should clearly delineate, through a combination of theoretical analysis and demonstrated prototypes, that the proposed solution can achieve better than 3 dB of insertion loss, better than 70 dB of rejection, less than 1 dB of ripple, small shape factors, power handling greater than +20 dBm, VSWR less than 2, and robust operation in a harsh space environment. Phase 2 will leverage the analysis and prototypes developed in Phase 1 to meet to the specifications for space-based communication links and will deliver a demonstration unit of the proposed technology for testing. Phase 2 will also evaluate component reliability to ensure robust operation across the harsh temperature, vibration, shock, and other conditions encountered in space operation.
- NASA seeks to integrate RFID, antenna, flexible organic material (e.g., Liquid-crystal polymer with constant dielectric properties from 1-110 GHz) and energy-scavenging technologies to develop ultra-low-cost enhanced range sensor surface nodes. This new generation of conformal wireless nodes based on the utilization of UHF semi-passive RFIDs on beacons and astronaut suits would enable the development of robust communication links through the implementation of very-large-scale ad-hoc networks for rugged

and/or emergency response environments. Many technical challenges are associated with the development and enhancement of localization and precise tracking of assets for long-duration missions. To leverage terrain-adaptive navigation solutions, inventory tracking, and astronaut body area network applications, several quantum leap technologies including semi-passive RFID-enabled wearable tags and multi-hopping inflatable beacons need to be advanced to demonstrate ranges in excess of 200 m. Astronauts wearing at least 4 miniaturized ultra-low-power inertial sensors at spacings below the operation wavelength of 2.4GHz (EVA) could enable RFID-enabled inflatable beacons for accurate tracking and navigation. The capability of state-of-the-art wireless systems to provide precise timing/time-tracking with nanosecond accuracy coupled with ultra-low-power wearable inertial sensors and low-power multi-hopping algorithms between beacon-mounted and astronaut-mounted RFIDs can enable true mobility location awareness in ranges in excess of 500/1000 meters. Low power beacons (assuming a duty cycle of 5-10 %) can be solar powered and fabricated in an inflatable triangular shape. It has already been proven that some solar-powered "semi-passive" RFID's with a single-hop range of 100+m consumes only 80 microwatts and can be improved by a factor of 3 to 5. Yet, to have a practical ad-hoc beacon network with effective beacon-to-beacon and beacon-to-RFID ranges in excess of 1 km, with beacon power levels between 20 microwatts to 5 milliwatts, various technical challenges need to be addressed: solar panels should achieve efficiencies greater than 50% and should be easily printed as a substrate of the printed beacon antennas, the electronics should operate in sub-threshold domain, the IC power consumption should be below 20 microwatts, and the antenna should feature at least two different frequencies for redundancy. Solutions should consider employing power scavenging merging dynamic/kinetic energy from the astronaut motion (mounted on boots), solar energy (through thin-films on uniform), thermal/vibration energy (through inkjet-printed nanotube-based wearable textiles), thus minimizing the use of portable battery. Phase 1 effort should introduce an "ad-hoc" wearable network of 3-5 RFID-enabled wearable inertial sensors that could provide voice-level communication with inflatable beacons with total power consumption below 500 microwatts. Up to 5 hops with 300m + hop will be investigated for enhanced range wireless links for 433 MHz, 900MHz and integration. The prototype should include 5+ wearable tags and 5+ inflatable beacons and 3 test frequencies. Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 multi-tag, multi-scenario hardware demonstration prototype unit.

Far-Term Focus Areas:

- The promise of high-performance, multi-functional, nanostructured materials has led to intense interest in developing them for applications for human spaceflight and exploration. These materials (notably single wall carbon nanotubes) exhibit extraordinary mechanical, electrical, and thermal properties at the nanoscale and possess exceptionally high surface area. The development of nano-scale communication devices and systems including nano-antennas, nano-transceivers, etc. are of interest for nano-spacecraft applications.
- Quantum entanglement or 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.
- Innovative approaches to use of medium to high frequency (300 KHz-30MHz) bands for applications benefiting future lunar missions. Concepts, studies, development of key technologies are needed to perform non-line-of-sight communication for potential use on the surface of the Moon. 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 lunar surface links.
- Ultra-wideband (UWB) or impulse radio wireless communications, navigation and tracking for lunar applications. UWB has the capability of pervasive wireless transmission of data, video, etc., very fine time resolution, low power spectral density, and resistance to multipath. Device, component and/or subsystems that can enable use of UWB for space-based applications are sought, including but not limited to: transceivers, highly efficient antennas; array beamformers; space-time processing techniques; accurate timing generators for sub-nanosecond pulse widths; matched filters; channel estimators; low power, high

bandwidth A/D converters with extended time sampling.

O1.06 Long Range Optical Telecommunications

Lead Center: JPL

Participating Center(s): ARC, 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:** 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.
- **Small lightweight two-axis gimbals:** Approximately 1 kg in mass capable to actuating payload mass of approximately 6 kg at rates up to 5 degrees/second, with less than 30 micro-radian rms error and blind-pointing accuracy of less than 35 micro-radian. Assume that the payload is shaped as an 8-cm diameter cylinder, 30-cm long, with uniformly distributed mass. 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 (
- **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 (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 Radiation levels of at least 100 Mrad (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 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 $\sim \$1.5M$ 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 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.

Research should be conducted to convincingly prove technical feasibility during Phase 1, with clear pathways to demonstrating and delivering functional hardware, meeting all objectives and specifications, in Phase 2.

O1.07 Long Range Space RF Telecommunications

Lead Center: JPL

Participating Center(s): ARC, GRC, GSFC

Solicitation Summary

This solicitation seeks to develop innovative long-range RF telecommunications technologies supporting the needs of space missions.

Purpose (based on NASA needs) and current state-of-the-art

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 about 2 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%.

Specifications and Requirements

- Ultra-small, light-weight, low-cost, low-power, modular deep-space transceivers, transponders and components, incorporating MMICs and Bi-CMOS circuits;

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- MMIC modulators with drivers to provide large linear phase modulation (above 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%) 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 techniques and/or wide band-gap semiconductor devices at X-band (8.4 GHz) and Ka-band (26 GHz, 32 GHz and 38 GHz);
 - Epitaxial GaN films with threading dislocations less than 106 per cm² for use in space qualified wide band-gap semiconductor devices at X- and Ka-band;
 - 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);
 - SSPAs, modulators and MMICs for 26 GHz Ka-band (lunar communication);
 - Improved integrated non-linear amplifier/modulator designs that reduce crest-factor impacts and significantly enhance the efficiency of high peak-to-average power ratio waveforms, such as 802.11 and 802.16;
 - TWTAs operating at millimeter wave frequencies (e.g. W-Band) and at data rates of 10 Gbps or higher;
 - Ultra low-noise amplifiers (MMICs or hybrid) for RF front-ends (
 - MEMS-based RF switches and photonic control devices needed for use in reconfigurable antennas, phase shifters, amplifiers, oscillators, and in-flight reconfigurable filters. Frequencies of interest include VHF, UHF, L-, S-, X-, Ka-, V-band (60 GHz) and W-band (94 GHz). Of particular interest is Ka-band from 25.5 - 27 GHz and 31.5 - 34 GHz.

Phase 1 Deliverables

Feasibility study, including simulations and measurements, proving the proposed approach to develop a given product. Verification matrix of measurements to be performed at the end of Phase 2, along with specific quantitative pass-fail ranges for each quantity listed.

Phase 2 Deliverables

Working engineering model of proposed product, along with full report of on development and measurements, including populated verification matrix from Phase 1.

O1.08 Lunar Surface Communication Networks and Orbit Access Links

Lead Center: GRC

Participating Center(s): GSFC, JPL, JSC

This solicitation seeks to develop a highly robust, bidirectional, and disruption-tolerant communications network for the lunar surface and lunar orbital access links. Exploration of lunar and planetary surfaces will require short-range (~1.6 km line-of sight, ~5.6 km non-line-of-sight) bi-directional, often highly asymmetric, and robust multiple-point links to provide on-demand, disruption and delay-tolerant, and autonomous interconnection among surface-based assets. Minimization of communication asset scheduling, and other ground operation support, is highly desirable.

Some of the nodes will be fixed, such as base stations and relays to orbital assets, and some transportable, such as rovers and humans. The ability to meet the demanding environment presented by lunar and planetary surfaces will encompass the development and integration of a number of communication and networking technologies and protocols.

NASA lunar surface networks will be dynamic in nature, and required to deliver multiple data flows with different priorities (operational voice, command/control, telemetry, various qualities of video flows, and others). Bandwidth and power efficient approaches to mobile ad hoc networks are desired. Quality of Service (QoS) algorithms in a Mobile Ad hoc Network (MANET) setting will need to be developed and tailored to NASA mission specific needs and for the lunar surface environment. Exploitation of delay/disruption tolerant network (DTN) technology to maximize autonomy of the communication infrastructure and to minimize demands on channel capacity is of significant interest. Advantages and disadvantages associated with parallel DTN and IP networks, and a competing DTN-over-IP network architecture, should be considered. Possible associated considerations include routing, security, and QoS.

These lunar and planetary surface networks will need to seamlessly interface with communications access terminals and orbiting relays that also can provide autonomous connectivity to Earth based assets. The access link communications system will encompass the development and integration of a number of communications and networking technologies and protocols to meet the stringent demands of continuous interoperable communications. Human exploration, therefore, requires the development of innovative communication protocols that exploit persistent storage on mobile and stationary nodes to ensure timely and reliable delivery of data even when no stable end-to-end paths exist. Solutions must exploit stability when it exists to nearly approximate the performance of conventional MANET protocols. The capability of the network to provide infrastructure-based position determination and navigation is of interest to NASA, especially when coverage issues arise and/or orbiter access links are unavailable. The extent to which the network can support localization of mobile nodes should be addressed, and network architecture options that could further support navigation should be identified.

Frequency bands of interest are UHF (401 - 402 MHz, 25 kHz bandwidth), S-band (2.4 - 2.483 GHz), and Ka-band (22.55 - 23.55 GHz). Existing commercial standards for the PHY and MAC layers should be leveraged to the extent possible while meeting other requirements, with modifications considered when necessary. Results from NASA's Lunar Architecture Team, as well as technology trade studies performed for NASA's Constellation Systems, should be referenced for input regarding data flows, coverage, network requirements, etc. EVA study results can be found at:

EVA Technology Development path loss study: <http://gltrs.grc.nasa.gov/reports/2007/TM-2007-214825.pdf> [13]

Specific Subtopic Capabilities to Address This Year

This year's call intends to focus innovations in 4 key areas. Participants should focus their proposed innovation in one or more of these key areas:

- Differentiated services and QoS support in dynamic wireless networks when safety-of-life and data flows critical to the mission are traversing the network.
- DTN prototype protocol development and demonstration in an emulated operational network.

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- Secure data transfers over mobile, dynamic wireless networks with potential interferers and/or interceptors.
 - Position determination and navigation based novel uses of the network infrastructure (e.g. utilizing radiometric information from the network signaling).

Proposal should address the following:

- Network traffic models
- Network architecture (both hardware and software)
- Spectrum usage
- Security plan (if the proposal deals with particular innovations in this area)
- Identification of software and/or hardware technologies common to networking components that will have the largest impact on size, weight, and power reduction while not compromising the goals of the network architecture as listed above.

Phase 1 Deliverables

A trade analysis identifying novel software and/or hardware technologies common to networking components that will have the largest impact on size, weight, and power reduction while not compromising the goals of the network architecture is the most important aspect of the Phase 1 deliverable. It is not reasonable to expect that all issues and technologies concerning the network architecture proposed will be developed under a Phase 2 contract. However, the proposer should identify and rank novel hardware/software components based on size/weight/power reduction that will enable the proposed network architecture. The proposer should also identify how they are uniquely qualified to develop the novel technologies to products beneficial to NASA, DoD, and perhaps commercial interests.

The Phase 1 proposal should clearly state the assumptions, proposed network architecture, and innovations regarding the 4 key areas mentioned above.

Phase 2 Deliverables

The novel software and/or hardware component identified in Phase 1 will be developed to a state in which it may be demonstrated and the feasibility of the approach on an actual platform may be quantitatively evaluated by NASA testing at the completion of the Phase 2 contract. (TRL 4 or better).

Lead Center: JPL

Participating Center(s): GRC, GSFC

New technology is sought to improve resource optimization and the user interface of planning and scheduling tools for NASA's Space Communications Infrastructure. The software created should have a commercialization approach with the new modules fitting into an existing or in development planning and scheduling tool.

Purpose (based on NASA needs) and the current state of the art:

The current infrastructure for NASA Space Communications provides services for near-Earth spacecraft and deep space planetary missions. The infrastructure assets include the Deep Space Network (DSN), the Ground Network (GN), and the Space Network (SN). Recent planning for the Vision for Space Exploration (VSE) for human exploration to the Moon and beyond as well as maintaining vibrant space and Earth science programs resulted in a new concept of the communications architecture. The future communications architecture will evolve from the present legacy assets and with addition of new assets.

NASA seeks automation technologies that will facilitate scheduling of oversubscribed communications resources to support: (1) Increased numbers of missions and customers; (2) Increased number and complexity of constraints (as required by new antenna types); and (3) decreased operations budgets (both core communications network operations and mission side operations budgets).

Core Capabilities:

Intelligent Assistants

In order to automate the user's provision of requirements and refinement of the schedule, "intelligent assistant" software should manage the user interface. Assistants should streamline access and modification of requirement and schedule information. By modeling the user, this software can adjust the level of autonomy enabling decisions to be made by the user or the automated system. Assistants should try to minimize user involvement without making decisions the user would prefer to make. The assistants should adapt to the user by learning their control preferences. This technology should apply to local/centralized and collaborative scheduling.

In a conflict-aware scheduling system (especially in a collaborative scheduling environment), conflicts are prevalent. With the concept of one big schedule from the beginning of time, real time, to the end of time, resolving conflicts become a difficult task especially since resolving conflicts in a local sense may affect the global schedule. Therefore, an intelligent assistant may provide decision support to the system or the users to assist conflict resolution. This may involve a set of rules combining with certain local/global optimization to generate a list of options for the system or users to choose from.

Resource Optimization

The goal of schedule optimization is to produce allocations that yield the best objectives. These may include maximizing DSN utilization, minimizing loss of desired tracking time, and optimizing project satisfaction. Each project may have their own definition of satisfaction such as maximal science data returned, maximal tracking time, best allocation of the day/week, etc. The difficulty is that we may not satisfy all of these objectives during the optimization process. Obviously, optimal solution for one objective may produce worse results for the other objectives. One possible solution is to map all of these objectives to an overall system goal. This mapping is

normally non-linear. Technology needs to be developed for this non-linear mapping for scoring in addition to regular optimization approaches.

Optional Capabilities:

Multiple Agents

In an environment where all system variables can be controlled by a single controller, an optimal solution for the objective function can be achieved by finding the right set of variables. In a collaborative environment with multiple decision makers where each decision maker can only control a subset of the variables, modeling and optimization become a very complex issue. In the proposed collaborative scheduling approach, there are many users/agents that will control their own allocations with interaction with the others. How we model their interactions and define system policy so the interaction can achieve the overall system goal is an important topic. The approach for multiple decision-maker collaboration has been studied in the area of Game Theory. The applications cover many areas including economics and engineering. The major solutions include Pareto, Nash, and Stackelberg. There are many new research areas including incentive control, collaborative control, Ordinal Games, etc. Note that intelligent assistants and multiple agents represent different points on the spectrum of automation. Current operations utilize primarily manual collaborative scheduling, intelligent assistants would enhance users ability to participate in this process and intelligent agents could more automate individual customers scheduling. Ideally, proposed intelligent assistants and distributed agents would also be able to represent customers who do not wish to expose their general preferences and constraints.

A start for reference material on this subtopic may be found at the following:

<http://ai.jpl.nasa.gov> [14] in the publications area;

<http://scp.gsfc.nasa.gov/gn/gnusersguide3.pdf> [15], NASA Ground Network User's Guide, Chapter 9 Scheduling; and

<http://scp.gsfc.nasa.gov/tdrss/guide.html> [16], Space Network User's Guide, SpaceOps Conference Proceedings.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

Phase 1 Deliverables

Propose demonstration of Intelligent Assistants, Resource Optimization, or Multiple Agents on a number of communication asset allocation problem sets (involving dozens of missions, communications assets, and operational constraints). End Phase deliverable would include a detailed rationale for ROI in usage of said technology to communications asset allocation based on knowledge of current and future operations flows.

Phase 2 Deliverables

Demonstrate Intelligent Assistants, Resource Optimization, or Multiple Agents on actual or surrogate

communication asset scheduling datasets. Deliverables would include use cases and some evidence of utility of deployment of developed technology.

The proposer to this subtopic is advised that the products proposed may be included in a future small satellite flight opportunity. Please see the SMD Topic S4 on Small Satellites for details regarding those opportunities. If the proposer would like to have their proposal considered for flight in the small satellite program, the proposal should state such and recommend a pathway for that possibility.

Space Transportation Topic O2

Achieving space flight can be astonishing. It is an undertaking of great complexity, requiring numerous technological and engineering disciplines and a high level of organizational skill. Overcoming Earth's gravity to achieve orbit demands collections of quality data to maintain the security required of the range. The harsh environment of space puts tight constraints on the equipment needed to perform the necessary functions. Not only is there a concern for safety but the 2004 Space Transportation Policy directive states that the U.S. must maintain robust transportation capabilities to assure access to space. Given this backdrop, this topic is designed to address technologies to enable a safer and more reliable space transportation capability. Automated collection of range data, acquisition of specialized weather data, and instrumentation for space transportation system testing are all required. The following subtopics are required to secure technologies for these capabilities.

Sub Topics:

O2.01 Automated Collection and Transfer of Launch Range Data (Surveillance/Intrusion, Weather)

Lead Center: KSC

Participating Center(s): GRC, GSFC

NASA is seeking innovative technologies for sensors and instrumentation technologies which expedite range clearance by providing real-time situational awareness for safe Range operations from processing to launch and recovery. These sensors and instruments are expected to operate, as a payload, on mobile or deployable Unmanned Aerial Systems (UAS), High Altitude Airships (HAA), buoys, etc. NASA is also seeking innovative technologies to remotely measure electric fields aloft in order to reduce the threat of destruction of a launch vehicle by rocket triggered lightning.

Purpose: NASA is embarking on a new era of space exploration with new launch vehicles and demands for availability to support launch times within hours of one another to ensure mission success. This availability requirement is allocated across the entire launch operations which includes the Range that provides clear corridor of land, air and sea for the vehicles to transit through, as they ascent or return. The current Range infrastructure is aging, labor intensive and independent, and would benefit from new sensors and instrumentation that improve the situational awareness (including weather) of those that are responsible for ensuring public safety, mission assurance and efficient operations.

To aid in this situational awareness the new sensors and instrumentation must be able to operate in the environment that takes advantage of mobile or deployable Unmanned Aerial Systems (UAS), High Altitude Airships (HAA), buoys, etc. Use of these vehicles as a platform is intended to increase the Ranges availability while reducing the cost of operations. Size, power, weight and stability of these systems, that operate on these platforms, will be a major constraint their use.

These sensors and instrumentation provide for the remote detection, recognition, and identification of persons and objects that have intruded into areas of the range that must be cleared in order to conduct safe launch operations. This would include a wide spectrum of optical, infrared, Radio Frequency (RF), and millimeter wave sensors for this purpose. In order to achieve accurate identification, time and position of intruding entities multiple sensors and instruments may be used, or combined through the use of neural networks and data fusion techniques. This will require the use of standards for communications, so that, data from individual sensors or instruments can be combined on a platform and processed on-board, or communicated to central location where a fused solution is processed.

The sensors, instrumentation and algorithms to remotely measure electric fields aloft will reduce the threat of destruction of launch vehicles during ascent by improving the prediction of potential lightning strikes to vehicles due to triggered lightning. Potential candidate technologies include new algorithms to take advantage of existing dual-polarized Doppler five-cm weather radar capability, or entirely new technologies for the remote sensing of electric fields. The ability to economically measure the incremental ballistic wind velocities along the predicted trajectory of launch vehicles at remote and evolving launch ranges at altitudes up to 100 kft via fixed and mobile LIDAR approaches is also highly desirable.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

02.02 Ground Test Facility Technologies

Lead Center: SSC

Participating Center(s): GRC, MSFC

NASA's Stennis Space Center (SSC) is interested with expanding its suite of test facility modeling tools as well as non-intrusive plume technologies that provide information on propulsion system health, the environments produced by the plumes and the effects of plumes and constituents on facilities and the environment.

Facility Modeling Tools and Methods

Developing and verifying test facilities is complex and expensive. The wide range of pressures, flow rates, and temperatures necessary for engine testing results in complex relationships and dynamics. It is not realistic to physically test each component and the component-to-component interaction in all states before designing a

system. Currently, systems must be tuned after fabrication, requiring extensive testing and verification. Tools using computational methods to accurately model and predict system performance are required that integrate simple interfaces with detailed design and/or analysis software. SSC is interested in improving capabilities and methods to accurately predict dynamic responses for transient fluid structure interactions, convective, conductive, and radiant heat transfer for propellant systems, exhaust systems and other components used in rocket propulsion testing. Also of interest is the modeling and prediction of condensation, diffusion, stratification, and concentration gradients for fluid mixtures commonly encountered in testing, such as propellants and purges.

Vacuum System Technologies

Stennis is constructing the new A3 test stand which is designed to test a very large (294,000 lbf thrust) cryogenic rocket engine at a simulated altitude of 100,000 feet. When the air in the engine test chamber is evacuated, the simulated altitude pressures inside the test chamber will be less than 0.20 PSIA. This will result in a very unique environment with extremely low pressures inside a very large chamber and ambient pressures outside this chamber. Due to the unique nature of this test facility, new technologies and measurement techniques will need to be developed to monitor and analyze this environment. These include but are not limited to instrument closeouts at vacuum pressures for hundreds of channels of instrumentation entering the chamber, new sealing technologies for large cryogenic piping entering this very large test cell wall to seal against this unique environment, material fatigue measurement and predictions, inspection techniques for the vacuum chamber structures and diffuser ducting, etc.

Component Design, Prediction and Modeling

Improved capabilities to predict and model the behavior of components (valves, check valves, chokes, etc.) during the facility design process are needed. This capability is required for modeling components in high pressure (to 12,000 psi), with flow rates up to several thousand lb/sec, in cryogenic environments and must address two-phase flows.

Challenges include: accurate, efficient, thermodynamic state models; cavitation models for propellant tanks, valve flows, and run lines; reduction in solution time; improved stability; acoustic interactions; fluid-structure interactions in internal flows.

Plume Environments Measurements

Advanced instrumentation and sensors to monitor the near field and far field effects and products of exhaust plumes. Examples are the levels of acoustic energy and thermal radiation and their interaction/coupling with test articles and facilities and measurements of the final exhaust species that will affect the environment.

Major challenge: Large scale engine plume dispersion modeling and validation.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract. Expected TRL range from 3 to 5.

Processing and Operations Topic O3

The Space Operations Mission Directorate (SOMD) is responsible for providing mission critical space exploration services to both NASA customers and to other partners within the U.S. and throughout the world: from flying the Space Shuttle, to assembling the International Space Station; ensuring safe and reliable access to space; maintaining secure and dependable communications between platforms across the solar system; and ensuring the health and safety of our Nation's astronauts. Each of the activities includes both ground-based and in-flight processing and operations tasks. Support for these tasks that ensures they are accomplished efficiently and accurately enables successful missions and healthy crew.

Sub Topics:

O3.01 Human Interface Systems and Technologies

Lead Center: GRC

Participating Center(s): ARC, GSFC

The focus of this sub topic is on the development of systems and technologies that advance TRL of man/machine interfaces for humans in space environments. Specific areas of interest include, but are not limited to, high fidelity inbound and outbound speech and audio systems along with data entry/data presentation devices, cameras, metabolic monitoring, health monitoring devices, interfaces that support human/robot interaction, high-level communications protocols and/or standardized interfaces for transmitting and receiving data related to human monitoring systems or human interface systems. Technologies and systems should resolve issues that are peculiar to human/machine interaction in the space environments or exploit unique features of the space environment or both. Interest exists for application to micro-gravity space suits, planetary space suits as well as space-based "shirtsleeve environments" such as onboard the ISS, shuttle or other crew modules. The particular focus area of the topic this year is on Advanced Data Entry systems.

Advanced Data Entry

Terrestrial user-interface devices for controlling portable processing equipment such as laptop computers typically rely on keyboard or touchpad input. Such devices are problematic in the space environment since a suited crewmember must interact with the processing equipment while wearing a pressurized glove. Speech recognition technologies have been proposed and investigated to provide a data entry capability for suited crewmembers. However, speech recognition technologies typically incur a high computational loading burden. Alternative methods and technologies for data entry are anticipated to result in significantly lower processing burden and therefore reduced Size Weight and Power (SWaP) and enhanced system reliability. Preference will be given to proposals that indicate the resulting system will have a low computational burden.

Currently, the main purpose of a suit's processing system is for providing life-support data-acquisition, monitoring, telemetry, and crewmember alerts. The traditional approach to interact with the EVA processing system is with suit-mounted toggle switches optimally sized for a gloved hand and located in the suit's chest area. NASA envisions future generations of suits to contain advanced communication, navigation, and information processing capabilities that will require better ways of interacting with the suited crewmember. It is likely that the processing unit(s) will be installed within the suit's backpack-mounted portable life support unit or in close proximity.

Crewmember usability and efficient operation are prime features of the next-generation input device. The device must operate robustly in the space environment and on the surface of remote planetary bodies. Devices must be tolerant of dust, vacuum, and radiation exposure. During Extra-Vehicular Activity (EVA), a suited crewmember needs to achieve as high a level of mobility as possible, so a suit-mounted computer-input device must not impede the movements of the suited crewmember or unduly burden the suit system with weight, volume, or electrical power constraints.

NASA is seeking systems, subsystems and/or technologies in support of improvements in suit-mounted computer system data entry user-interface devices. Devices or systems should allow the suited crewmember to control a computer processing system and provide text input and/or spatial indication accurately, at high speed, without little or no user fatigue. Possible interactions for data entry include, but are not limited to: inputting direction or positions (for navigation or robotic-aid purposes), inserting notes (e.g., field or experiment notes, images, labeling of images), and selecting/marking items on lists (e.g., zooming, drilling down lists, scrolling through lists, moving items). Concepts may consider that provide solutions installed internally (within the pure-oxygen pressurized envelop of the suit), externally (mounted on the exterior of the suit), or a combination of the two:

Particular interest is in the areas of:

- Human interface devices that support manual control of mechanical devices such as rovers or tools;
- Chording keyboards, suit or glove mounted fabric keyboards or touch-pads;
- Techniques for routing wires or connections between the user interface device and the computer-processing unit;
- Techniques for routing the wires past bearings or avoidance of such.

Other technologies will be considered.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract. Preference will be given to proposals that support in-flight demonstration opportunities on the ISS at the completion of the Phase 2 contract.

03.02 Vehicle Integration and Ground Processing

Lead Center: KSC

Participating Center(s): MSFC, SSC

This solicitation seeks to create new and innovative technology solutions for assembly, test, integration and processing of the launch vehicle, spacecraft and payloads; end-to-end launch services; and research and development, design, construction and operation of spaceport services. The following areas are of particular interest.

Propellant Servicing Technologies Enabling Lower Life Cycle Costs

Technologies for advanced cryogenic fluid storage and transfer, servicing of chilled/densified fluids and advances in state-of-the-art ground insulation are needed to reduce launch operation costs by minimizing consumable losses. Solutions in support of helium conservation and recovery; recapture, reduction, and elimination of cryogenic propellants vented to atmosphere (zero boil-off); insulation for improved storage and distribution minimizing thermal losses; fire resistant liquid oxygen pumping systems; and instrumentation advances to enable high efficiency operations. Providing solutions with higher efficiency, lower maintenance and longer life while improving safety and improving liquid quality delivery.

Corrosion Control

Technologies for the prevention, detection and mitigation of corrosion/erosion in spaceport facilities and ground support equipment including refractory concrete. Solutions for: damage responsive coatings with corrosion inhibitors; poor-performing refractory concrete; protective coatings for non-painted surfaces; and new environmentally friendly protective coating options to replace products lost due to EPA regulation changes. Providing coating/protection solutions that meet current and emerging environmental restrictions and can endure the corrosive and highly acidic launch environment.

Spaceport Processing Systems Evaluation/Inspection Tools

Technologies in support of defect detection in composite materials; methods for determining structural integrity of bonded assemblies; and non-intrusive inspection of Composite Overwrapped Pressure Vessels (COPV), Orion heat shield and painted surfaces. Solutions for detecting and pinpointing corrosion under painted surfaces; predicting remaining coatings effectiveness/life expectancy; identifying composite defects and evaluating integrity; non-destructive measurement and evaluation of COPV; and damage inspection and acceptance testing of Orion heat shield. Providing solutions that reduce inspection times and provide higher confidence in system reliability and safety concerns and lower life cycle costs.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

This subtopic is also a subtopic for the "Low-Cost and Reliable Access to Space (LCRATS)" topic. Proposals to this subtopic may gain additional consideration to the extent that they effectively address the LCRATS topic (See topic O5 under the Space Operations Mission Directorate).

O3.03 Enabling Research for ISS

Lead Center: JSC

Participating Center(s): GRC, KSC, MSFC

The focus of this sub-topic is on the development of systems and technologies that provide innovative ways to leverage the existing ISS facilities for new payloads or provide on orbit analysis to enhance capabilities, reduce sample return requirements, or enable sample return for existing payloads.

Current utilization of ISS is limited by upmass, downmass, crew time and by the capabilities of the interfaces and hardware already developed. Innovative ways of interfacing existing hardware such as being able to use the light microscopy module (LMM) in the Fluids Integrated Rack (FIR) as a life science microscope could increase biotechnology research capabilities. Enabling additional cell and molecular biology culture techniques by providing innovative hardware to allow for safe, contained transfer of cells from container to container within the Microgravity Sciences Glove Box (MSG) would permit new types of studies on ISS. On orbit analysis techniques that would reduce or remove the need for downmass (such as a system for gene array tests, or kits for DNA extractions for long term storage) are also examples of hardware possibilities that would extend and enable additional research.

Capabilities that extend the types of studies that can be completed in orbit are not limited to the above examples or to biotechnology disciplines. Innovative methods for further subdividing payloads lockers to enable numerous pico-payloads, or developing an innovative generic control system to interface with existing ISS control systems are a further examples of the type of technology that is requested under this subtopic.

The existing hardware suite and interfaces available on ISS can be found at:

http://www.nasa.gov/mission_pages/station/science/experiments/Discipline.html [6]

Due to the difficulty and complexity of qualifying hardware for human spaceflight, proposals under this subtopic are expected to advance the development to a level demonstrating the technology in the lab or relevant environment under the SBIR program.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward Phase 2 hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

NASA is seeking innovative research in the areas of positioning, navigation, and timing (PNT) that have relevance to Space Communications and Navigation programs and goals, as described at <http://www.spacecomm.nasa.gov> [17]. NASA's Space Communication and Navigation Office considers the three elements of PNT to represent distinct, constituent capabilities: (1) positioning, by which we mean accurate and precise determination of an asset's location and orientation referenced to a coordinate system; (2) navigation, by which we mean determining an asset's current and/or desired absolute or relative position and velocity state, and applying corrections to course, orientation, and velocity to attain achieve the desired state; and (3) timing, by which we mean an asset's acquiring from a standard, maintaining within user-defined parameters, and transferring where required, an accurate and precise representation of time. NASA has divided its PNT interests into six focus areas: (1) Global Positioning System (GPS) (2) Distress Alerting Satellite System (DASS) (3) Flight Dynamics (4) Tracking and Data Relay Satellite System (TDRSS) (5) TDRSS Augmentation Service for Satellites (TASS) (6) Geodesy. This year, NASA seeks technology in focus areas (1), (3), (4), and (5), and related areas that provides PNT support and services for NASA's current tracking and communications networks and systems-including tracking during launch and landing operations, and research and technology relevant to the planning and development of PNT support and services for NASA's Project Constellation, including lunar surface operations, and other Exploration and Science Programs that NASA may undertake over the next two decades. Some of the subtopics in this topic could result in products that may be included in future flight opportunities. Please see the Science MD Topic S4 for more details as to the requirements for small satellite flight opportunities, and the Facilitated Access to the Space Environment for Technology Development and Training (FAST) website at http://ipp.nasa.gov/ii_fast.htm [5].

Sub Topics:

O4.01 Metric Tracking of Launch Vehicles

Lead Center: KSC

Participating Center(s): GSFC, MSFC

Range Safety requires accurate and reliable tracking data for launch vehicles. Onboard GPS receivers must maintain lock, reacquire very quickly and operate securely in a highly-dynamic environment. GPS Course Acquisition Code (CA) does not require classified decryption codes and has an accuracy of better than 30 m and 1 m/s. Although this accuracy is good enough for most Range Safety needs, better accuracy is needed for antenna pointing, docking maneuvers and attitude determination. CA code also offers little protection against deliberately transmitted false signals or "spoofing".

This solicitation seeks proposals in the following areas:

- Innovative technologies to increase the accuracy of the L1 C/A navigation solution by combining the pseudo ranges and phases of the L1 C/A signals, and use of the L2 and L5 carrier. Factors that degrade the GPS signal can be obtained by differencing the available carrier phase and pseudo range measurements and then removing this difference from the navigation solution.
- Technologies that combine spatial processing of signals from multiple antennas with temporal processing techniques to mitigate interference signals received by the GPS receiver. The coordinated response of adaptive pattern control (beam and null steering) and digital excision of certain interfering signal components minimizes strong jamming signals. Adaptive nulling minimizes interfering signals by the optimal control of the GPS antenna pattern (null steering).

These technologies should be independent of any particular GPS receiver design.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration unit or software package for NASA testing at the completion of the

Phase 2 contract.

04.02 On-Orbit PNT (Positioning, Navigation, and Timing) Sensors and Components

Lead Center: GSFC

Participating Center(s): GRC, JPL, JSC

This solicitation seeks proposals that will serve NASA's ever-evolving set of near-Earth and interplanetary missions that require precise determination of spacecraft position and velocity in order to achieve mission success. While the definition of "precise" depends upon the mission context, typical scenarios have required meter-level or better position accuracies, and sub-millimeter-level or better velocity accuracies.

Research should be conducted to demonstrate technical feasibility during Phase 1, and show a path toward a Phase 2 hardware and/or software demonstration of a demonstration unit or software package that will be delivered to NASA for testing at the completion of the Phase 2 contract. The Small Spacecraft Build effort highlighted in Topic S4 (Low-cost Small Spacecraft and Technologies) of the solicitation participates in this subtopic. Offerors are encouraged to take this in consideration as a possible flight opportunity when proposing work to this subtopic.

Purpose: NASA Needs vs. Current State of the Art

This solicitation is primarily focused on NASA's needs in three focused areas: onboard near-Earth navigation systems; onboard deep-space navigation systems; technologies supporting improved TDRSS-based navigation. Proposals that leverage state-of-the-art capabilities already developed by NASA such as GEONS (<http://techtransfer.gsfc.nasa.gov/ft-tech-GEONS.html> [18]), Navigator (<http://techtransfer.gsfc.nasa.gov/ft-tech-GPS-NAVIGATOR.html> [19]), GIPSY, Electra, and Blackjack are especially encouraged. NASA is not interested in funding efforts that seek to "re-invent the wheel" by duplicating the many investments that NASA and others have already made in establishing the current state-of-the-art.

General Operational Specifications and Requirements:

Core Capabilities:

Onboard Near-Earth Navigation System

NASA seeks proposals that would develop a commercially viable transceiver with embedded orbit determination software that would provide enhanced accuracy and integrity for autonomous onboard GPS- and TDRSS-based navigation and time-transfer in near-Earth space via augmentation messages broadcast by TDRSS. The augmentation message should include information on the TDRS orbits, status, and health that could be provided by future TDRS, and should provide information on the GPS constellation that is based on NASA's TDRSS Augmentation for Satellites Signal (TASS). Proposers are advised that NASA's GEONS and GIPSY orbit determination software packages already support the capability to ingest TASS messages.

Onboard Deep-Space Navigation System

NASA seeks proposals that would develop an onboard autonomous navigation and time-transfer system that can reduce DSN tracking requirements. Such systems should provide accuracy comparable to delta differenced one-way ranging (DDOR) solutions anywhere in the inner solar system, and exceed DDOR solution accuracy beyond the orbit of Jupiter. Proposers are advised that NASA's GEONS and DS-1 navigation software packages already support the capability to ingest many one-way forward Doppler, optical sensor observation, and accelerometer data types.

Technologies Supporting Improved TDRSS-based Navigation

NASA seeks proposals that would provide improvements in TDRS orbit knowledge, TDRSS radiometric tracking, ground-based orbit determination, and Ground Terminal improvements that improve navigation accuracy for TDRS users. Methods for improving TDRS orbit knowledge should exploit the possible future availability of accelerometer data collected onboard future TDRS.

Optional Capabilities:

NASA may consider other proposals relevant to NASA's needs for precise spacecraft navigation and tracking that demonstrably advance the state-of-the-art.

Development Timeline Associated with NASA Needs:

Phase 1 deliverables should include documentation of technical feasibility, which should at minimum show a path toward hardware and/or software demonstration of a demonstration unit or software package in Phase 2.

Phase 2 deliverables should include a demonstration unit or software.

The proposer to this subtopic is advised that the products proposed may be included in a future small satellite flight opportunity. Please see the SMD Topic S4 on Small Satellites for details regarding those opportunities. If the proposer would like to have their proposal considered for flight in the small satellite program, the proposal should state such and recommend a pathway for that possibility.

04.03 Lunar Surface Navigation

Lead Center: GRC

Participating Center(s): GSFC, JPL, JSC

In order to provide location awareness, precision position fixing, best heading and traverse path planning for planetary EVA, manned rovers and lunar surface mobility units NASA has established requirements for onboard

navigation capabilities for surface-mobile elements of lunar missions. Proposals are specifically sought which address the following needs:

- Asset localization within a work area. Specifically, real-time relative location of vehicles and EVA crewmembers for safety and task efficiency.
- EVA crew localization for emergency walk back to a safe haven (lander, habitat, fixed reference point, etc.)
- Fixed asset localization with respect to global coordinates.
- Traverse-path planning systems and navigation-specific displays are also of interest.
- Novel navigation techniques that utilize repurposed flight vehicle sensors (INS, AHRS, low light imager, star trackers, etc.)

This topic will develop systems, technologies and analysis in support of the required capabilities of lunar surface mobility elements. Contemplated navigation systems could employ celestial references, passive or active optical information such as optical flow or range to local terrain features, inertial sensor information or other location-specific sensed data or combinations thereof. However, radiometric measurements are considered to be concomitant to the lunar communications network and the lunar network will likely be used to communicate state information between lunar mission elements. As such, the main emphasis of this topic is on systems that exploit radiometric measurements such as range, Doppler or Angle of Arrival. Radiometric measurements can be considered between lunar mission elements such as surface mobility units, elements of a lunar surface architecture (such as surface landers or habitation units or other surface mobility units) or elements of the lunar communications and navigation infrastructure such as surface communications towers or lunar communication/navigation orbiters. Note that the constellation of moon-orbiting communication/navigation satellites will support both polar outpost missions as well as short term sortie missions that can occur anywhere on the lunar surface. This constellation will likely consist of no more than six satellites and may be only be one or two satellites. Earth-based nodes are not excluded from consideration, nor are two-way radiometric measurements, nor are non-NASA-standard modulation schemes.

Emphasis of the development is on navigation accuracy, position estimate update rate (minimized correlation time), minimum Size Weight and Power (SWaP), systems that operate effectively with minimal communications/navigation infrastructure (such as towers or orbiters) or with complete autonomy, with minimal crew involvement or completely automatically. Unified concepts and systems that provide a range of hardware capabilities (possibly trading accuracy with SWaP) and/or support dual-use (e.g., navigation and communication) are of interest.

Mature system concepts and technologies including system demonstration with TRL 6 components and internalized (by NASA) standards are required at the end of a Phase 2. Candidates for technology infusion include developmental EVA space suits and prototype crew and robotic rovers. An example rover system is the Lunar Electric Rover (LER). The LER (<http://www.nasa.gov/exploration/home/LER.html> [20]) is a sport utility sized, 12-wheeled, pressurized vehicle capable of supporting 14-day missions with two astronauts. Recent tests have included 140km treks across rugged terrain in Arizona. Future testing will extend the distance. Examples of a developmental EVA space suit include the Mark iii spacesuit and the REI suit (c.f. http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20080012574_2008010837.pdf [21]). Demonstration opportunities occur several times a year at lunar analog exercises such as the Desert Research and Technology Studies (D-RATS, c.f. http://en.wikipedia.org/wiki/Desert_Research_and_Technology_Studies [22]) and the Haughton Field test (c.f. http://ti.arc.nasa.gov/projects/haughton_field/ [23]).

O4.04 Flight Dynamics Technologies and Software

Lead Center: GRC

Participating Center(s): GSFC, JPL

NASA is beginning to invest in re-engineering its suite of tools and facilities that provide navigation and mission design services for design and operations of near-Earth and interplanetary missions. This solicitation seeks proposals that will develop flight dynamics technologies and software that support these efforts.

In the context of this solicitation, flight dynamics technologies and software are algorithms and software that may be used in ground support facilities, or onboard a spacecraft, so as to provide Position, Navigation, and Timing (PNT) services that reduce the need for ground tracking and ground navigation support. Flight dynamics technologies and software also provide critical support to pre-flight mission design, planning, and analysis activities.

This solicitation is primarily focused on NASA's needs in the following focused areas:

- Applications of cutting-edge estimation techniques, such as sigma-point and particle filters, to spaceflight navigation problems.
- Applications of estimation techniques that have an expanded state vector (beyond position and velocity components) to monitor non-Gaussian noise processes to improve upon the overall system accuracy.
- Applications of creative estimation techniques that combine measurements from multiple sensor suites to improve upon the overall system accuracy.
- Applications of advanced dynamical theories to space mission design and analysis, especially in the context of unstable orbital trajectories in the vicinity of small bodies and libration points.
- Addition of novel measurement technologies to existing NASA onboard navigation software that is licensed by the proposer.
- Addition of orbit determination capabilities to existing NASA mission design software that is either freely available via NASA Open Source Agreements, or that is licensed by the proposer.

Proposals that leverage state-of-the-art capabilities already developed by NASA such as GPS-Enhanced Onboard Navigation Software (<http://techtransfer.gsfc.nasa.gov/ft-tech-GEONS.html> [18]), General Mission Analysis Tool (<http://sourceforge.net/projects/gmat/> [24]), GPS-Inferred Positioning System and Orbit Analysis Simulation Software, (<http://gipsy.jpl.nasa.gov/orms/goa/> [25]), 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.

Technologies and software should support a broad range of spaceflight customers. Technologies and software specifically focused on a particular mission's or mission set's needs, for example rendezvous and docking, or formation flying, are the subject of other solicitations by the relevant sponsoring organizations and should not be submitted in response to this solicitation.

Research should be conducted to demonstrate technical feasibility during Phase 1, and show a path toward a Phase 2 demonstration of a software package that will be delivered to NASA for testing at the completion of the Phase 2 contract.

The proposer to this subtopic is advised that the products proposed may be included in a future small satellite flight opportunity. Please see the SMD Topic S4 on Small Satellites for details regarding those opportunities. If the proposer would like to have their proposal considered for flight in the small satellite program, the proposal should state such and recommend a pathway for that possibility.

04.05 Space-Based Range Technologies

Lead Center: GSFC

Participating Center(s): AFRC, GRC

The vision of Space-Based Range architecture is to assure public safety, reduce the costs of launch operations, enable multiple simultaneous launch operations, decrease response time, and improve geographic and temporal flexibility. This sub-topic seeks to reduce or eliminate the need for redundant range assets and deployed down-range assets that are currently used to provide for Line-of-Sight (LOS) Tracking Telemetry and Control (TT&C) with sub-orbital platforms and orbit-insertion launch vehicles. In order to achieve this, specific advancements are needed in TT&C.

Position, Attitude, and Inertial Metrics

Realization of a Space-Based Range requires the development of highly accurate and stable integrated metric tracking and inertial measurement units. The focus is on technologies that enable and advance development of low Size, Weight, and Power (SWaP), tactical grade, integrated metric tracking units that provide highly accurate and stable positioning, attitude, and inertial measurements on high dynamic platforms.

Factors to address include:

- Easy coupling of IMUs, gyros, accelerometers, and/or attitude determining GPS receivers that will provide very high frequency integrated metric solutions;

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- The ability to reliably function on spin-stabilized rockets (up to 7 rps), during sudden jerk and acceleration maneuvers, and in high vibration environments is critical;
 - Advancements in MEMs-based IMUs and accelerometers, algorithm techniques and Kalman filtering, phased-based attitude determination, single aperture systems, quick Time to First Fix and reacquisition.

Space-Based Telemetry

There are varying applications for space-based transceivers, each necessitating a different set of requirements. The desired focus is very low SWaP, tactical grade, highly reliable, and easily reconfigurable transceivers capable of establishing and maintaining unbroken satellite communication links for telemetry and/or control. This technology will serve applications which include low-cost sub-orbital missions, secondary communications systems for orbit insertion vehicles, low cost and size orbital payloads (typically LEO), and flight test articles. Durations will range from minutes to several weeks and the ability to operate on highly dynamic platforms is critical. High data rate links are highly desired, thus the use of NASA's TDRSS is emphasized, although other commercial satellite systems which can provide nearly global and high data rate links can also be explored.

Factors to address include:

- Advancements in software based radios and coding techniques;
- Use of the latest semiconductor technologies (GaN or other);
- Advanced heat dissipation techniques (to allow small packaging and long duration operating times);
- Immunity to corona breakdown;
- Ease of data interfacing.

RF power output requirements range from a few watts to as high as 100 W. Special consideration should be given to transceiver capability vs. packaging that would allow for customizable configurations depending on the target application. That is, a modular or stacking design with a common bus architecture should be considered where the RF and digital sections are separated. This could allow for a base digital and DC power design that will support multiple RF slices (such as a low, medium, or high power slice). Also, to satisfy missions who require unidirectional communications, a modular design could allow for separate transmitter and receiver modules/slices.

Phase 1 Deliverables

A final report containing optimal design for the technology concept including feasibility of concept, a detailed path towards Phase 2 hardware and/or software demonstration. The report shall also provide options for potential Phase 2 funding from other government agencies (OGA).

Phase 2 Deliverables

A working proof-of-concept demonstrated and delivered to NASA for testing and verification.

Coding, Modulation, and Compression Topic O1.01

This subtopic aims to develop innovative technology in three key areas of space communications: modulation, forward error-correction (FEC) coding, and data compression. The objective is to provide the best possible trade-off of coding gain, bandwidth efficiency, complexity (mass or power), and rate-distortion, so that the total science/engineering value can be maximized while using the smallest amount of spacecraft energy possible. This will enable NASA to meet a wide range of requirements for its future space missions at near Earth, lunar, and deep space distances.

These future missions will use many link types (direct-to-Earth, TDRS relay, lander-to-orbiter relay, and short-proximity links), frequencies (S-, X-, and Ka-bands), and application-specific performance requirements (latency, complexity). The state-of-the-art in the three areas addressed by this subtopic is summarized here:

- Modulation: BPSK and QPSK for deep space, and BPSK, QPSK, SQPSK, and 8-PSK for near Earth (TDRS) applications; GMSK for bandwidth efficient applications
- Coding: CCSDS turbo codes and LDPC codes (See <http://public.ccsds.org/publications/archive/131x0b1.pdf> [9] and <http://public.ccsds.org/publications/archive/131x1o2e2.pdf> [10])
- Compression: the CCSDS standard (<http://public.ccsds.org/publications/archive/122x0b1c2.pdf> [11])

Technology development is needed in the following areas:

Modulation

There is a need for the implementation and demonstration of ground receivers and flight receivers that exhibit very low implementation loss for 8-PSK and GMSK (in addition to BPSK, QPSK, and SQPSK) for operation ranges from 8 bps (emergency) through 100 Mbps (high rate Ka-band). Emphasis is placed on minimizing implementation loss (

Phase 1 tasks should target completion of a fixed-point design whose performance can be verified by simulation (in, e.g., Simulink or SPW). Phase 2 technology target is a hardware demonstration at TRL 5.

Coding

There is a need to interface a receiver as above with a high-performing LDPC decoder. Government licensing of LDPC decoding technology (Verilog source) is available. What is needed here is the development of the following:

- FPGA simulations of all 10 CCSDS LDPC codes down to a bit error rate of $1e^{-10}$ and a codeword error rate of $1e^{-9}$, and with a goal of identifying the "error floor" of each of the codes.
- Improved decoding algorithms that reduce the observed error floor. It is known that observed error floors for these codes are a characteristic of standard belief propagation (BP) decoding, and not because of the minimum distance properties of the codes. Variations of standard decoding may not be susceptible to the same trapping sets, thereby improving error floor performance. These methods include (a) optimally decoding the 4-cycles, (b) converting 4-cycles to equivalent trees, (c) BP decoding with damping, and (d) using min in place of min* in the later iterations of the decoder. These and other variations should be tested particularly on the k=1024, r=4/5 code, which is expected to exhibit the highest error floor.

The target is a finished product at TRL 5.

Data Compression

Development of a radiation-tolerant high-speed (over 100 Msamples/sec) lossless compression component conforming to CCSDS 121.0-B-1, "lossless data compression" (www.ccsds.org [12]) allowing input dynamic range to over 24-bit/sample. Options should include user-supplied external predictor, as well as providing potential applications to hyper-spectral data by taking advantage of the spectral correlation in such data sets.

Development to TRL 5 is desired.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration and deliver a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

The proposer to this subtopic is advised that the products proposed may be included in a future small satellite flight opportunity. Please see the SMD Topic S4 on Small Satellites for details regarding those opportunities. If the proposer would like to have their proposal considered for flight in the small satellite program, the proposal should state such and recommend a pathway for that possibility.

Sub Topics:

Antenna Technology Topic O1.02

NASA seeks advanced antenna systems in the following areas: phased array antennas; ground-based uplink antenna array designs; high-efficiency, miniature antennas; smart, reconfigurable antennas; large aperture inflatable/deployable antennas; antenna adaptive beam correction with pointing control; parallelized numerical solvers for antenna modeling and design; and communication antennas with improved performance.

Phased Array Antennas

High performance phased array antennas are needed for (1) high-data rate communication and (2) remote sensing applications. The frequencies of interest are P-, L-, C-, S-, X-, Ku-, Ka-, and W-band. Potential communications applications include: lunar and planetary exploration, landers, probes, Lunar Relay Satellites, lunar rovers, lunar habitats, lunar surface EVA, suborbital vehicles, sounding rockets, balloons, unmanned aerial vehicles (UAV's), TDRSS communication, and expendable launch vehicles (ELV's). Potential remote sensing applications include: radiometers, passive radar interferometer platforms, and synthetic aperture radar (SAR) platforms for planetary science.

Multi-band phased array technology such as S- and Ka-band phased array antennas, which can dynamically reconfigure active element coupling in order to operate in either band as required in order to maximize flexibility, efficiency and minimize the mass of hardware delivered to the moon for lunar surface system operations, are of interest. The goal is to maximize flexibility and capability to share lunar communications infrastructure and therefore minimize mass of radio components that must be delivered to the lunar surface.

There is also a high interest in developing phased array antennas for space-based range applications to accommodate dynamic maneuvers.

The arrays are required to be aerodynamic or conformal in shape for sounding rockets, UAV's, and expendable platforms. They must also be able to withstand the launch environment. The balloon vehicles communicate primarily with TDRS and can tolerate a wide range of mechanical dimensions.

The main challenges/tradeoffs to be addressed are achieving low mass, low cost, high power efficiency, thermal stability of active array electronics, and coverage area (i.e., highly steerable arrays). Active arrays with features such as T/R module self-calibration for thermal stability, true time delay (TTD), low-cost highly-integrated MMIC-based T/R modules (e.g., SiGe/GaAs technology), multiple beam-forming capability, low-loss feeds for radiometer applications are also of interest. Advances in digital beam-forming techniques, including those based on superconducting digital signal processing methods, are also desirable.

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. Some concepts currently under consideration are the development of medium-size (12-m class) antennas (hundreds of them are expected to be required) for transmit/receive (Tx/Rx) ground-based arrays. 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. The uplink frequency will be in the 7.1-8.6 GHz range (X-band) in the near term, and may be at higher frequencies in the future; it will likely carry digital modulation at rates from 10 kbps to 30 Mbps. An EIRP of at least 500 GW is required, and some applications contemplate an EIRP as high as 10 TW. A major challenge in the uplink array design is minimizing the life-cycle cost of an array.

Other challenges for ground-based antennas include the development of low cost, reliable components for critical antenna systems; advanced, ultra-phase-stable electronics, and phase calibration techniques; improved understanding of atmospheric effects on signal coherence; and integrated low-noise receiver-transmitter technology. Phase calibration techniques needed to ensure coherent addition of the signals from individual antennas at the spacecraft are also required. It is important to understand whether space-based techniques are required or if ground-based techniques are adequate. In general, a target spacecraft in deep space cannot be used for calibration because of the long round-trip communication delay.

Design of ultra-phase-stable electronics to maintain the relative phase among antennas is also needed. These will minimize the need for continuous, extensive and/or disruptive calibrations. A primary related effort currently underway is understanding the effect of the medium (primarily the Earth's troposphere) on the coherence of the signals at the target spacecraft. Generally, turbulence in the medium tends to disrupt the coherence in a way that is time-dependent and site-dependent. A quantitative understanding of these effects is needed. Consequently, techniques for integrating a very low-noise, cryogenically cooled receiver with a medium power (1-200 W) transmitter, are desired. If transmitters and receivers are combined on the same antenna, the performance of each should be compromised as little as possible, and the low cost and high reliability should be maintained.

High-Efficiency, Miniature Antennas

High efficiency, low-cost, low-mass, broadband or dual-band miniaturized antennas (UHF or X-band) that radiate circular polarization with full hemispherical coverage are desirable. These antennas must be able to withstand launch and re-entry environments and must be low profile/conformal.

The emergence of frequency-agile radios increases emphasis of antenna capable of bidirectional communications across multiple bands. Accordingly, emphasis on small size, high efficiency and low cost of ownership is desirable. Miniaturization of L-, S-, and C- band for Micro Air Vehicles is also of interest.

Miniaturized antennas that are wearable or can be highly integrated into the host structure/entity, are also desirable. Examples include EVA's space suits made with textile antennas, fractal antennas, or visor mounted antennas. These miniaturized antennas should also be multi-directional to support astronaut mobility, support multi-band operation, and/or possess a broad bandwidth. Antennas should be low/self-powered, small, and efficient, and compatible with communication equipment that can provide high data rate coverage at short ranges (~1.5 - 3 km, horizon for the Moon for EVA).

Smart, Reconfigurable Antennas

NASA is interested in smart, reconfigurable antennas for applications in lunar and planetary operations. 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 lunar and planetary surface exploration (e.g., rovers, pressurized surface vehicles, habitats, etc.). Desirable features include multi-beam operation to support connectivity to different communication nodes on lunar and planetary surfaces, or in support of communication links for satellite relays around planetary orbits. The antenna shall also be highly directive, multi-frequency and compatible with the Multiple Input Multiple Output (MIMO) concept.

Large Aperture Inflatable/Deployable Antennas

Large aperture inflatable/deployable membrane antennas to significantly reduce stowage volume (packaging)

efficiencies as high as 50:1), provide high deployment reliability, and significantly reduced mass density (i.e.,

Novel materials (including memory matrix materials), low fabrication costs and deployment and construction methods using low emissive materials to enable passive microwave instrument application are also beneficial. Structural health monitoring systems are needed to support pre-flight integration, and test activities to determine in-flight system health, are of interest. The ability to incorporate structural considerations for mission applications is also desired (e.g., aero-braking for deep space planetary missions).

Membrane materials for large inflatable membrane antennas for remote sensing applications for earth and planetary science missions are of particular interest to the Science Mission Directorate. The current state of the art for mechanical deployable antennas is reaching limits on packaging efficiencies. Reflectors manufactured from polymer films could enable greater packaging efficiencies due to their low mass, high packaging efficiencies, solar radiation resistance, and cryogenic flexibility. However, most polymer films, including polyimide polymer films, have many challenges that limit their usefulness in practical space applications. Active membrane control system concepts, developed to reduce shape errors, often add unwanted bulk and mass to the antenna system. While other concepts will be entertained, specific membrane material technology innovations of interest are listed below:

- Polymer membrane (0.5 mil to 2.0 mil) material exhibiting zero or near-zero Coefficient of Thermal Expansion (CTE).
- Polymer membrane material exhibiting durability to the space environment, including atomic oxygen, VUV, solar particulate radiation, and temperature extremes.
- Thin film deployment methods that deploy the antenna surface substantially free of wrinkles.
- Innovative intrinsically electroactive polymer membrane actuation mechanisms that can be used to shape-correct the antenna surface.

Additionally, composite materials for large deployable antenna reflector structures for remote sensing applications for earth and planetary science missions with high specific stiffness composite materials that can be packed compactly and deployed multiple times for ground evaluation of the antenna structure prior to launch and deployment in space are of interest. Investigators should consider materials that can be folded and deployed on the order of 5 to 10 times with up to 180 degree bends that retain their structural integrity and shape accuracy upon final deployment. The deployment of these materials should require low energy. Rigidizable materials (Shape Memory Polymers, Shape Memory Composites, UV Activated Composites, etc.) could be considered to obtain the appropriate structural stiffness and post-deployment precision.

Prospective proposers are advised to review Subtopic S1.02, Active Microwave Technologies, for additional remote sensing applications needs, and indicate applicability in their proposal(s).

Antenna Adaptive Beam Correction with Pointing Control

Antenna adaptive beam correction with pointing control that can provide spacecraft knowledge with fine beam pointing with sub-milliradian precision (e.g.,

Parallelized Numerical Solvers for Antenna Modeling/Design

Development of full 3-D electromagnetic (EM) solvers that take advantage of new software engineering approaches (e.g., object oriented programming) and parallel computing resources for fast and accurate modeling/design of antennas, antennas with feed structures, and antennas in multi-path environment are of interest. Numerical solvers offering fast and accurate synthesis via search algorithms (e.g., genetic algorithm) of patch arrays and waveguide slot arrays, to reduce design time, are also of interest. All solvers must aim toward experimental validation of actual antenna concept being simulated.

Communication Antennas with Improved Performance

High performance, low-cost antennas are needed for a variety of missions for communicating with TDRSS, GPS (L1, L2, and L5 bands), or the Deep Space Network (DSN). The frequency bands of interest are L-, S-, X-, Ku-, and Ka-band. Antenna concepts that offer significant improvement in cost and performance (e.g., mass, gain, efficiency, VSWR, axial ratio, bandwidth, power handling, vibration tolerance, etc.) over existing off-the-shelf antennas would be of interest. Novel isoflux antennas at S- and X-band would also be of interest. Antennas must be able to withstand launch environments.

Deliverables and Development Timeline

After a possible Phase 3 development activity, these technologies are expected to ready for insertion at TRL 6 by 2015. Therefore a TRL progression from an entry TRL of 1 - 2 for Phase 1 in January 2010 followed by an exit TRL of 3 - 4 after Phase 2 is reasonable.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward Phase 2 hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

Phase 1 Deliverables

A final report containing optimal design for the technology concept including feasibility of concept and a detailed path towards Phase 2 hardware and/or software demonstration. The report shall also provide options for potential Phase 3 funding from other government agencies (OGA).

Phase 2 Deliverables

A working proof-of-concept demonstrated and delivered to NASA for testing and verification.

Sub Topics:

Reconfigurable/Reprogrammable Communication Systems Topic O1.03

NASA seeks novel approaches in reconfigurable, reprogrammable transceiver systems for Space Operations, Exploration, Science, and Aeronautics research. Exploration of Lunar and Mars environments will require advancements in radio communication systems to manage the demands of the harsh space environment on space electronics, maintain flexibility and adaptability to changing needs and requirements, and provide flexibility and survivability due to increased mission durations. NASA missions can have vastly different transceiver requirements

(e.g., 1's to 10's Mbps at UHF- and S-band frequency bands up to 10's to 1000's Mbps at X- and Ka-band frequency bands.) and available resources depending on the science objective, operating environment, and spacecraft resources. For example, deep space missions are often power constrained; operating over large distances, and subsequently have lower data transmission rates when compared to near-Earth or near planetary satellites. These requirements and resource limitations are known prior to launch; therefore, the scalability feature can be used to maximize transceiver efficiency while minimizing resources consumed. Larger platforms such as vehicles or relay spacecraft may provide more resources but may also be expected to perform more complex functions or support multiple and simultaneous communication links to a diverse set of assets.

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. Topics of interest include the development of software defined radios or radio subsystems which demonstrate reconfigurability, flexibility, reduced power consumption of digital signal processing systems, increased performance and bandwidth, reduced software qualification cost, and error detection and mitigation technologies. Complex reconfigurable systems will provide multiple channel and multiple and simultaneous waveforms. Areas of interest to develop and/or demonstrate are as follows:

- Enable advancements in bandwidth capacity, reduced resource consumption, or adherence to the Space Telecommunications Radio System (STRS) standard and open hardware and software interfaces. Techniques should include fault tolerant, reliable software execution, reprogrammable digital signal processing devices.
- Reconfigurable software and firmware which provide access control, authentication, and data integrity checks of the reconfiguration process including partial reconfiguration which allows simultaneous operation and upload of new waveforms or functions.
- Operator or automated reconfiguration or waveform load detection failure and the ability to provide access back to a known, reliable operational state. An automated restore capability ensures the system can revert to a baseline configuration, thereby avoiding permanent communications loss due to an errant reconfiguration process or logic upset.
- Develop dynamic or distributed on-board processing architectures to provide reconfigurability and processing capacity. For example, demonstrate technologies to enable a common processing system capacity for communications, science, and health monitoring.
- Adaptive modulation and waveform recognition techniques are desired to enable transceivers to exchange waveforms with other assets automatically or through ground control.
- Low overhead, low complexity hardware and software architectures to enable hardware or software component or design reuse (e.g., software portability) that demonstrates cost or time savings. Emphasis should be on the application of open standards architecture to facilitate interoperability among different vendors to minimize the operational impact of upgrading hardware and software components.
- Software tools or tool chain methodologies to enable both design and software modeling and code reuse and advancements in optimized code generation for digital signal processing systems.
- Use of reconfigurable logic devices in software defined radios is expected to increase in the future to provide reconfigurability and on-orbit flexibility for waveforms and applications. As the densities of these devices continue to increase and feature size decreases, the susceptibility of the electronics to single event effects also increases. Novel approaches to mitigate single event effects in reconfigurable logic caused by charged particles are sought to improve reliability. New methods should show advancements in reduced cost, power consumption or complexity compared to traditional approaches such as voting schemes and scrubbing.

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- Techniques and implementations to provide a core capability within the software defined radio in the event of failure or disruption of the primary waveform and/or system hardware. Communication loss should be detected and core capability (e.g., "gold" waveform code) automatically executed to provide access control and restore operation.
 - Innovative solutions to software defined radio implementations that reduce power consumption and mass. Solutions should enable future hardware scalability among different mission classes (e.g., low rate deep space to moderate or high rate near planetary, or relay spacecraft) and should promote modularity and common, open interfaces.
 - In component technology, advancements in analog-to-digital converters or digital-to-analog converters to increase sampling and resolution capabilities, novel techniques to increase memory densities, and advancements in processing and reconfigurable logic technology each reducing power consumption and improving performance in harsh space environments.
 - Development of radio technology that allows the incorporation of Space Network (SN) waveforms and candidate Lunar Surface System (LSS) wideband waveforms such as 802.11 and 802.16 into a single multimode radio capable of supporting simultaneous communications with space and lunar network assets. Development and implementation of direct RF to digital technologies that are currently emerging and can offer significant improvements in the flexibility of software or multi-mode radios. The goal is to maximize flexibility and capability to share lunar communications infrastructure and therefore minimize mass of radio components that must be delivered to the lunar surface.
 - Small, lightweight all-digital reconfigurable radios and transceivers that eliminate analog front ends that operate across multiple bands, are sought for applications that involve network enhanced telemetry, leading towards adaptive and cognitive radio applications. Application of reconfigurable systems in airborne and terrestrial systems is of interest.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward Phase 2 hardware and software demonstration and delivering a hardware demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

Sub Topics:

Miniaturized Digital EVA Radio Topic O1.04

As NASA embarks upon deep space human exploration, the next-generation EVA radio will be a pivotal technology and integral part of lunar surface systems success. It will facilitate surface operations, enable crew mobility, and support point to multi-point communications across rovers, landers, habitat, and other astronauts. Driven by Communications, Command, Control, and Information (C3I) interoperability, tight power budgets, and extreme miniaturization, this mobile radio platform must be power efficient and highly adaptive. With a scant EVA radio power budget of less than four watts, the S-band (2.4 - 2.483 GHz) adaptive radio must deliver voice, telemetry, and high-definition motion imagery transmissions. To surmount interference, the radio must support frequency diversity over the specified S-band spectrum of 2.4 - 2.483 Ghz. During nominal operations, it is designed to operate with a mobile ad hoc network (MANET) so the coverage for communications can be extended indefinitely with node additions. It will communicate to fixed and mobile nodes, including lunar base stations, landers, habitats, rovers, and other astronauts. Therefore, it must support multiple bandwidths, waveforms, and energy profiles. To achieve the overarching communication goals of small form factor, ultra-power , and reconfigurability, NASA needs to extend the state-of-the art in two key areas:

Tunable RF Front End and Transceiver

The major impetus behind the MEMS technology stems from compactness which leads to lower power dissipation, higher levels of integration, lower weight, volume, and cost. To shrink form factor and enable efficient surface operations, one of the cornerstone radio components of this radio is the tunable filter. Recent advances in RF MEMS filters and resonator technology have permitted very high quality factors (>1000) at GHz frequencies. Achieving high and excellent tuning range (>2:1) to bandwidth ratio without cryogenic cooling is now viable for the S-band frequency. For reliability, the tunable filter should employ a contact-less tuning scheme.

Also, a new class of MEMS-based frequency synthesizers offers dramatic reduction in noise, power, and form factor. One should leverage emerging microscale resonator technologies to the maximum extent. Low phase noise synthesizers running at ultra low power levels are viable using high Q resonator technologies MEMS resonators-based phase lock loop offers compelling power and noise performance enhancements.

Power-Aware Processing

To support QoS of different applications, it's not enough to optimize power at design time, but dynamic power management must be employed to ensure power efficiency. To maximum power efficiency, it must be able to adjust power and update rates to suit diverse missions. Users should be able to specify Quality of Service (QoS) for different data streams. The radio must have the capability to scale power, select the optimum mode of operation, and minimum energy profile. During low-rate-processing intensive modes, including local processing and compression of telemetry data and voice, highly energy-efficient low-voltage, low-performance modes must be used. For high-rate-processing intensive modes, like advance signal encoding of high motion imagery, medium performance modes must be used; and during active communication modes (which may have a low duty-cycle), ultra-high-performance modes must be used. Accordingly, the digital platform must be highly agile and use-case aware to continuously minimize energy. Below are the desirable technology features.

Bear in mind, research should be conducted to demonstrate technical feasibility during Phase 1 and to show a path towards a hardware and software demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

Phase 1 Deliverables

Conduct design trade analyses between power, performance, and flexibility. Estimate mass, volume, power, max/min range, and data rates for dynamic quality of service- voice, telemetry, video- standard and high definition TV at S-band (2.4 - 2.483 GHz), backed with analyses and simulation to ensure achievable performance and power goals.

Develop a promising MEMS-based system-on-chip radio design with the following features:

- **Variation-tolerant, performance-scalable architectures:** Hardware must sense its own limitation at a dynamically varying, performance-driven optimal energy operating point, and reconfigure accordingly. If variability is stressed at the low-voltage operating point, redundant hardware should be used to improve reliability; if throughput is stressed at the high-performance operating point, redundant hardware should be used to increase parallelism.
- **Highly agile platform components (SRAM and logic):** Circuits should use functionality assists, including

selective biasing, leakage-control, routine resources, etc., that get engaged dynamically depending on the operating point.

- **Energy-aware algorithms for adaptive hardware:** Algorithms must be aware of the different hardware operating-points and associated architecture. For instance, during low-power modes targeting voice and data (for telemetry), occasional high through-put applications (like high motion imagery) should dynamically switch to algorithms employing extreme parallelism in order to support a minimum operating voltage.
- **Extreme power converters:** To minimize off-chip components, DC-DC converters should use a single reconfigurable architecture that efficiently delivers load powers ranging from micro-Watts, at low-voltages, to Watts, at high voltages.
- **High performance ultra-low power ADCs:** Exploit novel ADCs with sampling frequencies in tunable multi GHz range (preferable double digits). Variable resolution up to 20 bits or higher with ultra-low power jitters for finer resolutions at higher bits and comparators managed for higher bits with minimum power overheads. A high sampling rate is desirable. SNR optimizations and efficient signal recovery demonstration is a requirement for validating ADC capabilities.
- **Modularity and extensibility:** Enabling platform must support open architecture and accommodate rapid upgrades, multiple protocols, new technology advances, complete re-configurability of functionality, and evolution of lunar communications and network infrastructure.

One significant prerequisite to Phase 2 is the development of most promising MEMS-based transceiver system-on-chip (SoC) architecture. The offeror must demonstrate the ability to achieve significant advantage in compactness and ensure power efficiency and reliability.

Phase 2 Deliverables

Develop a reliable, intelligent, and power-efficient MEMS-based EVA digital radio prototype unit, demonstrating robust and dynamic power management. The miniaturized radio technology must reach TRL=5 at the end of Phase 2.

Demonstrate RF performance and power consumption of less than four watts, delivering voice, telemetry, and standard and high-definition video motion imagery at 2.4 - 2.483 GHz (S-band). With power constraints of under four watts, performance and reliability must be assured for multiple bandwidths and data transmissions of telemetry, voice, and high-rate video.

Sub Topics:

Transformational Communications Technology Topic O1.05

NASA seeks revolutionary, highly innovative, transformational communications technologies that have the potential to enable order of magnitude performance improvements for space operations, exploration systems, and science mission applications.

Research emphasizing both nearer-term and far-term technologies is focused (but not limited to) in the following areas:

Near-Term Focus Areas:

- Develop novel techniques to reduce the size, weight, and power (SWAP) of communications transceivers 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. Great demands will be placed on these communication transceivers to assure crew safety and robustness in harsh deep-space environments for long duration missions. Investigate and demonstrate novel RF communication technologies to alleviate the demanding requirements on analog to digital converters (ADCs) and digital signal processors (DSPs). For software-defined radios, such requirements can result in high ADC power consumption, large form factor, and expensive components, which can pose problems for power and weight constrained deep space missions.
- Significant component-level technical advances are needed in the area of UHF/VHF filter technologies. Novel, smaller form factor, lower cost, higher performance, and lower weight than existing devices are to be demonstrated employing new technologies such as MEMS resonators (e.g., electrostatic, piezoelectric) and tunable dielectrics. Filter solutions that offer a bandwidth tunability or reconfigurability and filter banks are also sought. Fractional bandwidths of 0.1% to greater than 2% are of interest, where for narrower bandwidths, operating stability across temperature is necessary. At the conclusion of Phase 1, proposers should clearly delineate, through a combination of theoretical analysis and demonstrated prototypes, that the proposed solution can achieve better than 3 dB of insertion loss, better than 70 dB of rejection, less than 1 dB of ripple, small shape factors, power handling greater than +20 dBm, VSWR less than 2, and robust operation in a harsh space environment. Phase 2 will leverage the analysis and prototypes developed in Phase 1 to meet to the specifications for space-based communication links and will deliver a demonstration unit of the proposed technology for testing. Phase 2 will also evaluate component reliability to ensure robust operation across the harsh temperature, vibration, shock, and other conditions encountered in space operation.
- NASA seeks to integrate RFID, antenna, flexible organic material (e.g., Liquid-crystal polymer with constant dielectric properties from 1-110 GHz) and energy-scavenging technologies to develop ultra-low-cost enhanced range sensor surface nodes. This new generation of conformal wireless nodes based on the utilization of UHF semi-passive RFIDs on beacons and astronaut suits would enable the development of robust communication links through the implementation of very-large-scale ad-hoc networks for rugged and/or emergency response environments. Many technical challenges are associated with the development and enhancement of localization and precise tracking of assets for long-duration missions. To leverage terrain-adaptive navigation solutions, inventory tracking, and astronaut body area network applications, several quantum leap technologies including semi-passive RFID-enabled wearable tags and multi-hopping inflatable beacons need to be advanced to demonstrate ranges in excess of 200 m. Astronauts wearing at least 4 miniaturized ultra-low-power inertial sensors at spacings below the operation wavelength of 2.4GHz (EVA) could enable RFID-enabled inflatable beacons for accurate tracking and navigation. The capability of state-of-the-art wireless systems to provide precise timing/time-tracking with nanosecond accuracy coupled with ultra-low-power wearable inertial sensors and low-power multi-hopping algorithms between beacon-mounted and astronaut-mounted RFIDs can enable true mobility location awareness in ranges in excess of 500/1000 meters. Low power beacons (assuming a duty cycle of 5-10 %) can be solar powered and fabricated in an inflatable triangular shape. It has already been proven that some solar-powered "semi-passive" RFID's with a single-hop range of 100+m consumes only 80 microwatts and can be improved by a factor of 3 to 5. Yet, to have a practical ad-hoc beacon network with effective beacon-to-beacon and beacon-to-RFID ranges in excess of 1 km, with beacon power levels between 20 microwatts to 5 milliwatts, various technical challenges need to be addressed: solar panels should achieve efficiencies greater than 50% and should be easily printed as a substrate of the printed beacon antennas, the electronics should operate in sub-threshold domain, the IC power consumption should be below 20 microwatts, and the antenna should feature at least two different frequencies for redundancy. Solutions should consider employing power scavenging merging dynamic/kinetic energy from the astronaut motion (mounted on boots), solar energy (through thin-films on uniform), thermal/vibration energy (through inkjet-printed nanotube-based wearable textiles), thus minimizing the use of portable battery. Phase 1 effort

should introduce an "ad-hoc" wearable network of 3-5 RFID-enabled wearable inertial sensors that could provide voice-level communication with inflatable beacons with total power consumption below 500 microwatts. Up to 5 hops with 300m + hop will be investigated for enhanced range wireless links for 433 MHz, 900MHz and integration. The prototype should include 5+ wearable tags and 5+ inflatable beacons and 3 test frequencies. Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 multi-tag, multi-scenario hardware demonstration prototype unit.

Far-Term Focus Areas:

- The promise of high-performance, multi-functional, nanostructured materials has led to intense interest in developing them for applications for human spaceflight and exploration. These materials (notably single wall carbon nanotubes) exhibit extraordinary mechanical, electrical, and thermal properties at the nanoscale and possess exceptionally high surface area. The development of nano-scale communication devices and systems including nano-antennas, nano-transceivers, etc. are of interest for nano-spacecraft applications.
- Quantum entanglement or 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.
- Innovative approaches to use of medium to high frequency (300 KHz-30MHz) bands for applications benefiting future lunar missions. Concepts, studies, development of key technologies are needed to perform non-line-of-sight communication for potential use on the surface of the Moon. 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 lunar surface links.
- Ultra-wideband (UWB) or impulse radio wireless communications, navigation and tracking for lunar applications. UWB has the capability of pervasive wireless transmission of data, video, etc., very fine time resolution, low power spectral density, and resistance to multipath. Device, component and/or subsystems that can enable use of UWB for space-based applications are sought, including but not limited to: transceivers, highly efficient antennas; array beamformers; space-time processing techniques; accurate timing generators for sub-nanosecond pulse widths; matched filters; channel estimators; low power, high bandwidth A/D converters with extended time sampling.

Sub Topics:

Long Range Optical Telecommunications Topic O1.06

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

- **Systems:** 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.
- **Small lightweight two-axis gimbals:** Approximately 1 kg in mass capable to actuating payload mass of approximately 6 kg at rates up to 5 degrees/second, with less than 30 micro-radian rms error and blind-

pointing accuracy of less than 35 micro-radian. Assume that the payload is shaped as an 8-cm diameter cylinder, 30-cm long, with uniformly distributed mass. 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 (
- **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 (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 Radiation levels of at least 100 Mrad (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 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 ~\$1.5M 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 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.

Research should be conducted to convincingly prove technical feasibility during Phase 1, with clear pathways to demonstrating and delivering functional hardware, meeting all objectives and specifications, in Phase 2.

Sub Topics:

Long Range Space RF Telecommunications Topic O1.07

Solicitation Summary

This solicitation seeks to develop innovative long-range RF telecommunications technologies supporting the needs of space missions.

Purpose (based on NASA needs) and current state-of-the-art

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 about 2 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%.

Specifications and Requirements

- 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 large linear phase modulation (above 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%) 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 techniques and/or wide band-gap semiconductor devices at X-band (8.4 GHz) and Ka-band (26 GHz, 32 GHz and 38 GHz);
- Epitaxial GaN films with threading dislocations less than 106 per cm² for use in space qualified wide band-gap semiconductor devices at X- and Ka-band;
- 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);
- SSPAs, modulators and MMICs for 26 GHz Ka-band (lunar communication);
- Improved integrated non-linear amplifier/modulator designs that reduce crest-factor impacts and significantly enhance the efficiency of high peak-to-average power ratio waveforms, such as 802.11 and 802.16;
- TWTAs operating at millimeter wave frequencies (e.g. W-Band) and at data rates of 10 Gbps or higher;
- Ultra low-noise amplifiers (MMICs or hybrid) for RF front-ends (
- MEMS-based RF switches and photonic control devices needed for use in reconfigurable antennas, phase shifters, amplifiers, oscillators, and in-flight reconfigurable filters. Frequencies of interest include VHF, UHF, L-, S-, X-, Ka-, V-band (60 GHz) and W-band (94 GHz). Of particular interest is Ka-band from 25.5 - 27 GHz and 31.5 - 34 GHz.

Phase 1 Deliverables

Feasibility study, including simulations and measurements, proving the proposed approach to develop a given

product. Verification matrix of measurements to be performed at the end of Phase 2, along with specific quantitative pass-fail ranges for each quantity listed.

Phase 2 Deliverables

Working engineering model of proposed product, along with full report of on development and measurements, including populated verification matrix from Phase 1.

Sub Topics:

Lunar Surface Communication Networks and Orbit Access Links Topic O1.08

This solicitation seeks to develop a highly robust, bidirectional, and disruption-tolerant communications network for the lunar surface and lunar orbital access links. Exploration of lunar and planetary surfaces will require short-range (~1.6 km line-of sight, ~5.6 km non-line-of-sight) bi-directional, often highly asymmetric, and robust multiple-point links to provide on-demand, disruption and delay-tolerant, and autonomous interconnection among surface-based assets. Minimization of communication asset scheduling, and other ground operation support, is highly desirable. Some of the nodes will be fixed, such as base stations and relays to orbital assets, and some transportable, such as rovers and humans. The ability to meet the demanding environment presented by lunar and planetary surfaces will encompass the development and integration of a number of communication and networking technologies and protocols.

NASA lunar surface networks will be dynamic in nature, and required to deliver multiple data flows with different priorities (operational voice, command/control, telemetry, various qualities of video flows, and others). Bandwidth and power efficient approaches to mobile ad hoc networks are desired. Quality of Service (QoS) algorithms in a Mobile Ad hoc NETWORK (MANET) setting will need to be developed and tailored to NASA mission specific needs and for the lunar surface environment. Exploitation of delay/disruption tolerant network (DTN) technology to maximize autonomy of the communication infrastructure and to minimize demands on channel capacity is of significant interest. Advantages and disadvantages associated with parallel DTN and IP networks, and a competing DTN-over-IP network architecture, should be considered. Possible associated considerations include routing, security, and QoS.

These lunar and planetary surface networks will need to seamlessly interface with communications access terminals and orbiting relays that also can provide autonomous connectivity to Earth based assets. The access link communications system will encompass the development and integration of a number of communications and networking technologies and protocols to meet the stringent demands of continuous interoperable communications. Human exploration, therefore, requires the development of innovative communication protocols that exploit persistent storage on mobile and stationary nodes to ensure timely and reliable delivery of data even when no stable end-to-end paths exist. Solutions must exploit stability when it exists to nearly approximate the performance of conventional MANET protocols. The capability of the network to provide infrastructure-based position determination and navigation is of interest to NASA, especially when coverage issues arise and/or orbiter access links are unavailable. The extent to which the network can support localization of mobile nodes should be addressed, and network architecture options that could further support navigation should be identified.

Frequency bands of interest are UHF (401 - 402 MHz, 25 kHz bandwidth), S-band (2.4 - 2.483 GHz), and Ka-band (22.55 - 23.55 GHz). Existing commercial standards for the PHY and MAC layers should be leveraged to the extent possible while meeting other requirements, with modifications considered when necessary. Results from NASA's Lunar Architecture Team, as well as technology trade studies performed for NASA's Constellation Systems, should

be referenced for input regarding data flows, coverage, network requirements, etc. EVA study results can be found at:

EVA Technology Development path loss study: <http://gltrs.grc.nasa.gov/reports/2007/TM-2007-214825.pdf> [13]

Specific Subtopic Capabilities to Address This Year

This year's call intends to focus innovations in 4 key areas. Participants should focus their proposed innovation in one or more of these key areas:

- Differentiated services and QoS support in dynamic wireless networks when safety-of-life and data flows critical to the mission are traversing the network.
- DTN prototype protocol development and demonstration in an emulated operational network.
- Secure data transfers over mobile, dynamic wireless networks with potential interferers and/or interceptors.
- Position determination and navigation based novel uses of the network infrastructure (e.g. utilizing radiometric information from the network signaling).

Proposal should address the following:

- Network traffic models
- Network architecture (both hardware and software)
- Spectrum usage
- Security plan (if the proposal deals with particular innovations in this area)
- Identification of software and/or hardware technologies common to networking components that will have the largest impact on size, weight, and power reduction while not compromising the goals of the network architecture as listed above.

Phase 1 Deliverables

A trade analysis identifying novel software and/or hardware technologies common to networking components that will have the largest impact on size, weight, and power reduction while not compromising the goals of the network architecture is the most important aspect of the Phase 1 deliverable. It is not reasonable to expect that all issues and technologies concerning the network architecture proposed will be developed under a Phase 2 contract. However, the proposer should identify and rank novel hardware/software components based on size/weight/power reduction that will enable the proposed network architecture. The proposer should also identify how they are uniquely qualified to develop the novel technologies to products beneficial to NASA, DoD, and perhaps commercial interests.

The Phase 1 proposal should clearly state the assumptions, proposed network architecture, and innovations regarding the 4 key areas mentioned above.

Phase 2 Deliverables

The novel software and/or hardware component identified in Phase 1 will be developed to a state in which it may be demonstrated and the feasibility of the approach on an actual platform may be quantitatively evaluated by NASA testing at the completion of the Phase 2 contract. (TRL 4 or better).

Sub Topics:

Software for Space Communications Infrastructure Operations Topic O1.09

New technology is sought to improve resource optimization and the user interface of planning and scheduling tools for NASA's Space Communications Infrastructure. The software created should have a commercialization approach with the new modules fitting into an existing or in development planning and scheduling tool.

Purpose (based on NASA needs) and the current state of the art:

The current infrastructure for NASA Space Communications provides services for near-Earth spacecraft and deep space planetary missions. The infrastructure assets include the Deep Space Network (DSN), the Ground Network (GN), and the Space Network (SN). Recent planning for the Vision for Space Exploration (VSE) for human exploration to the Moon and beyond as well as maintaining vibrant space and Earth science programs resulted in a new concept of the communications architecture. The future communications architecture will evolve from the present legacy assets and with addition of new assets.

NASA seeks automation technologies that will facilitate scheduling of oversubscribed communications resources to support: (1) Increased numbers of missions and customers; (2) Increased number and complexity of constraints (as required by new antenna types); and (3) decreased operations budgets (both core communications network operations and mission side operations budgets).

Core Capabilities:

Intelligent Assistants

In order to automate the user's provision of requirements and refinement of the schedule, "intelligent assistant" software should manage the user interface. Assistants should streamline access and modification of requirement and schedule information. By modeling the user, this software can adjust the level of autonomy enabling decisions to be made by the user or the automated system. Assistants should try to minimize user involvement without making decisions the user would prefer to make. The assistants should adapt to the user by learning their control preferences. This technology should apply to local/centralized and collaborative scheduling.

In a conflict-aware scheduling system (especially in a collaborative scheduling environment), conflicts are prevalent. With the concept of one big schedule from the beginning of time, real time, to the end of time, resolving conflicts become a difficult task especially since resolving conflicts in a local sense may affect the global schedule. Therefore, an intelligent assistant may provide decision support to the system or the users to assist conflict resolution. This may involve a set of rules combining with certain local/global optimization to generate a list of options for the system or users to choose from.

Resource Optimization

The goal of schedule optimization is to produce allocations that yield the best objectives. These may include maximizing DSN utilization, minimizing loss of desired tracking time, and optimizing project satisfaction. Each project may have their own definition of satisfaction such as maximal science data returned, maximal tracking time, best allocation of the day/week, etc. The difficulty is that we may not satisfy all of these objectives during the optimization process. Obviously, optimal solution for one objective may produce worse results for the other objectives. One possible solution is to map all of these objectives to an overall system goal. This mapping is normally non-linear. Technology needs to be developed for this non-linear mapping for scoring in addition to regular optimization approaches.

Optional Capabilities:

Multiple Agents

In an environment where all system variables can be controlled by a single controller, an optimal solution for the objective function can be achieved by finding the right set of variables. In a collaborative environment with multiple decision makers where each decision maker can only control a subset of the variables, modeling and optimization become a very complex issue. In the proposed collaborative scheduling approach, there are many users/agents that will control their own allocations with interaction with the others. How we model their interactions and define system policy so the interaction can achieve the overall system goal is an important topic. The approach for multiple decision-maker collaboration has been studied in the area of Game Theory. The applications cover many areas including economics and engineering. The major solutions include Pareto, Nash, and Stackelberg. There are many new research areas including incentive control, collaborative control, Ordinal Games, etc. Note that intelligent assistants and multiple agents represent different points on the spectrum of automation. Current operations utilize primarily manual collaborative scheduling, intelligent assistants would enhance users ability to participate in this process and intelligent agents could more automate individual customers scheduling. Ideally, proposed intelligent assistants and distributed agents would also be able to represent customers who do not wish to expose their general preferences and constraints.

A start for reference material on this subtopic may be found at the following:

<http://ai.jpl.nasa.gov> [14] in the publications area;

<http://scp.gsfc.nasa.gov/gn/gnusersguide3.pdf> [15], NASA Ground Network User's Guide, Chapter 9 Scheduling; and

<http://scp.gsfc.nasa.gov/tdrss/guide.html> [16], Space Network User's Guide, SpaceOps Conference Proceedings.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a

Phase 2 hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

Phase 1 Deliverables

Propose demonstration of Intelligent Assistants, Resource Optimization, or Multiple Agents on a number of communication asset allocation problem sets (involving dozens of missions, communications assets, and operational constraints). End Phase deliverable would include a detailed rationale for ROI in usage of said technology to communications asset allocation based on knowledge of current and future operations flows.

Phase 2 Deliverables

Demonstrate Intelligent Assistants, Resource Optimization, or Multiple Agents on actual or surrogate communication asset scheduling datasets. Deliverables would include use cases and some evidence of utility of deployment of developed technology.

The proposer to this subtopic is advised that the products proposed may be included in a future small satellite flight opportunity. Please see the SMD Topic S4 on Small Satellites for details regarding those opportunities. If the proposer would like to have their proposal considered for flight in the small satellite program, the proposal should state such and recommend a pathway for that possibility.

Sub Topics:

Automated Collection and Transfer of Launch Range Data (Surveillance/Intrusion, Weather) Topic O2.01
NASA is seeking innovative technologies for sensors and instrumentation technologies which expedite range clearance by providing real-time situational awareness for safe Range operations from processing to launch and recovery. These sensors and instruments are expected to operate, as a payload, on mobile or deployable Unmanned Aerial Systems (UAS), High Altitude Airships (HAA), buoys, etc. NASA is also seeking innovative technologies to remotely measure electric fields aloft in order to reduce the threat of destruction of a launch vehicle by rocket triggered lightning.

Purpose: NASA is embarking on a new era of space exploration with new launch vehicles and demands for availability to support launch times within hours of one another to ensure mission success. This availability requirement is allocated across the entire launch operations which includes the Range that provides clear corridor of land, air and sea for the vehicles to transit through, as they ascent or return. The current Range infrastructure is aging, labor intensive and independent, and would benefit from new sensors and instrumentation that improve the situational awareness (including weather) of those that are responsible for ensuring public safety, mission assurance and efficient operations.

To aid in this situational awareness the new sensors and instrumentation must be able to operate in the environment that takes advantage of mobile or deployable Unmanned Aerial Systems (UAS), High Altitude Airships (HAA), buoys, etc. Use of these vehicles as a platform is intended to increase the Ranges availability while reducing the cost of operations. Size, power, weight and stability of these systems, that operate on these platforms, will be a major constraint their use.

These sensors and instrumentation provide for the remote detection, recognition, and identification of persons and objects that have intruded into areas of the range that must be cleared in order to conduct safe launch operations. This would include a wide spectrum of optical, infrared, Radio Frequency (RF), and millimeter wave sensors for this purpose. In order to achieve accurate identification, time and position of intruding entities multiple sensors and instruments may be used, or combined through the use of neural networks and data fusion techniques. This will require the use of standards for communications, so that, data from individual sensors or instruments can be combined on a platform and processed on-board, or communicated to central location where a fused solution is processed.

The sensors, instrumentation and algorithms to remotely measure electric fields aloft will reduce the threat of destruction of launch vehicles during ascent by improving the prediction of potential lightning strikes to vehicles due to triggered lightning. Potential candidate technologies include new algorithms to take advantage of existing dual-polarized Doppler five-cm weather radar capability, or entirely new technologies for the remote sensing of electric fields. The ability to economically measure the incremental ballistic wind velocities along the predicted trajectory of launch vehicles at remote and evolving launch ranges at altitudes up to 100 kft via fixed and mobile LIDAR approaches is also highly desirable.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

Sub Topics:

Ground Test Facility Technologies Topic O2.02

NASA's Stennis Space Center (SSC) is interested with expanding its suite of test facility modeling tools as well as non-intrusive plume technologies that provide information on propulsion system health, the environments produced by the plumes and the effects of plumes and constituents on facilities and the environment.

Facility Modeling Tools and Methods

Developing and verifying test facilities is complex and expensive. The wide range of pressures, flow rates, and temperatures necessary for engine testing results in complex relationships and dynamics. It is not realistic to physically test each component and the component-to-component interaction in all states before designing a system. Currently, systems must be tuned after fabrication, requiring extensive testing and verification. Tools using computational methods to accurately model and predict system performance are required that integrate simple interfaces with detailed design and/or analysis software. SSC is interested in improving capabilities and methods to accurately predict dynamic responses for transient fluid structure interactions, convective, conductive, and radiant heat transfer for propellant systems, exhaust systems and other components used in rocket propulsion testing. Also of interest is the modeling and prediction of condensation, diffusion, stratification, and concentration gradients for

fluid mixtures commonly encountered in testing, such as propellants and purges.

Vacuum System Technologies

Stennis is constructing the new A3 test stand which is designed to test a very large (294,000 lbf thrust) cryogenic rocket engine at a simulated altitude of 100,000 feet. When the air in the engine test chamber is evacuated, the simulated altitude pressures inside the test chamber will be less than 0.20 PSIA. This will result in a very unique environment with extremely low pressures inside a very large chamber and ambient pressures outside this chamber. Due to the unique nature of this test facility, new technologies and measurement techniques will need to be developed to monitor and analyze this environment. These include but are not limited to instrument closeouts at vacuum pressures for hundreds of channels of instrumentation entering the chamber, new sealing technologies for large cryogenic piping entering this very large test cell wall to seal against this unique environment, material fatigue measurement and predictions, inspection techniques for the vacuum chamber structures and diffuser ducting, etc.

Component Design, Prediction and Modeling

Improved capabilities to predict and model the behavior of components (valves, check valves, chokes, etc.) during the facility design process are needed. This capability is required for modeling components in high pressure (to 12,000 psi), with flow rates up to several thousand lb/sec, in cryogenic environments and must address two-phase flows.

Challenges include: accurate, efficient, thermodynamic state models; cavitation models for propellant tanks, valve flows, and run lines; reduction in solution time; improved stability; acoustic interactions; fluid-structure interactions in internal flows.

Plume Environments Measurements

Advanced instrumentation and sensors to monitor the near field and far field effects and products of exhaust plumes. Examples are the levels of acoustic energy and thermal radiation and their interaction/coupling with test articles and facilities and measurements of the final exhaust species that will affect the environment.

Major challenge: Large scale engine plume dispersion modeling and validation.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract. Expected TRL range from 3 to 5.

Sub Topics:

Human Interface Systems and Technologies Topic O3.01

The focus of this sub topic is on the development of systems and technologies that advance TRL of man/machine interfaces for humans in space environments. Specific areas of interest include, but are not limited to, high fidelity inbound and outbound speech and audio systems along with data entry/data presentation devices, cameras, metabolic monitoring, health monitoring devices, interfaces that support human/robot interaction, high-level communications protocols and/or standardized interfaces for transmitting and receiving data related to human monitoring systems or human interface systems. Technologies and systems should resolve issues that are peculiar to human/machine interaction in the space environments or exploit unique features of the space environment or both. Interest exists for application to micro-gravity space suits, planetary space suits as well as space-based "shirtsleeve environments" such as onboard the ISS, shuttle or other crew modules. The particular focus area of the topic this year is on Advanced Data Entry systems.

Advanced Data Entry

Terrestrial user-interface devices for controlling portable processing equipment such as laptop computers typically rely on keyboard or touchpad input. Such devices are problematic in the space environment since a suited crewmember must interact with the processing equipment while wearing a pressurized glove. Speech recognition technologies have been proposed and investigated to provide a data entry capability for suited crewmembers. However, speech recognition technologies typically incur a high computational loading burden. Alternative methods and technologies for data entry are anticipated to result in significantly lower processing burden and therefore reduced Size Weight and Power (SWaP) and enhanced system reliability. Preference will be given to proposals that indicate the resulting system will have a low computational burden.

Currently, the main purpose of a suit's processing system is for providing life-support data-acquisition, monitoring, telemetry, and crewmember alerts. The traditional approach to interact with the EVA processing system is with suit-mounted toggle switches optimally sized for a gloved hand and located in the suit's chest area. NASA envisions future generations of suits to contain advanced communication, navigation, and information processing capabilities that will require better ways of interacting with the suited crewmember. It is likely that the processing unit(s) will be installed within the suit's backpack-mounted portable life support unit or in close proximity.

Crewmember usability and efficient operation are prime features of the next-generation input device. The device must operate robustly in the space environment and on the surface of remote planetary bodies. Devices must be tolerant of dust, vacuum, and radiation exposure. During Extra-Vehicular Activity (EVA), a suited crewmember needs to achieve as high a level of mobility as possible, so a suit-mounted computer-input device must not impede the movements of the suited crewmember or unduly burden the suit system with weight, volume, or electrical power constraints.

NASA is seeking systems, subsystems and/or technologies in support of improvements in suit-mounted computer system data entry user-interface devices. Devices or systems should allow the suited crewmember to control a computer processing system and provide text input and/or spatial indication accurately, at high speed, without little or no user fatigue. Possible interactions for data entry include, but are not limited to: inputting direction or positions (for navigation or robotic-aid purposes), inserting notes (e.g., field or experiment notes, images, labeling of images), and selecting/marketing items on lists (e.g., zooming, drilling down lists, scrolling through lists, moving items). Concepts may consider that provide solutions installed internally (within the pure-oxygen pressurized envelop of the suit), externally (mounted on the exterior of the suit), or a combination of the two:

Particular interest is in the areas of:

- Human interface devices that support manual control of mechanical devices such as rovers or tools;
- Chording keyboards, suit or glove mounted fabric keyboards or touch-pads;
- Techniques for routing wires or connections between the user interface device and the computer-processing unit;
- Techniques for routing the wires past bearings or avoidance of such.

Other technologies will be considered.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract. Preference will be given to proposals that support in-flight demonstration opportunities on the ISS at the completion of the Phase 2 contract.

Sub Topics:

Vehicle Integration and Ground Processing Topic O3.02

This solicitation seeks to create new and innovative technology solutions for assembly, test, integration and processing of the launch vehicle, spacecraft and payloads; end-to-end launch services; and research and development, design, construction and operation of spaceport services. The following areas are of particular interest.

Propellant Servicing Technologies Enabling Lower Life Cycle Costs

Technologies for advanced cryogenic fluid storage and transfer, servicing of chilled/densified fluids and advances in state-of-the-art ground insulation are needed to reduce launch operation costs by minimizing consumable losses. Solutions in support of helium conservation and recovery; recapture, reduction, and elimination of cryogenic propellants vented to atmosphere (zero boil-off); insulation for improved storage and distribution minimizing thermal losses; fire resistant liquid oxygen pumping systems; and instrumentation advances to enable high efficiency operations. Providing solutions with higher efficiency, lower maintenance and longer life while improving safety and improving liquid quality delivery.

Corrosion Control

Technologies for the prevention, detection and mitigation of corrosion/erosion in spaceport facilities and ground support equipment including refractory concrete. Solutions for: damage responsive coatings with corrosion inhibitors; poor-performing refractory concrete; protective coatings for non-painted surfaces; and new environmentally friendly protective coating options to replace products lost due to EPA regulation changes. Providing coating/protection solutions that meet current and emerging environmental restrictions and can endure the corrosive and highly acidic launch environment.

Spaceport Processing Systems Evaluation/Inspection Tools

Technologies in support of defect detection in composite materials; methods for determining structural integrity of bonded assemblies; and non-intrusive inspection of Composite Overwrapped Pressure Vessels (COPV), Orion heat shield and painted surfaces. Solutions for detecting and pinpointing corrosion under painted surfaces; predicting remaining coatings effectiveness/life expectancy; identifying composite defects and evaluating integrity; non-destructive measurement and evaluation of COPV; and damage inspection and acceptance testing of Orion heat shield. Providing solutions that reduce inspection times and provide higher confidence in system reliability and safety concerns and lower life cycle costs.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

This subtopic is also a subtopic for the "Low-Cost and Reliable Access to Space (LCRATS)" topic. Proposals to this subtopic may gain additional consideration to the extent that they effectively address the LCRATS topic (See topic O5 under the Space Operations Mission Directorate).

Sub Topics:

Enabling Research for ISS Topic O3.03

The focus of this sub-topic is on the development of systems and technologies that provide innovative ways to leverage the existing ISS facilities for new payloads or provide on orbit analysis to enhance capabilities, reduce sample return requirements, or enable sample return for existing payloads.

Current utilization of ISS is limited by upmass, downmass, crew time and by the capabilities of the interfaces and hardware already developed. Innovative ways of interfacing existing hardware such as being able to use the light microscopy module (LMM) in the Fluids Integrated Rack (FIR) as a life science microscope could increase biotechnology research capabilities. Enabling additional cell and molecular biology culture techniques by providing innovative hardware to allow for safe, contained transfer of cells from container to container within the Microgravity Sciences Glove Box (MSG) would permit new types of studies on ISS. On orbit analysis techniques that would reduce or remove the need for downmass (such as a system for gene array tests, or kits for DNA extractions for long term storage) are also examples of hardware possibilities that would extend and enable additional research.

Capabilities that extend the types of studies that can be completed in orbit are not limited to the above examples or to biotechnology disciplines. Innovative methods for further subdividing payloads lockers to enable numerous pico-payloads, or developing an innovative generic control system to interface with existing ISS control systems are a further examples of the type of technology that is requested under this subtopic.

The existing hardware suite and interfaces available on ISS can be found at:

http://www.nasa.gov/mission_pages/station/science/experiments/Discipline.html [6]

Due to the difficulty and complexity of qualifying hardware for human spaceflight, proposals under this subtopic are expected to advance the development to a level demonstrating the technology in the lab or relevant environment under the SBIR program.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward Phase 2 hardware and software demonstration and delivering a demonstration unit or software package for NASA testing at the completion of the Phase 2 contract.

Sub Topics:

Metric Tracking of Launch Vehicles Topic O4.01

Range Safety requires accurate and reliable tracking data for launch vehicles. Onboard GPS receivers must maintain lock, reacquire very quickly and operate securely in a highly-dynamic environment. GPS Course Acquisition Code (CA) does not require classified decryption codes and has an accuracy of better than 30 m and 1 m/s. Although this accuracy is good enough for most Range Safety needs, better accuracy is needed for antenna pointing, docking maneuvers and attitude determination. CA code also offers little protection against deliberately transmitted false signals or "spoofing".

This solicitation seeks proposals in the following areas:

- Innovative technologies to increase the accuracy of the L1 C/A navigation solution by combining the pseudo ranges and phases of the L1 C/A signals, and use of the L2 and L5 carrier. Factors that degrade the GPS signal can be obtained by differencing the available carrier phase and pseudo range measurements and then removing this difference from the navigation solution.
- Technologies that combine spatial processing of signals from multiple antennas with temporal processing techniques to mitigate interference signals received by the GPS receiver. The coordinated response of adaptive pattern control (beam and null steering) and digital excision of certain interfering signal components minimizes strong jamming signals. Adaptive nulling minimizes interfering signals by the optimal control of the GPS antenna pattern (null steering).

These technologies should be independent of any particular GPS receiver design.

Research should be conducted to demonstrate technical feasibility during Phase 1 and show a path toward a Phase 2 hardware and software demonstration unit or software package for NASA testing at the completion of the

Phase 2 contract.

Sub Topics:

On-Orbit PNT (Positioning, Navigation, and Timing) Sensors and Components Topic O4.02

This solicitation seeks proposals that will serve NASA's ever-evolving set of near-Earth and interplanetary missions that require precise determination of spacecraft position and velocity in order to achieve mission success. While the definition of "precise" depends upon the mission context, typical scenarios have required meter-level or better position accuracies, and sub-millimeter-level or better velocity accuracies.

Research should be conducted to demonstrate technical feasibility during Phase 1, and show a path toward a Phase 2 hardware and/or software demonstration of a demonstration unit or software package that will be delivered to NASA for testing at the completion of the Phase 2 contract. The Small Spacecraft Build effort highlighted in Topic S4 (Low-cost Small Spacecraft and Technologies) of the solicitation participates in this subtopic. Offerors are encouraged to take this in consideration as a possible flight opportunity when proposing work to this subtopic.

Purpose: NASA Needs vs. Current State of the Art

This solicitation is primarily focused on NASA's needs in three focused areas: onboard near-Earth navigation systems; onboard deep-space navigation systems; technologies supporting improved TDRSS-based navigation. Proposals that leverage state-of-the-art capabilities already developed by NASA such as GEONS (<http://techtransfer.gsfc.nasa.gov/ft-tech-GEONS.html> [18]), Navigator (<http://techtransfer.gsfc.nasa.gov/ft-tech-GPS-NAVIGATOR.html> [19]), GIPSY, Electra, and Blackjack are especially encouraged. NASA is not interested in funding efforts that seek to "re-invent the wheel" by duplicating the many investments that NASA and others have already made in establishing the current state-of-the-art.

General Operational Specifications and Requirements:

Core Capabilities:

Onboard Near-Earth Navigation System

NASA seeks proposals that would develop a commercially viable transceiver with embedded orbit determination software that would provide enhanced accuracy and integrity for autonomous onboard GPS- and TDRSS-based navigation and time-transfer in near-Earth space via augmentation messages broadcast by TDRSS. The augmentation message should include information on the TDRS orbits, status, and health that could be provided by future TDRS, and should provide information on the GPS constellation that is based on NASA's TDRSS Augmentation for Satellites Signal (TASS). Proposers are advised that NASA's GEONS and GIPSY orbit determination software packages already support the capability to ingest TASS messages.

Onboard Deep-Space Navigation System

NASA seeks proposals that would develop an onboard autonomous navigation and time-transfer system that can

reduce DSN tracking requirements. Such systems should provide accuracy comparable to delta differenced one-way ranging (DDOR) solutions anywhere in the inner solar system, and exceed DDOR solution accuracy beyond the orbit of Jupiter. Proposers are advised that NASA's GEONS and DS-1 navigation software packages already support the capability to ingest many one-way forward Doppler, optical sensor observation, and accelerometer data types.

Technologies Supporting Improved TDRSS-based Navigation

NASA seeks proposals that would provide improvements in TDRS orbit knowledge, TDRSS radiometric tracking, ground-based orbit determination, and Ground Terminal improvements that improve navigation accuracy for TDRS users. Methods for improving TDRS orbit knowledge should exploit the possible future availability of accelerometer data collected onboard future TDRS.

Optional Capabilities:

NASA may consider other proposals relevant to NASA's needs for precise spacecraft navigation and tracking that demonstrably advance the state-of-the-art.

Development Timeline Associated with NASA Needs:

Phase 1 deliverables should include documentation of technical feasibility, which should at minimum show a path toward hardware and/or software demonstration of a demonstration unit or software package in Phase 2.

Phase 2 deliverables should include a demonstration unit or software.

The proposer to this subtopic is advised that the products proposed may be included in a future small satellite flight opportunity. Please see the SMD Topic S4 on Small Satellites for details regarding those opportunities. If the proposer would like to have their proposal considered for flight in the small satellite program, the proposal should state such and recommend a pathway for that possibility.

Sub Topics:

Lunar Surface Navigation Topic O4.03

In order to provide location awareness, precision position fixing, best heading and traverse path planning for planetary EVA, manned rovers and lunar surface mobility units NASA has established requirements for onboard navigation capabilities for surface-mobile elements of lunar missions. Proposals are specifically sought which address the following needs:

- Asset localization within a work area. Specifically, real-time relative location of vehicles and EVA crewmembers for safety and task efficiency.

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- EVA crew localization for emergency walk back to a safe haven (lander, habitat, fixed reference point, etc.)
 - Fixed asset localization with respect to global coordinates.
 - Traverse-path planning systems and navigation-specific displays are also of interest.
 - Novel navigation techniques that utilize repurposed flight vehicle sensors (INS, AHRS, low light imager, star trackers, etc.)

This topic will develop systems, technologies and analysis in support of the required capabilities of lunar surface mobility elements. Contemplated navigation systems could employ celestial references, passive or active optical information such as optical flow or range to local terrain features, inertial sensor information or other location-specific sensed data or combinations thereof. However, radiometric measurements are considered to be concomitant to the lunar communications network and the lunar network will likely be used to communicate state information between lunar mission elements. As such, the main emphasis of this topic is on systems that exploit radiometric measurements such as range, Doppler or Angle of Arrival. Radiometric measurements can be considered between lunar mission elements such as surface mobility units, elements of a lunar surface architecture (such as surface landers or habitation units or other surface mobility units) or elements of the lunar communications and navigation infrastructure such as surface communications towers or lunar communication/navigation orbiters. Note that the constellation of moon-orbiting communication/navigation satellites will support both polar outpost missions as well as short term sortie missions that can occur anywhere on the lunar surface. This constellation will likely consist of no more than six satellites and may be only be one or two satellites. Earth-based nodes are not excluded from consideration, nor are two-way radiometric measurements, nor are non-NASA-standard modulation schemes.

Emphasis of the development is on navigation accuracy, position estimate update rate (minimized correlation time), minimum Size Weight and Power (SWaP), systems that operate effectively with minimal communications/navigation infrastructure (such as towers or orbiters) or with complete autonomy, with minimal crew involvement or completely automatically. Unified concepts and systems that provide a range of hardware capabilities (possibly trading accuracy with SWaP) and/or support dual-use (e.g., navigation and communication) are of interest.

Mature system concepts and technologies including system demonstration with TRL 6 components and internalized (by NASA) standards are required at the end of a Phase 2. Candidates for technology infusion include developmental EVA space suits and prototype crew and robotic rovers. An example rover system is the Lunar Electric Rover (LER). The LER (<http://www.nasa.gov/exploration/home/LER.html> [20]) is a sport utility sized, 12-wheeled, pressurized vehicle capable of supporting 14-day missions with two astronauts. Recent tests have included 140km treks across rugged terrain in Arizona. Future testing will extend the distance. Examples of a developmental EVA space suit include the Mark iii spacesuit and the REI suit (c.f. http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20080012574_2008010837.pdf [21]). Demonstration opportunities occur several times a year at lunar analog exercises such as the Desert Research and Technology Studies (D-RATS, c.f. http://en.wikipedia.org/wiki/Desert_Research_and_Technology_Studies [22]) and the Haughton Field test (c.f. http://ti.arc.nasa.gov/projects/haughton_field/ [23]).

Sub Topics:

Flight Dynamics Technologies and Software Topic O4.04

NASA is beginning to invest in re-engineering its suite of tools and facilities that provide navigation and mission design services for design and operations of near-Earth and interplanetary missions. This solicitation seeks proposals that will develop flight dynamics technologies and software that support these efforts.

In the context of this solicitation, flight dynamics technologies and software are algorithms and software that may be used in ground support facilities, or onboard a spacecraft, so as to provide Position, Navigation, and Timing (PNT) services that reduce the need for ground tracking and ground navigation support. Flight dynamics technologies and software also provide critical support to pre-flight mission design, planning, and analysis activities.

This solicitation is primarily focused on NASA's needs in the following focused areas:

- Applications of cutting-edge estimation techniques, such as sigma-point and particle filters, to spaceflight navigation problems.
- Applications of estimation techniques that have an expanded state vector (beyond position and velocity components) to monitor non-Gaussian noise processes to improve upon the overall system accuracy.
- Applications of creative estimation techniques that combine measurements from multiple sensor suites to improve upon the overall system accuracy.
- Applications of advanced dynamical theories to space mission design and analysis, especially in the context of unstable orbital trajectories in the vicinity of small bodies and libration points.
- Addition of novel measurement technologies to existing NASA onboard navigation software that is licensed by the proposer.
- Addition of orbit determination capabilities to existing NASA mission design software that is either freely available via NASA Open Source Agreements, or that is licensed by the proposer.

Proposals that leverage state-of-the-art capabilities already developed by NASA such as GPS-Enhanced Onboard Navigation Software (<http://techtransfer.gsfc.nasa.gov/ft-tech-GEONS.html> [18]), General Mission Analysis Tool (<http://sourceforge.net/projects/gmat/> [24]), GPS-Inferred Positioning System and Orbit Analysis Simulation Software, (<http://gipsy.jpl.nasa.gov/orms/goa/> [25]), 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.

Technologies and software should support a broad range of spaceflight customers. Technologies and software specifically focused on a particular mission's or mission set's needs, for example rendezvous and docking, or formation flying, are the subject of other solicitations by the relevant sponsoring organizations and should not be submitted in response to this solicitation.

Research should be conducted to demonstrate technical feasibility during Phase 1, and show a path toward a Phase 2 demonstration of a software package that will be delivered to NASA for testing at the completion of the Phase 2 contract.

The proposer to this subtopic is advised that the products proposed may be included in a future small satellite flight opportunity. Please see the SMD Topic S4 on Small Satellites for details regarding those opportunities. If the

proposer would like to have their proposal considered for flight in the small satellite program, the proposal should state such and recommend a pathway for that possibility.

Sub Topics:

Space-Based Range Technologies Topic O4.05

The vision of Space-Based Range architecture is to assure public safety, reduce the costs of launch operations, enable multiple simultaneous launch operations, decrease response time, and improve geographic and temporal flexibility. This sub-topic seeks to reduce or eliminate the need for redundant range assets and deployed down-range assets that are currently used to provide for Line-of-Sight (LOS) Tracking Telemetry and Control (TT&C) with sub-orbital platforms and orbit-insertion launch vehicles. In order to achieve this, specific advancements are needed in TT&C.

Position, Attitude, and Inertial Metrics

Realization of a Space-Based Range requires the development of highly accurate and stable integrated metric tracking and inertial measurement units. The focus is on technologies that enable and advance development of low Size, Weight, and Power (SWaP), tactical grade, integrated metric tracking units that provide highly accurate and stable positioning, attitude, and inertial measurements on high dynamic platforms.

Factors to address include:

- Easy coupling of IMUs, gyros, accelerometers, and/or attitude determining GPS receivers that will provide very high frequency integrated metric solutions;
- The ability to reliably function on spin-stabilized rockets (up to 7 rps), during sudden jerk and acceleration maneuvers, and in high vibration environments is critical;
- Advancements in MEMs-based IMUs and accelerometers, algorithm techniques and Kalman filtering, phased-based attitude determination, single aperture systems, quick Time to First Fix and reacquisition.

Space-Based Telemetry

There are varying applications for space-based transceivers, each necessitating a different set of requirements. The desired focus is very low SWaP, tactical grade, highly reliable, and easily reconfigurable transceivers capable of establishing and maintaining unbroken satellite communication links for telemetry and/or control. This technology will serve applications which include low-cost sub-orbital missions, secondary communications systems for orbit insertion vehicles, low cost and size orbital payloads (typically LEO), and flight test articles. Durations will range from minutes to several weeks and the ability to operate on highly dynamic platforms is critical. High data rate links are highly desired, thus the use of NASA's TDRSS is emphasized, although other commercial satellite systems which can provide nearly global and high data rate links can also be explored.

Factors to address include:

- Advancements in software based radios and coding techniques;
- Use of the latest semiconductor technologies (GaN or other);
- Advanced heat dissipation techniques (to allow small packaging and long duration operating times);
- Immunity to corona breakdown;
- Ease of data interfacing.

RF power output requirements range from a few watts to as high as 100 W. Special consideration should be given to transceiver capability vs. packaging that would allow for customizable configurations depending on the target application. That is, a modular or stacking design with a common bus architecture should be considered where the RF and digital sections are separated. This could allow for a base digital and DC power design that will support multiple RF slices (such as a low, medium, or high power slice). Also, to satisfy missions who require unidirectional communications, a modular design could allow for separate transmitter and receiver modules/slices.

Phase 1 Deliverables

A final report containing optimal design for the technology concept including feasibility of concept, a detailed path towards Phase 2 hardware and/or software demonstration. The report shall also provide options for potential Phase 2 funding from other government agencies (OGA).

Phase 2 Deliverables

A working proof-of-concept demonstrated and delivered to NASA for testing and verification.

Sub Topics:
