

Spectrum Efficiency, Energy Efficiency, and Security (SpecEES): Enabling Spectrum for All

PROGRAM SOLICITATION

NSF 19-529

REPLACES DOCUMENT(S):

NSF 17-601



National Science Foundation

Directorate for Engineering
Division of Electrical, Communications and Cyber Systems

Directorate for Computer & Information Science & Engineering
Division of Computer and Network Systems

Full Proposal Deadline(s) (due by 5 p.m. submitter's local time):

February 13, 2019

IMPORTANT INFORMATION AND REVISION NOTES

Any proposal submitted in response to this solicitation should be submitted in accordance with the revised *NSF Proposal & Award Policies & Procedures Guide (PAPPG) (NSF 19-1)*, which is effective for proposals submitted, or due, on or after January 28, 2019.

SUMMARY OF PROGRAM REQUIREMENTS

General Information

Program Title:

Spectrum Efficiency, Energy Efficiency, and Security (SpecEES): Enabling Spectrum for All

Synopsis of Program:

The National Science Foundation's Directorates for Engineering (ENG) and Computer and Information Science and Engineering (CISE) are coordinating efforts to identify bold new concepts to significantly improve the efficiency of radio spectrum utilization while addressing new challenges in energy efficiency and security, thus enabling spectrum access for all users and devices, and allowing traditionally underserved Americans to benefit from wireless-enabled goods and services. The SpecEES program solicitation (pronounced "SpecEase") seeks to fund innovative collaborative team research that transcends the traditional boundaries of existing programs.

Cognizant Program Officer(s):

Please note that the following information is current at the time of publishing. See program website for any updates to the points of contact.

- Jenshan Lin, ENG/ECCS, telephone: (703) 292-8339, email: jenlin@nsf.gov
- Monisha Ghosh, CISE/CNS, telephone: (703) 292-8950, email: mghosh@nsf.gov
- Akbar Sayeed, ENG/ECCS, telephone: (703) 292-8339, email: asayeed@nsf.gov
- Lawrence S. Goldberg, ENG/ECCS, telephone: (703) 292-8339, email: lgoldber@nsf.gov

Applicable Catalog of Federal Domestic Assistance (CFDA) Number(s):

- 47.041 --- Engineering
- 47.070 --- Computer and Information Science and Engineering

Award Information

Anticipated Type of Award: Standard Grant

Estimated Number of Awards: 12 to 15

Approximately 12-15 awards are anticipated, each up to \$750,000 total and up to 3 years in duration, subject to the availability of funds and quality of proposals received.

Anticipated Funding Amount: \$9,000,000

Estimated program budget, number of awards and average award size/duration are subject to the availability of funds.

Eligibility Information

Who May Submit Proposals:

Proposals may only be submitted by the following:

- Institutions of Higher Education (IHEs) - Two- and four-year IHEs (including community colleges) accredited in, and having a campus located in the US, acting on behalf of their faculty members. Special Instructions for International Branch Campuses of US IHEs: If the proposal includes funding to be provided to an international branch campus of a US institution of higher education (including through use of subawards and consultant arrangements), the proposer must explain the benefit(s) to the project of performance at the international branch campus, and justify why the project activities cannot be performed at the US campus.
- Non-profit, non-academic organizations: Independent museums, observatories, research labs, professional societies and similar organizations in the U.S. associated with educational or research activities.

Who May Serve as PI:

There are no restrictions or limits.

Limit on Number of Proposals per Organization:

There are no restrictions or limits.

Limit on Number of Proposals per PI or Co-PI: 1

An individual may be listed as PI, co-PI, and/or senior personnel on only one proposal submitted in response to this solicitation. In the event that an individual exceeds this limit, only the first proposal received before the deadline will be accepted, and the remainder will be returned without review.

Proposal Preparation and Submission Instructions

A. Proposal Preparation Instructions

- **Letters of Intent:** Not required
- **Preliminary Proposal Submission:** Not required
- **Full Proposals:**
 - Full Proposals submitted via FastLane: *NSF Proposal and Award Policies and Procedures Guide* (PAPPG) guidelines apply. The complete text of the PAPPG is available electronically on the NSF website at: https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg.
 - Full Proposals submitted via Grants.gov: *NSF Grants.gov Application Guide: A Guide for the Preparation and Submission of NSF Applications via Grants.gov* guidelines apply (Note: The *NSF Grants.gov Application Guide* is available on the Grants.gov website and on the NSF website at: https://www.nsf.gov/publications/pub_summ.jsp?ods_key=grantsgovguide).

B. Budgetary Information

- **Cost Sharing Requirements:**

Inclusion of voluntary committed cost sharing is prohibited.
- **Indirect Cost (F&A) Limitations:**

Not Applicable
- **Other Budgetary Limitations:**

Not Applicable

C. Due Dates

- **Full Proposal Deadline(s)** (due by 5 p.m. submitter's local time):

Proposal Review Information Criteria

Merit Review Criteria:

National Science Board approved criteria. Additional merit review considerations apply. Please see the full text of this solicitation for further information.

Award Administration Information

Award Conditions:

Standard NSF award conditions apply.

Reporting Requirements:

Standard NSF reporting requirements apply.

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I. INTRODUCTION

Dramatic growth in wireless communications has created a shortage in the available radio spectrum. Wireless communications services for cellular phones, television, and broadband Internet access have to compete with existing users in radar, government communications, scientific observations, and environmental monitoring. The way forward is to increase the efficiency of spectrum sharing among the multitude of users.

NSF provides ongoing support for basic research at the frontiers of wireless communications and networking, through core programs such as Communications, Circuits and Sensing-Systems (CCSS), Networking Technology and Systems (NeTS), and Communications and Information Foundations (CIF) within the Directorates for Engineering (ENG) and Computer and Information Science and Engineering (CISE). As a result of past investments in wireless research, two important issues are now at the forefront of spectrum efficiency research and at the core of the SpecEES program: security and energy efficiency while achieving efficient spectrum sharing. The open access nature of radio transmission makes wireless communications inherently vulnerable to security breaches such as eavesdropping, jamming, and specially-crafted malicious attacks. At the same time, spectrum sharing is a highly cooperative operation that relies on other users to determine spectrum availability and ensure fair sharing of spectrum access. These two facts make it easy for spectrum to be abused—whether accidentally due to implementation error, or intentionally due to malicious intent to disrupt the

communications of others or use spectrum to one's own advantage. Thus, there is a strong need for effective mechanisms to ensure that spectrum-sharing users can communicate securely and the system can operate in conformance with established protocols.

In addition, current and next-generation wireless applications demand more and better functionality and performance from new electronic devices; these demands translate into greater energy demands. Despite important advances in battery technology, the gap between energy storage and demand continues to grow. Even more importantly for spectrum sharing, reducing the amount of transmit power in the airwaves can lessen interference among devices. Energy-efficient devices, protocols, and network architectures will further reduce the number of transmissions and prolong the battery life of mobile devices. Therefore, it is essential to pursue fundamental research on new components, techniques, algorithms, and architectures to achieve energy-efficient sensing, communications and networking in a shared spectrum environment.

The research and technology challenges underlying spectrum efficiency, security, and energy efficiency are inter-related and require innovations across the physical, networking and higher layers. The SpecEES program is aimed at enabling cross-disciplinary team research that transcends the traditional boundaries of existing NSF programs to tackle the spectrum efficiency, energy efficiency and security challenges in the conception, design and realization of future wireless networks.

Research and development on next-generation wireless communications and networking will drive information technology and innovation-based economic growth. SpecEES will advance spectrum utilization through synergistic breakthroughs in spectrum efficiency, energy efficiency, and security.

II. PROGRAM DESCRIPTION

The goal of the SpecEES program is to enable next-generation wireless communications and networking that are spectrum-efficient, energy-efficient, and secure in a dynamic spectrum environment. In particular, the program solicits proposals that address the challenge of **spectral efficiency**, and that also specifically address research challenges related to either **energy efficiency** or **security**, or **both**, in spectrum utilization. **Each proposal must explicitly state in the Project Summary whether energy efficiency and/or security will be addressed. In addition, the proposal must have collaborative teaming to tackle cross-layer issues, from the physical layer to the network layer and above.**

SpecEES projects must address spectral efficiency as the primary goal. Fundamental advances in radio hardware, signal processing, sensing, network protocols, and access architectures are needed to enable efficient and dynamic spectrum sharing among a large number of users and devices. For example, access to spectrum is evolving from a strict per-band operation to a multi-frequency agile dynamic spectrum access model. However, such access architectures are limited in multiple dimensions, such as the sharing time scale, number of frequency bands that can be shared, number of devices/networks that can participate in the access model, and trust relationships that can be supported. The ability for any wireless device to access any swath of available spectrum whenever and wherever available is a highly desirable aspect of spectrum access architecture. This capability needs to be robust, resilient and scalable across the number of devices and the bands that are being shared. New approaches are sought in all layers of the protocol stack, and collaborative efforts that combine technologies at multiple layers are particularly encouraged. Key research topics of interest include, but are not limited to:

- Reconfigurable radio frequency components such as filters, transceivers, and antennas that can rapidly adapt over a wide frequency range of operation;
- Novel transceiver architectures for low-power, spectrum-efficient communications or sensing;
- Advanced spectrum sensing techniques to quickly and accurately identify transmission opportunities over a very wide spectrum and/or a large spatial area;
- Innovative protocols and network architectures to coordinate access to the shared spectrum among a large number of users and devices;
- Co-existence of various wireless systems including communications, radar, and radio astronomy;
- Metrics for dynamic spectrum monitoring, measurements, and analysis;
- Advances in massive MIMO systems.

It should be noted that operating at a higher frequency band in radio spectrum (e.g., millimeter-wave and terahertz) where larger bandwidths are available to support higher data rates does not necessarily lead to higher spectral efficiency or efficient use of the spectrum.

Innovative approaches to achieving spectral efficiency must also take into consideration energy efficiency and/or security. Therefore, in addition to the spectrum efficiency challenges described above, SpecEES projects must address one or both of the following challenges as well:

Energy Efficiency: Taking energy efficiency into consideration while achieving spectrum efficiency is a major undertaking. On the hardware front, energy efficiency is critically dependent on such power-hungry components as power amplifiers, analog-to-digital converters and phase-locked loops. At millimeter-wave frequencies and above, performance limitations on active devices make efficient signal generation and processing a challenge. Antenna arrays with a large number of elements for achieving spatial multiplexing and interference cancellation must rely on complex beamforming and processing operations. Moreover, the overall energy efficiency of a spectrum sharing system will depend not only on the energy consumed for data transmission, but also on spectrum sensing, dynamic spectrum access, scheduling and synchronization of transmission and reception, associated signaling traffic, and associated computational resources. Therefore, the design and operation of an energy-efficient communications system involves tradeoffs among energy consumption, communication reliability, data rate, and spectrum efficiency. These characteristics point toward a holistic approach to maximizing energy efficiency of the system, by jointly considering hardware limitations, spectrum sensing capabilities, and algorithmic complexities. Energy-efficient solutions are sought at various layers, including circuits and transceiver architectures, amplifiers and low-loss passives, signal modulation and processing, network protocols and algorithms; the approaches must account for effects on other layers, as well as the overall system-level efficiency. Use of quantitative metrics to assess the overall energy efficiency and spectrum efficiency of the proposed spectrum research is encouraged.

Security: Security is a critical aspect in wireless systems. Innovations that enable more efficient spectral usage may be vulnerable to

known security threats or may introduce new attacks. Spectrum sharing relies on cooperation among all parties and hinges on effective dissemination of the necessary operational information. At times, different parties might require different levels of information sharing, and information security and privacy considerations might work against sharing of such information. Additionally, techniques designed to secure wireless communication networks might adversely impact spectrum and energy efficiency. These scenarios are often encountered, for example, in mission-critical military communication systems or commercial cellular data networks. In the near future, highly programmable software defined radio devices can lead to malicious attacks or inadvertent, erroneous transmissions—both of which will cause interference to incumbent users. Highly dynamic and flexible spectrum access protocols also make the detection of such transmissions difficult.

Data analytics techniques that can be leveraged to assess security and privacy vulnerabilities, as well as to predict and enhance system trustworthiness in the context of spectrum efficiency are highly desirable. Signal-processing and hardware designs for rapid transmitter identification and localization, tools for device verification and protocol compliance-checking, and spectrum-efficient algorithms for secure, privacy-preserving information sharing are crucial for spectrum sharing systems, as are policy enforcement mechanisms and trust verification services. The SpecEES program seeks novel approaches to these challenges that also enhance spectrum efficiency.

SpecEES requires collaborative team proposals that transcend the traditional boundaries of existing programs to enable hardware, algorithmic, protocol, and architectural advances to realize spectrum efficiency, energy efficiency, and security. In addition, fundamental understanding of the tradeoffs among these three objectives is desired to advance the frontier of next-generation wireless technologies. Proposers are encouraged to look at the reports of multiple workshops convened by the federal Networking and Information Technology Research and Development (NITRD) program's Wireless Spectrum Research and Development (WSRD) Interagency Working Group (IWG) at <<https://go.usa.gov/xRV8Q>> for detailed discussion of challenges and opportunities related to these objectives. Proposers are strongly encouraged to consider actively engaging spectrum stakeholders such as industry and government as part of their broader impacts activities.

Experiments involving transmissions in certain frequency bands may require a license to operate. For questions regarding the proposed frequency usage and the license requirement, please contact the NSF Electromagnetic Spectrum Management Office (email: esm@nsf.gov) for assistance.

Please note: Each proposal budget must include funding for travel to Washington, DC, for a PI or Co-PI and up to one other project participant to attend annual two-day PI meetings during the award period.

III. AWARD INFORMATION

Anticipated Type of Award: Standard Grant

Estimated Number of Awards: Approximately 12-15 awards are anticipated, each up to \$750,000 total and up to 3 years in duration, subject to the availability of funds and quality of proposals received.

Anticipated Funding Amount: \$9,000,000

Estimated program budget, number of awards and average award size/duration are subject to the availability of funds.

IV. ELIGIBILITY INFORMATION

Who May Submit Proposals:

Proposals may only be submitted by the following:

- Institutions of Higher Education (IHEs) - Two- and four-year IHEs (including community colleges) accredited in, and having a campus located in the US, acting on behalf of their faculty members. Special Instructions for International Branch Campuses of US IHEs: If the proposal includes funding to be provided to an international branch campus of a US institution of higher education (including through use of subawards and consultant arrangements), the proposer must explain the benefit(s) to the project of performance at the international branch campus, and justify why the project activities cannot be performed at the US campus.
- Non-profit, non-academic organizations: Independent museums, observatories, research labs, professional societies and similar organizations in the U.S. associated with educational or research activities.

Who May Serve as PI:

There are no restrictions or limits.

Limit on Number of Proposals per Organization:

There are no restrictions or limits.

Limit on Number of Proposals per PI or Co-PI: 1

An individual may be listed as PI, co-PI, and/or senior personnel on only one proposal submitted in response to this

solicitation. In the event that an individual exceeds this limit, only the first proposal received before the deadline will be accepted, and the remainder will be returned without review.

Additional Eligibility Info:

Synergistic collaborations or partnerships with industry or government are encouraged where appropriate, though no NSF funds will be provided to these organizations.

Researchers from foreign academic institutions who contribute essential expertise to the project may participate as senior personnel or collaborators but may not receive NSF support.

V. PROPOSAL PREPARATION AND SUBMISSION INSTRUCTIONS

A. Proposal Preparation Instructions

Full Proposal Preparation Instructions: Proposers may opt to submit proposals in response to this Program Solicitation via Grants.gov or via the NSF FastLane system.

- Full proposals submitted via FastLane: Proposals submitted in response to this program solicitation should be prepared and submitted in accordance with the general guidelines contained in the *NSF Proposal & Award Policies & Procedures Guide* (PAPPG). The complete text of the PAPPG is available electronically on the NSF website at: https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg. Paper copies of the PAPPG may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-7827 or by e-mail from nsfpubs@nsf.gov. Proposers are reminded to identify this program solicitation number in the program solicitation block on the NSF Cover Sheet For Proposal to the National Science Foundation. Compliance with this requirement is critical to determining the relevant proposal processing guidelines. Failure to submit this information may delay processing.
- Full proposals submitted via Grants.gov: Proposals submitted in response to this program solicitation via Grants.gov should be prepared and submitted in accordance with the *NSF Grants.gov Application Guide: A Guide for the Preparation and Submission of NSF Applications via Grants.gov*. The complete text of the *NSF Grants.gov Application Guide* is available on the Grants.gov website and on the NSF website at: (https://www.nsf.gov/publications/pub_summ.jsp?ods_key=grantsgovguide). To obtain copies of the Application Guide and Application Forms Package, click on the Apply tab on the Grants.gov site, then click on the Apply Step 1: Download a Grant Application Package and Application Instructions link and enter the funding opportunity number, (the program solicitation number without the NSF prefix) and press the Download Package button. Paper copies of the Grants.gov Application Guide also may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-7827 or by e-mail from nsfpubs@nsf.gov.

In determining which method to utilize in the electronic preparation and submission of the proposal, please note the following:

Collaborative Proposals. All collaborative proposals submitted as separate submissions from multiple organizations must be submitted via the NSF FastLane system. PAPPG Chapter II.D.3 provides additional information on collaborative proposals.

See PAPPG Chapter II.C.2 for guidance on the required sections of a full research proposal submitted to NSF. Please note that the proposal preparation instructions provided in this program solicitation may deviate from the PAPPG instructions.

The Project Description must contain, as a separate section of less than a page, a section labeled "Addressing SpecEES Solicitation Specific Review Criteria". This section should provide a description of how the SpecEES solicitation specific review criteria are addressed in the proposal and include references to other relevant sections in the proposal for additional details.

B. Budgetary Information

Cost Sharing:

Inclusion of voluntary committed cost sharing is prohibited.

Budget Preparation Instructions:

Each proposal budget must include funding for travel to Washington, DC, for a PI or Co-PI and up to one other project participant to attend annual two-day PI meetings during the award period.

C. Due Dates

- **Full Proposal Deadline(s)** (due by 5 p.m. submitter's local time):

February 13, 2019

D. FastLane/Grants.gov Requirements

For Proposals Submitted Via FastLane:

To prepare and submit a proposal via FastLane, see detailed technical instructions available at: <https://www.fastlane.nsf.gov/a1/newstan.htm>. For FastLane user support, call the FastLane Help Desk at 1-800-673-6188 or e-mail fastlane@nsf.gov. The FastLane Help Desk answers general technical questions related to the use of the FastLane system. Specific questions related to this program solicitation should be referred to the NSF program staff contact(s) listed in Section VIII of this funding opportunity.

For Proposals Submitted Via Grants.gov:

Before using Grants.gov for the first time, each organization must register to create an institutional profile. Once registered, the applicant's organization can then apply for any federal grant on the Grants.gov website. Comprehensive information about using Grants.gov is available on the Grants.gov Applicant Resources webpage: <http://www.grants.gov/web/grants/applicants.html>. In addition, the NSF Grants.gov Application Guide (see link in Section V.A) provides instructions regarding the technical preparation of proposals via Grants.gov. For Grants.gov user support, contact the Grants.gov Contact Center at 1-800-518-4726 or by email: support@grants.gov. The Grants.gov Contact Center answers general technical questions related to the use of Grants.gov. Specific questions related to this program solicitation should be referred to the NSF program staff contact(s) listed in Section VIII of this solicitation.

Submitting the Proposal: Once all documents have been completed, the Authorized Organizational Representative (AOR) must submit the application to Grants.gov and verify the desired funding opportunity and agency to which the application is submitted. The AOR must then sign and submit the application to Grants.gov. The completed application will be transferred to the NSF FastLane system for further processing.

Proposers that submitted via FastLane are strongly encouraged to use FastLane to verify the status of their submission to NSF. For proposers that submitted via Grants.gov, until an application has been received and validated by NSF, the Authorized Organizational Representative may check the status of an application on Grants.gov. After proposers have received an e-mail notification from NSF, Research.gov should be used to check the status of an application.

VI. NSF PROPOSAL PROCESSING AND REVIEW PROCEDURES

Proposals received by NSF are assigned to the appropriate NSF program for acknowledgement and, if they meet NSF requirements, for review. All proposals are carefully reviewed by a scientist, engineer, or educator serving as an NSF Program Officer, and usually by three to ten other persons outside NSF either as *ad hoc* reviewers, panelists, or both, who are experts in the particular fields represented by the proposal. These reviewers are selected by Program Officers charged with oversight of the review process. Proposers are invited to suggest names of persons they believe are especially well qualified to review the proposal and/or persons they would prefer not review the proposal. These suggestions may serve as one source in the reviewer selection process at the Program Officer's discretion. Submission of such names, however, is optional. Care is taken to ensure that reviewers have no conflicts of interest with the proposal. In addition, Program Officers may obtain comments from site visits before recommending final action on proposals. Senior NSF staff further review recommendations for awards. A flowchart that depicts the entire NSF proposal and award process (and associated timeline) is included in PAPPG Exhibit III-1.

A comprehensive description of the Foundation's merit review process is available on the NSF website at: https://www.nsf.gov/bfa/dias/policy/merit_review/.

Proposers should also be aware of core strategies that are essential to the fulfillment of NSF's mission, as articulated in *Building the Future: Investing in Discovery and Innovation - NSF Strategic Plan for Fiscal Years (FY) 2018 – 2022*. These strategies are integrated in the program planning and implementation process, of which proposal review is one part. NSF's mission is particularly well-implemented through the integration of research and education and broadening participation in NSF programs, projects, and activities.

One of the strategic objectives in support of NSF's mission is to foster integration of research and education through the programs, projects, and activities it supports at academic and research institutions. These institutions must recruit, train, and prepare a diverse STEM workforce to advance the frontiers of science and participate in the U.S. technology-based economy. NSF's contribution to the national innovation ecosystem is to provide cutting-edge research under the guidance of the Nation's most creative scientists and engineers. NSF also supports development of a strong science, technology, engineering, and mathematics (STEM) workforce by investing in building the knowledge that informs improvements in STEM teaching and learning.

NSF's mission calls for the broadening of opportunities and expanding participation of groups, institutions, and geographic regions that are underrepresented in STEM disciplines, which is essential to the health and vitality of science and engineering. NSF is committed to this principle of diversity and deems it central to the programs, projects, and activities it considers and supports.

A. Merit Review Principles and Criteria

The National Science Foundation strives to invest in a robust and diverse portfolio of projects that creates new knowledge and enables breakthroughs in understanding across all areas of science and engineering research and education. To identify which projects to support, NSF relies on a merit review process that incorporates consideration of both the technical aspects of a proposed project and its potential to contribute more broadly to advancing NSF's mission "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense; and for other purposes." NSF makes every effort to conduct a fair, competitive, transparent merit review process for the selection of projects.

1. Merit Review Principles

These principles are to be given due diligence by PIs and organizations when preparing proposals and managing projects, by reviewers when reading and evaluating proposals, and by NSF program staff when determining whether or not to recommend proposals for funding and while overseeing awards. Given that NSF is the primary federal agency charged with nurturing and supporting excellence in basic research and education, the following three principles apply:

- All NSF projects should be of the highest quality and have the potential to advance, if not transform, the frontiers of knowledge.
- NSF projects, in the aggregate, should contribute more broadly to achieving societal goals. These "Broader Impacts" may be accomplished through the research itself, through activities that are directly related to specific research projects, or through activities that are supported by, but are complementary to, the project. The project activities may be based on previously established and/or innovative methods and approaches, but in either case must be well justified.
- Meaningful assessment and evaluation of NSF funded projects should be based on appropriate metrics, keeping in mind the likely correlation between the effect of broader impacts and the resources provided to implement projects. If the size of the activity is limited, evaluation of that activity in isolation is not likely to be meaningful. Thus, assessing the effectiveness of these activities may best be done at a higher, more aggregated, level than the individual project.

With respect to the third principle, even if assessment of Broader Impacts outcomes for particular projects is done at an aggregated level, PIs are expected to be accountable for carrying out the activities described in the funded project. Thus, individual projects should include clearly stated goals, specific descriptions of the activities that the PI intends to do, and a plan in place to document the outputs of those activities.

These three merit review principles provide the basis for the merit review criteria, as well as a context within which the users of the criteria can better understand their intent.

2. Merit Review Criteria

All NSF proposals are evaluated through use of the two National Science Board approved merit review criteria. In some instances, however, NSF will employ additional criteria as required to highlight the specific objectives of certain programs and activities.

The two merit review criteria are listed below. **Both** criteria are to be given **full consideration** during the review and decision-making processes; each criterion is necessary but neither, by itself, is sufficient. Therefore, proposers must fully address both criteria. (PAPPG Chapter II.C.2.d(i). contains additional information for use by proposers in development of the Project Description section of the proposal). Reviewers are strongly encouraged to review the criteria, including PAPPG Chapter II.C.2.d(i), prior to the review of a proposal.

When evaluating NSF proposals, reviewers will be asked to consider what the proposers want to do, why they want to do it, how they plan to do it, how they will know if they succeed, and what benefits could accrue if the project is successful. These issues apply both to the technical aspects of the proposal and the way in which the project may make broader contributions. To that end, reviewers will be asked to evaluate all proposals against two criteria:

- **Intellectual Merit:** The Intellectual Merit criterion encompasses the potential to advance knowledge; and
- **Broader Impacts:** The Broader Impacts criterion encompasses the potential to benefit society and contribute to the achievement of specific, desired societal outcomes.

The following elements should be considered in the review for both criteria:

1. What is the potential for the proposed activity to
 - a. Advance knowledge and understanding within its own field or across different fields (Intellectual Merit); and
 - b. Benefit society or advance desired societal outcomes (Broader Impacts)?
2. To what extent do the proposed activities suggest and explore creative, original, or potentially transformative concepts?
3. Is the plan for carrying out the proposed activities well-reasoned, well-organized, and based on a sound rationale? Does the plan incorporate a mechanism to assess success?
4. How well qualified is the individual, team, or organization to conduct the proposed activities?
5. Are there adequate resources available to the PI (either at the home organization or through collaborations) to carry out the proposed activities?

Broader impacts may be accomplished through the research itself, through the activities that are directly related to specific research projects, or through activities that are supported by, but are complementary to, the project. NSF values the advancement of scientific knowledge and activities that contribute to achievement of societally relevant outcomes. Such outcomes include, but are not limited to: full participation of women, persons with disabilities, and underrepresented minorities in science, technology, engineering, and mathematics (STEM); improved STEM education and educator development at any level; increased public scientific literacy and public engagement with science and technology; improved well-being of individuals in society; development of a diverse, globally competitive STEM workforce; increased partnerships between academia, industry, and others; improved national security; increased economic competitiveness of the United States; and enhanced infrastructure for research and education.

Proposers are reminded that reviewers will also be asked to review the Data Management Plan and the Postdoctoral Researcher Mentoring Plan, as appropriate.

Additional Solicitation Specific Review Criteria

All proposals must clearly address the following solicitation-specific review criteria through well-identified proposal elements:

- To what extent does the proposed research advance the frontiers of spectral efficiency while addressing research challenges related to energy efficiency and/or security?
- Does the proposal have the required collaborative teaming to address research issues across multiple layers, from the physical layer to the network layer and above?
- What is the potential for the outcomes of proposed activities to inform industry and/or government on issues relating to spectrum usage?

B. Review and Selection Process

Proposals submitted in response to this program solicitation will be reviewed by Panel Review.

Reviewers will be asked to evaluate proposals using two National Science Board approved merit review criteria and, if applicable, additional program specific criteria. A summary rating and accompanying narrative will generally be completed and submitted by each reviewer and/or panel. The Program Officer assigned to manage the proposal's review will consider the advice of reviewers and will formulate a recommendation.

After scientific, technical and programmatic review and consideration of appropriate factors, the NSF Program Officer recommends to the cognizant Division Director whether the proposal should be declined or recommended for award. NSF strives to be able to tell applicants whether their proposals have been declined or recommended for funding within six months. Large or particularly complex proposals or proposals from new awardees may require additional review and processing time. The time interval begins on the deadline or target date, or receipt date, whichever is later. The interval ends when the Division Director acts upon the Program Officer's recommendation.

After programmatic approval has been obtained, the proposals recommended for funding will be forwarded to the Division of Grants and Agreements for review of business, financial, and policy implications. After an administrative review has occurred, Grants and Agreements Officers perform the processing and issuance of a grant or other agreement. Proposers are cautioned that only a Grants and Agreements Officer may make commitments, obligations or awards on behalf of NSF or authorize the expenditure of funds. No commitment on the part of NSF should be inferred from technical or budgetary discussions with a NSF Program Officer. A Principal Investigator or organization that makes financial or personnel commitments in the absence of a grant or cooperative agreement signed by the NSF Grants and Agreements Officer does so at their own risk.

Once an award or declination decision has been made, Principal Investigators are provided feedback about their proposals. In all cases, reviews are treated as confidential documents. Verbatim copies of reviews, excluding the names of the reviewers or any reviewer-identifying information, are sent to the Principal Investigator/Project Director by the Program Officer. In addition, the proposer will receive an explanation of the decision to award or decline funding.

VII. AWARD ADMINISTRATION INFORMATION

A. Notification of the Award

Notification of the award is made to *the submitting organization* by a Grants Officer in the Division of Grants and Agreements. Organizations whose proposals are declined will be advised as promptly as possible by the cognizant NSF Program administering the program. Verbatim copies of reviews, not including the identity of the reviewer, will be provided automatically to the Principal Investigator. (See Section VI.B. for additional information on the review process.)

B. Award Conditions

An NSF award consists of: (1) the award notice, which includes any special provisions applicable to the award and any numbered amendments thereto; (2) the budget, which indicates the amounts, by categories of expense, on which NSF has based its support (or otherwise communicates any specific approvals or disapprovals of proposed expenditures); (3) the proposal referenced in the award notice; (4) the applicable award conditions, such as Grant General Conditions (GC-1)*; or Research Terms and Conditions* and (5) any announcement or other NSF issuance that may be incorporated by reference in the award notice. Cooperative agreements also are administered in accordance with NSF Cooperative Agreement Financial and Administrative Terms and Conditions (CA-FATC) and the applicable Programmatic Terms and Conditions. NSF awards are electronically signed by an NSF Grants and Agreements Officer and transmitted electronically to the organization via e-mail.

*These documents may be accessed electronically on NSF's Website at https://www.nsf.gov/awards/managing/award_conditions.jsp?org=NSF. Paper copies may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-7827 or by e-mail from nsfpubs@nsf.gov.

More comprehensive information on NSF Award Conditions and other important information on the administration of NSF awards is contained in the NSF *Proposal & Award Policies & Procedures Guide* (PAPPG) Chapter VII, available electronically on the NSF Website at https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg.

C. Reporting Requirements

For all multi-year grants (including both standard and continuing grants), the Principal Investigator must submit an annual project report to the cognizant Program Officer no later than 90 days prior to the end of the current budget period. (Some programs or awards require submission of more frequent project reports). No later than 120 days following expiration of a grant, the PI also is required to submit a final project report, and a project outcomes report for the general public.

Failure to provide the required annual or final project reports, or the project outcomes report, will delay NSF review and processing of any future funding increments as well as any pending proposals for all identified PIs and co-PIs on a given award. PIs should examine the formats of the required reports in advance to assure availability of required data.

PIs are required to use NSF's electronic project-reporting system, available through Research.gov, for preparation and submission of annual and final project reports. Such reports provide information on accomplishments, project participants (individual and organizational), publications, and other specific products and impacts of the project. Submission of the report via Research.gov constitutes certification by the PI that the contents of the report are accurate and complete. The project outcomes report also must be prepared and submitted using Research.gov. This report serves as a brief summary, prepared specifically for the public, of the nature and outcomes of the project. This report will be posted on the NSF website exactly as it is submitted by the PI.

More comprehensive information on NSF Reporting Requirements and other important information on the administration of NSF awards is contained in the *NSF Proposal & Award Policies & Procedures Guide* (PAPPG) Chapter VII, available electronically on the NSF Website at https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg.

VIII. AGENCY CONTACTS

Please note that the program contact information is current at the time of publishing. See program website for any updates to the points of contact.

General inquiries regarding this program should be made to:

- Jenshan Lin, ENG/ECCS, telephone: (703) 292-8339, email: jenlin@nsf.gov
- Monisha Ghosh, CISE/CNS, telephone: (703) 292-8950, email: mghosh@nsf.gov
- Akbar Sayeed, ENG/ECCS, telephone: (703) 292-8339, email: asayeed@nsf.gov
- Lawrence S. Goldberg, ENG/ECCS, telephone: (703) 292-8339, email: lgoldber@nsf.gov

For questions related to the use of FastLane, contact:

- FastLane Help Desk, telephone: 1-800-673-6188; e-mail: fastlane@nsf.gov.

For questions relating to Grants.gov contact:

- Grants.gov Contact Center: If the Authorized Organizational Representatives (AOR) has not received a confirmation message from Grants.gov within 48 hours of submission of application, please contact via telephone: 1-800-518-4726; e-mail: support@grants.gov.

IX. OTHER INFORMATION

The NSF website provides the most comprehensive source of information on NSF Directorates (including contact information), programs and funding opportunities. Use of this website by potential proposers is strongly encouraged. In addition, "NSF Update" is an information-delivery system designed to keep potential proposers and other interested parties apprised of new NSF funding opportunities and publications, important changes in proposal and award policies and procedures, and upcoming NSF [Grants Conferences](#). Subscribers are informed through e-mail or the user's Web browser each time new publications are issued that match their identified interests. "NSF Update" also is available on [NSF's website](#).

Grants.gov provides an additional electronic capability to search for Federal government-wide grant opportunities. NSF funding opportunities may be accessed via this mechanism. Further information on Grants.gov may be obtained at <http://www.grants.gov>.

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NSF funds research and education in most fields of science and engineering. It does this through grants and cooperative agreements to more than 2,000 colleges, universities, K-12 school systems, businesses, informal science organizations and other research organizations throughout the US. The Foundation accounts for about one-fourth of Federal support to academic institutions for basic research.

NSF receives approximately 55,000 proposals each year for research, education and training projects, of which approximately 11,000 are funded. In addition, the Foundation receives several thousand applications for graduate and postdoctoral fellowships. The agency operates no laboratories itself but does support National Research Centers, user facilities, certain oceanographic vessels and Arctic and Antarctic research stations. The Foundation also supports cooperative research between universities and industry, US participation in international scientific and engineering efforts, and educational activities at every academic level.

Facilitation Awards for Scientists and Engineers with Disabilities (FASSED) provide funding for special assistance or equipment to enable persons with disabilities to work on NSF-supported projects. See the *NSF Proposal & Award Policies & Procedures Guide* Chapter

II.E.6 for instructions regarding preparation of these types of proposals.

The National Science Foundation has Telephonic Device for the Deaf (TDD) and Federal Information Relay Service (FIRS) capabilities that enable individuals with hearing impairments to communicate with the Foundation about NSF programs, employment or general information. TDD may be accessed at (703) 292-5090 and (800) 281-8749, FIRS at (800) 877-8339.

The National Science Foundation Information Center may be reached at (703) 292-5111.

The National Science Foundation promotes and advances scientific progress in the United States by competitively awarding grants and cooperative agreements for research and education in the sciences, mathematics, and engineering.

To get the latest information about program deadlines, to download copies of NSF publications, and to access abstracts of awards, visit the NSF Website at <https://www.nsf.gov>

- **Location:** 2415 Eisenhower Avenue, Alexandria, VA 22314
- **For General Information** (NSF Information Center): (703) 292-5111
- **TDD (for the hearing-impaired):** (703) 292-5090
- **To Order Publications or Forms:**
 - Send an e-mail to: nsfpubs@nsf.gov
 - or telephone: (703) 292-7827
- **To Locate NSF Employees:** (703) 292-5111

PRIVACY ACT AND PUBLIC BURDEN STATEMENTS

The information requested on proposal forms and project reports is solicited under the authority of the National Science Foundation Act of 1950, as amended. The information on proposal forms will be used in connection with the selection of qualified proposals; and project reports submitted by awardees will be used for program evaluation and reporting within the Executive Branch and to Congress. The information requested may be disclosed to qualified reviewers and staff assistants as part of the proposal review process; to proposer institutions/grantees to provide or obtain data regarding the proposal review process, award decisions, or the administration of awards; to government contractors, experts, volunteers and researchers and educators as necessary to complete assigned work; to other government agencies or other entities needing information regarding applicants or nominees as part of a joint application review process, or in order to coordinate programs or policy; and to another Federal agency, court, or party in a court or Federal administrative proceeding if the government is a party. Information about Principal Investigators may be added to the Reviewer file and used to select potential candidates to serve as peer reviewers or advisory committee members. See Systems of Records, [NSF-50](#), "Principal Investigator/Proposal File and Associated Records," 69 Federal Register 26410 (May 12, 2004), and [NSF-51](#), "Reviewer/Proposal File and Associated Records," 69 Federal Register 26410 (May 12, 2004). Submission of the information is voluntary. Failure to provide full and complete information, however, may reduce the possibility of receiving an award.

An agency may not conduct or sponsor, and a person is not required to respond to, an information collection unless it displays a valid Office of Management and Budget (OMB) control number. The OMB control number for this collection is 3145-0058. Public reporting burden for this collection of information is estimated to average 120 hours per response, including the time for reviewing instructions. Send comments regarding the burden estimate and any other aspect of this collection of information, including suggestions for reducing this burden, to:

Suzanne H. Plimpton
Reports Clearance Officer
Office of the General Counsel
National Science Foundation
Alexandria, VA 22314

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