NASA SBIR 2020 Phase I Solicitation

H9.07   Cognitive Communication

Lead Center: GRC

Participating Center(s): GSFC, JPL

Technology Area: TA5 Communication and Navigation

Scope Title

Lunar Cognitive Capabilities

Scope Description

NASA's Space Communication and Navigation (SCaN) program seeks innovative approaches to increase mission science data return, improve resource efficiencies for NASA missions and communication networks and ensure resilience in the unpredictable space environment. The Cognitive Communication subtopic specifically focuses on advances in space communication driven by on-board data processing and modern space networking capabilities. A cognitive system is envisioned to sense, detect, adapt, and learn from its experiences and environment to optimize the communications capabilities for the user mission satellite or network infrastructure. The underlying need for these technologies is to reduce both the mission and network operations burden.

Examples of these cognitive capabilities include:

- Link technologies - reconfiguration and autonomy, maximizing use of bandwidth while avoiding interference
- Network technologies - robust inter-satellite links, data storage/forwarding, multi-node routing in unpredictable environments
- System technologies - optimal scheduling techniques for satellite and surface relays in distributed and real-time environments

Through Space Policy Directive-1, NASA is committed to landing American astronauts on the Moon by 2024. In support of this goal, cognitive communication techniques are needed for lunar communication satellite and surface relays. Cognitive agents operating on lunar elements will manage communication, provide diagnostics, automate resource scheduling, and dynamically update data flow in response to the types of data flowing over the lunar network. Goals of this capability are to improve communications efficiency, mitigate channel impairments, and reduce operations complexity and cost through intelligent and autonomous communications and data handling.

Examples of research and/or technology development include:

- On-board processing technology and techniques to enable data switching, routing, storage, and processing on a relay spacecraft

- Data-centric, decentralized network data routing and scheduling techniques that are responsive to quality of service metrics
- Simultaneous wideband sensing and communications for S-, X-, and Ka-bands, coupled with algorithms that learn from the environment
- Artificial intelligence and machine learning algorithms applied to optimize space communication links, networks, or systems
- Flexible communication platforms with novel signal processing technology to support cognitive approaches
- Other innovative, related areas of interest to the field of cognitive communications

Proposals to this subtopic should consider application to a lunar communications architecture consisting of surface assets (e.g., astronauts, science stations, surface relays), lunar communication relay satellites, Gateway, and ground stations on Earth. The lunar communication relay satellites require technology with low size, weight, and power attributes suitable for small satellite (e.g., 50kg) or cubesat operations. Proposed solutions should highlight advancements to provide the needed communications capability while minimizing use of on-board resources such as power and propellant. Proposals should consider how the technology can mature into a successful demonstration in the lunar architecture.

References

Several related reference papers and articles include:

- "NASA Explores Artificial Intelligence for Space Communications"
  - https://www.nasa.gov/feature/goddard/2017/nasa-explores-artificial-intelligence-for-space-communications
- "Implementation of a Space Communications Cognitive Engine"
  - https://ntrs.nasa.gov/search.jsp?R=20180002166
- "Reinforcement Learning for Satellite Communications: From LEO to Deep Space Operations"
  - https://ieeexplore.ieee.org/document/8713802
- "Cognitive Communications and Networking Technology Infusion Study Report"
  - https://ntrs.nasa.gov/search.jsp?R=20190011723
- "Multi-Objective Reinforcement Learning-based Deep Neural Networks for Cognitive Space Communications"
  - https://ntrs.nasa.gov/search.jsp?R=20170009153
- "Assessment of Cognitive Communications Interest Areas for NASA Needs and Benefits"
  - https://ntrs.nasa.gov/search.jsp?R=20170009386
- "Architecture for Cognitive Networking within NASAs Future Space Communications Infrastructure"
  - https://ntrs.nasa.gov/search.jsp?R=20170001295
- "Modulation Classification of Satellite Communication Signals Using Cumulants and Neural Networks"
  - https://ntrs.nasa.gov/search.jsp?R=20170006541

A related conference, co-sponsored by NASA and the Institute of Electrical and Electronics Engineers (IEEE), the Cognitive Communications for Aerospace Applications Workshop, has additional information available at: http://ieee-ccaa.com/

Expected TRL or TRL range at completion of the project: 4 to 6

Desired Deliverables of Phase II

Prototype, Hardware, Software

Desired Deliverables Description

Phase I will study technical feasibility, infusion potential for lunar operations, clear/achievable benefits and show a path towards a Phase II implementation. Phase I deliverables can include a feasibility assessment and concept of operations of the research topic, simulations and/or measurements, validation of the proposed approach to develop a given product (TRL 3-4) and a plan for further development of the specific capabilities or products to be performed in Phase II. Early development, integration, test, and delivery prototype hardware/software is encouraged but not necessary.

Phase II will emphasize hardware/software development with delivery of specific hardware or software product for NASA targeting demonstration operations on a small satellite or cubesat platform. Phase II deliverables include a working prototype (engineering model) of the proposed product/platform or software, along with documentation of development, capabilities, and measurements, and related documents and tools as necessary for NASA to modify and use the cognitive software capability or hardware component(s). Hardware prototypes shall show a path towards flight demonstration, such as a flight qualification approach and preliminary estimates of thermal, vibration, and radiation capabilities of the flight hardware. Software prototypes shall be implemented on platforms that have a clear path to a flight qualifiable platform. Opportunities and plans should be identified for technology commercialization. Software applications and platform/infrastructure deliverables for software defined radio platforms shall be compliant with the latest NASA standard for software defined radios, the Space Telecommunications Radio System (STRS), NASA-STD-4009 and NASA-HNBK-4009.

State of the Art and Critical Gaps

To summarize NASA Technology Roadmap TA5: "As human and science exploration missions move further from Earth and become increasingly more complex, they present unique challenges to onboard communications systems and networks...Intelligent radio systems will help manage the increased complexity and provide greater capability to the mission to return more science data...Reconfigurable radio systems...could autonomously optimize the RF links, network protocols, and modes used based on the needs of the various mission phases. A cognitive radio system would sense its RF environment and adapt and learn from its various configuration changes to optimize the communications links throughout the system in order to maximize science data transfer, enable substantial efficiencies, and reduce latency. The challenges in this area are in the efficient integration of different capabilities and components, unexpected radio or system decisions or behavior, and methods to verify decision-making algorithms as compared to known, planned performance."

The technology need for the lunar communication architecture includes:

- Data routing from surface assets to a lunar communication relay satellite, where data is unscheduled, a-periodic, and ad-hoc
- Data routing between lunar relay satellites as necessary to conserve power, route data to Earth, and meet quality of service requirements
- Efficient use of lunar communication spectrum while co-existing with future/current interference sources
- On-demand communication resource scheduling
- Multi-hop, delay tolerant routing

Critical gaps between the state of the art and the technology need include:

- Implementation of artificial intelligence and machine learning techniques on SWaP-constrained platforms
- Integrated wide-band sensing and narrow-band communication on the same radio terminal
- Inter-satellite networking and routing, especially in unpredictable and unscheduled environments
- On-demand scheduling technology for communication links
- Cross-layer optimization approaches for optimum communication efficiency at a system level

Relevance / Science Traceability

Cognitive technologies are critical for the lunar communications architecture. The majority of lunar operations will be run remotely from Earth, which could require substantial coordination and planning as NASA, foreign space agencies, and commercial interests all place assets on the Moon. As lunar communications and networks become more complex, cognition and automation are essential to mitigate complexity and reduce operations costs. Machine learning will configure networks, choose radio configurations, adjust for impairments and failures, and monitor short and long term performance for improvements.