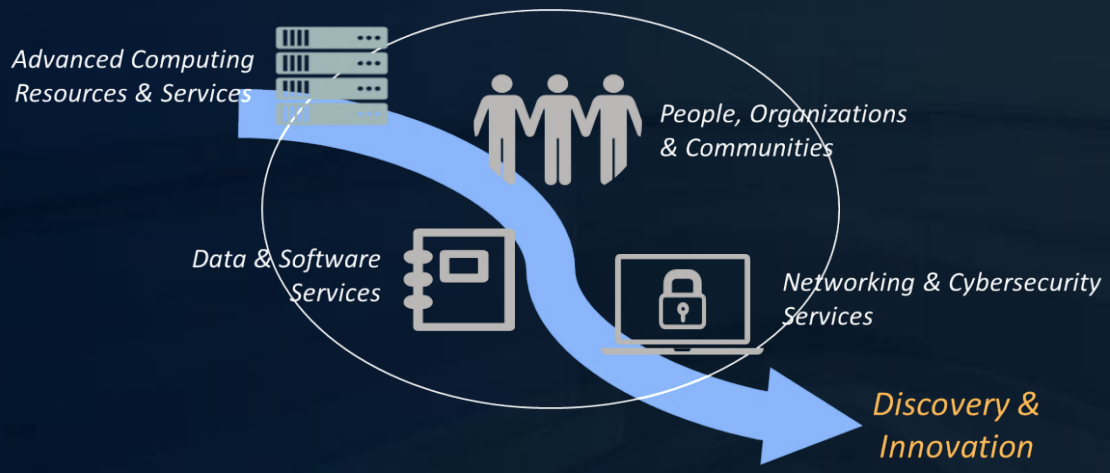
Transforming Science Through Cyberinfrastructure

NSF's Blueprint for a National Cyberinfrastructure Ecosystem for Science and Engineering in the 21st Century



Blueprint for International Research and Education Network Connections

Office of Advanced Cyberinfrastructure
Directorate for Computer & Information Science & Engineering
National Science Foundation

November 2019

Transforming Science Through Cyberinfrastructure: International Research and Education Network Connections

NSF's Blueprint for International Research and Education Network Connections for Accelerating Science and Engineering in the 21st Century

Executive Summary

The national research cyberinfrastructure (CI) has become critical to computational and data intensive research across all of science and engineering (S&E) in the 21st century. NSF recently shared a vision, developed by the National Science Foundation (NSF) Office of Advanced Cyberinfrastructure (OAC), for ***an agile, integrated, robust, trustworthy and sustainable CI ecosystem that drives new thinking and transformative discoveries in all areas of science and engineering (S&E) research and education***. The envisioned CI ecosystem integrates advanced CI resources, services and expertise towards collectively enabling new, transformative discoveries across all of S&E. This document is the third in this series of blueprint documents that outline NSF's plan for realizing this vision and presents a forward-looking blueprint for international networking connections that are essential for international science and engineering research and education collaborations involving the NSF research community.

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1 Introduction

The national research cyberinfrastructure (CI) has become critical to computational and data intensive research across all of science and engineering (S&E) in the 21st century. It is a key catalyst for discovery and innovation and plays a critical role in ensuring US leadership in S&E, economic competitiveness, and national security, consistent with the National Science Foundation's (NSF's) mission. NSF, through the Office of Advanced Cyberinfrastructure (OAC), has shared a vision[1] that calls for the broad availability and innovative use of ***an agile, integrated, robust, trustworthy and sustainable CI ecosystem*** that can ***drive new thinking and transformative discoveries in all areas of S&E research and education***.

NSF's vision for an agile, integrated, robust, trustworthy and sustainable CI ecosystem that drives new thinking and transformative discoveries in all areas of S&E research and education

- *View CI more holistically: CI continuum seamlessly integrating a spectrum of resources, tools, services, and expertise to enable transformative discoveries.*
- *Support translational research: Core innovations → development of community tools and frameworks → deployment and operation of sustainable production CI.*
- *Balance innovation with stability: Ensure continuity in production computational capacity while fostering innovation and transition to production.*
- *Couple discovery and CI innovation cycles : Rapidly address new challenges and opportunities in an era of disruptive technologies and evolving science needs.*
- *Improve usability: Ease pathways for discovering, accessing, understanding and using powerful CI capabilities and services to enhance researcher productivity and scientific impact.*

This document is the third in this series of blueprint documents that outline NSF's plan for realizing this vision. It presents a forward-looking blueprint for international research and education (R&E) network connections that are required by international S&E research and education collaborations involving the NSF research community. This blueprint is informed by the community through advisory bodies, requests for information (RFIs), workshops and conferences, and national initiatives (including those listed in the vision document).

2 NSF's International Networking Investments

2.1 Background

For 30 years, NSF has invested in Internet connectivity linking the scientific research and education communities in the US to the rest of the world. At first, NSF was the sole funder of international R&E connectivity. In the intervening decades, external funding has grown substantially. Today, trans-oceanic 100-gigabit-per-second (Gbps) links made available specifically to the R&E community approach or exceed an aggregate terabit-per-second (Tbps) between some continents, with some 100Gbps links dedicated to specific science communities

[1] "Transforming Science Through Cyberinfrastructure: NSF's Blueprint for a National Cyberinfrastructure Ecosystem for Science and Engineering in the 21st Century," https://www.nsf.gov/cise/oac/vision/blueprint-2019/.

and instruments. Consortia of funding sources have formed for some of these paths and the level of support, cooperation, and planning among participating national R&E networks (NRENs) and among other network asset owners and operators have never been stronger. The nature of investments has also evolved, with funding entities moving beyond multi-year circuit leases to long term acquisition of submarine cable spectrum and even partnering in building and operating new cable systems, ensuring greater predictability and stability as well as capacity. The emergence of Low Earth Orbit (LEO) satellite systems, both underway and in planning phases, promises new opportunities for R&E network connectivity to hard-to-reach scientific research and education locations.

At the same time, while some major scientific instrumentation (such as the Large Hydron Collider in CERN, Switzerland supporting High Energy Physics researchers, and the Large Synoptic Sky Survey (LSST) telescope under construction in Chile) has in place strong global network connectivity to deliver data to their user communities, other remote instruments have little or no Internet connectivity supporting their science mission. Multi-messenger Astrophysics (MMA), Earth Horizon Telescope (EHT) and the academic research vessel fleet are examples where lack of high bandwidth end-to-end connectivity may impact the rate of future scientific discovery.

In addition to the challenges of remote instrumentation connectivity, national R&E networks (NRENs) and other organizations have progressed in leveraging high performance R&E networking at regional and country levels in building and establishing shared, virtualized, distributed computing and storage platforms. Those activities and assets also present continued opportunities for international R&E infrastructure and services to significantly advance in both the integration of network capabilities and services up the stack, as well supporting the federation of those resources and services on a global scale.

2.2 The Current NSF International Networking Portfolio

NSF's networking investments are spread across two distinct OAC programs, one domestic, i.e., Campus Cyberinfrastructure (CC*); and the second international in scope, i.e., International Research Network Connections (IRNC). The CC* program is primarily a campus networking infrastructure and innovation program and has since expanded to support campus CI more broadly. Its investments include improvements and re-engineering at the campus level to support a range of data transfers supporting computational science and computer networks and systems research. This document focuses on IRNC, which represents 30 years of continuous NSF investment in international network connectivity in response to data driven needs of scientific advancement through global collaboration. It provides high performance network capacity linking U.S. and other regions in the world in support of global R&E collaborations, particularly those associated with international instruments and facilities.

During 2014-2019, the IRNC program has supported high performance network connectivity required by international science and engineering R&E collaborations including multiple 100Gbps connections between the U.S. and Asia, Europe, Africa and the Americas, and has addressed the following priorities: (1) link U.S. research networks with peer networks in other parts of the world and leverage existing international network connectivity; (2) support U.S. infrastructure and innovation of open network exchange points; (3) drive innovation and state-of-the-art capabilities for R&E Network Operation Centers (NOC); (4) stimulate the development, application and use of advanced network measurement capabilities and services across international network paths; and (5) support community engagement in training and human and network capacity building, and coordination in advanced network engineering.

NSF's 2014-2019 main IRNC portfolio (current as of 11/14/19) is summarized in Appendix 1. It totals twelve projects and is composed of: four Connections awards each supporting 100Gbps+ connectivity to the Americas, Australia and Pacific Islands, Japan and Asia, and Europe and Africa; three Open Exchange Point awards; three measurement projects; one primary NOC award; one outreach and engagement award; and one Africa planning award. Funding for the 2014-2019 IRNC portfolio exceeds $48M.

NSF's International Research and Education Network Connections (IRNC) Portfolio

Backbone Awards (100Gbps+ dedicated R&E network paths)
- *AmLight Express (multi 100Gbps US/Americas), FIU*
- *TransPac4 (100Gbps+ US/ Japan/Asia), Indiana U*
- *PIREN (200Gbps+ US/Australia/Pacific Islands), U of Hawaii*
- *NEAAR (multi 100Gbps to/from Europe), Indiana U*
- *US-Africa Spectrum Study (spectrum feasibility via Brazil), FIU*

Innovative Software defined Open Exchange Points Awards
- *PacWave (distributed Pacific Exchange Point), CENIC*
- *AtlanticWave (Miami Exchange Point for Americas), FIU*
- *StarLight (Chicago International Exchange Point), NWU*

Measurement and Operations
- *NetSage (Measurement), Indiana U*
- *Global NOC (Network Operations), Indiana U*

Training and Outreach
- *NSRC (Global R&E Networking Training/Outreach), U of Oregon*
- *PRAGMA (Pacific Rim Grid Miidleware Collaboration), UCSD*

High performance network connections funded by the IRNC program are intended to support science and engineering research and education applications. IRNC seeks solutions which provide the best economy of scale and demonstrate the ability to support the largest communities of interest with the broadest services. The ultimate goal of the program is to assist the U.S. research and education community by fostering state-of-the-art international network services and access to increased collaboration and data services. Through extended international network connections, additional research and production network services will be enabled, complementing those currently offered or planned by domestic research networks.

3 A Blueprint for International Research and Education Networking for Accelerating Science and Engineering in the 21st Century

This section presents NSF's forward-looking blueprint for international R&E network connections. NSF aims to conceptualize, pilot and implement a set of strategic international network connections that provide the core capabilities that are required by international S&E

collaborations involving the NSF community. Aligned with NSF's mission, these connections will be driven by current and future science needs. Furthermore, they will to extent possible complement investments by other Nations, respond to identified gaps in access and connectivity, and where possible, leverage international partnerships. In addition to providing core connectivity, services and expertise (which we call "base"), the international connections will explore science-driven connectivity to instruments and observatories in support of end-to-end applications ("applied"). Note that the CI services are complemented by the other components of the CI ecosystem as presented in NSF's CI vision[1]. The international R&E networking blueprint has two key components as illustrated in Figure 1 and described below.

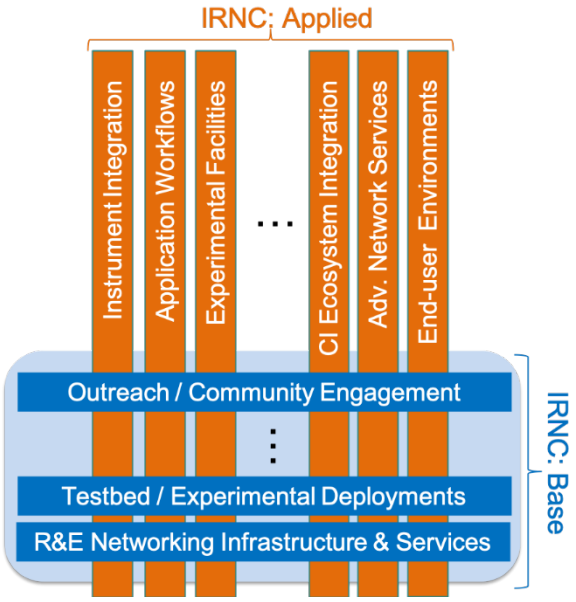

Figure 1. Overview of NSF's International Research Networking Ecosystem

OAC envisions future IRNC investments composed of two major components: (1) IRNC: Base, which provides dedicated R&E capacity between the U.S. and other parts of the world; and (2) IRNC: Applied, which focuses on end-to-end connectivity to major research facilities and integrated CI resources. Dividing the program into these two major areas allows OAC to focus investments and enable innovation in different components of the overall international research fabric.

3.1 IRNC: Base

Current and past IRNC program investments have largely focused on establishing and growing dedicated R&E network capacity between the U.S. and other regions of the world. Moving forward, the IRNC base component will support coordinated investment in conceptualizing and deploying international R&E networking infrastructure and services, experimental deployment of new capabilities using testbeds, and broadening impact and participation through data network centric activities.

3.2 IRNC: Applied

An emerging theme in international networking combines the horizontal axis of end-to-end connectivity with the vertical axis of application and user environment integration. That integration can also be viewed as distributed computing and storage resource integration. The applied component of the IRNC program moving forward will cover application-oriented IRNC topics including high performance network connectivity to remote scientific instruments and sites; and innovation and advancement of network services, engineering, capabilities through end-to-end scientific workflow integration with research platforms.

3.3 Putting the Plan into Action: Programs, Projects and Opportunities

NSF plans to move ahead aggressively to put this blueprint for international research and education network connections into action through programs and projects to ensure continuity of operations while also ensuring that the resulting services are responsive to current and emerging S&E needs. A notional timeline is presented in Figure 2 and is composed of:

- IRNC: Base, which will continue to support a basis international networking infrastructure and associated services as well as testbeds to drive innovation and user engagement and support.
- IRNC: Applied, which will constitute partnership between OAC and NSF science and engineering directorates.

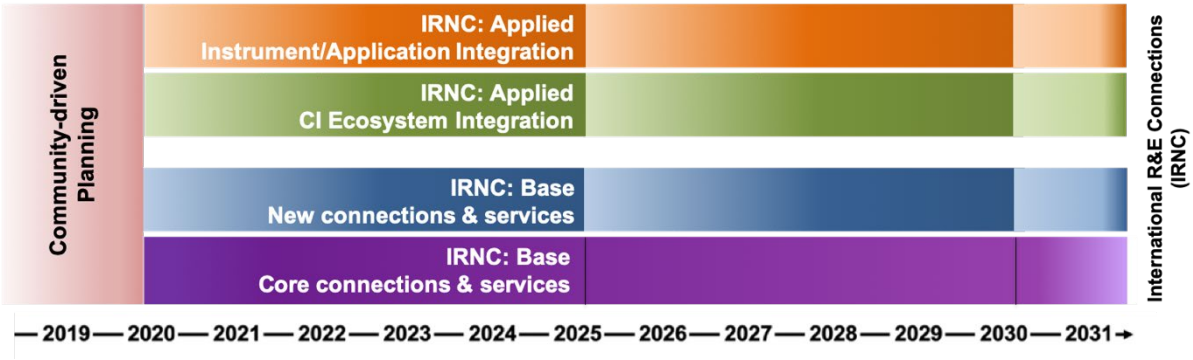

Figure 2. Notional execution timeline for the international research and education networking blueprint.

4 Ongoing Strategic Planning and Community Engagement

NSF will continue its strategic planning and community engagement activities as it explores other elements of computational ecosystem, including software and data systems and services, networking, cybersecurity, and learning and workforce development. NSF notes that this blueprint is the second of a series of blueprints focused on different elements of the CI ecosystem to be developed in partnership with the community.

Looking to the future, the road ahead for research CI promises to be exciting with many new opportunities. In the near term, NSF Big Ideas are moving into full gear with multiple new solicitations and are complemented by recent relevant national initiatives in areas such as Quantum Information Science (including a National Quantum Initiative Act signed into law in December 2018[2]) and Artificial Intelligence (including an Executive Order on *Maintaining American Leadership in Artificial Intelligence*[3]). NSF's investments, for example, as part of the Quantum Leap Big Idea[4], including the Quantum Computing & Information Science Faculty Fellows (QCIS-FF) program (NSF 19-507)[5], as well as foundational and translational Artificial Intelligence and Machine Learning[6] research [see, for example, the recently-launched National

[2] "National Quantum Initiative," https://www.congress.gov/115/bills/hr6227/BILLS-115hr6227enr.pdf.
[3] "Executive Order on Maintaining American Leadership in Artificial Intelligence," https://www.whitehouse.gov/presidential-actions/executive-order-maintaining-american-leadership-artificial-intelligence/.
[4] "NSF Quantum Leap Big Idea," https://www.nsf.gov/news/special_reports/big_ideas/quantum.jsp.
[5] "Quantum Computing & Information Science Faculty Fellows (QCIS-FF)," https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505535.
[6] "Artificial Intelligence (AI) at NSF," https://nsf.gov/cise/ai.jsp.

Artificial Intelligence (AI) Research Institutes program (NSF 20-503)[7]], will help define the nature and structure of the CI ecosystem over the longer term. NSF looks forward to continuing to work with the community to define the future of cyberinfrastructure research and research cyberinfrastructure, with the overarching goal of realizing and integrated CI ecosystem that transforms all of S&E research and education.

5 Conclusion

The NSF-funded CI ecosystem is playing an increasingly critical role across all of S&E research and education, enabling discoveries and driving innovation. It is an important part of the national CI ecosystem that is critical for ensuring US leadership in S&E, economic competitiveness and national security. As a result, it is essential that NSF strategically rethink and evolve this CI ecosystem in response to the changing nature of needs of S&E, driven by the changing technology landscape, and informed by community inputs. This document builds on the NSF's recently articulated vision for a national CI ecosystem that integrates computational, data, software, networking, and security resources, tool and services, and computational and data skills and expertise towards collectively enabling new, transformative discoveries across all of S&E, and presented NSF's blueprint for international research and education network connections to support science and engineering research and education in the 21st century. It also outlined a plan to implement this blueprint. The vision and blueprint presented in this document have been informed by the community through advisory bodies, requests for information (RFIs), workshops and conferences, and national initiatives. NSF intends to continue to work with the community to evolve and implement the vision and blueprint presented in this document, as well as to develop complementary blueprints for other CI elements.

[7] "National Artificial Intelligence (AI) Research Institutes," https://www.nsf.gov/pubs/2020/nsf20503/nsf20503.htm.

Appendix I. NSF's International Research and Education Network Connections (IRNC) Portfolio

Active IRNC Backbone Awards				
Title	**PI**	**Institution**	**Award#**	**Description**
AmLight Express	Ibarra, Julio	FIU	1451018	680Gbps+ US/Americas/Africa
TransPAC4	Schopf, Jennifer	Indiana U	1450904	100Gbps+ US/Japan/Asia
PIREN	Lassner, David	U of Hawaii	1451058	200Gbps+ US/Australia/Pacific Islands
NEAAR	Schopf, Jennifer	Indiana U.	1638863	100Gbps US/Europe/Africa

Active IRNC Exchange Point Awards				
Title	**PI**	**Institution**	**Award#**	**Description**
AtlanticWave	Ibarra, Julio	FIU	1451024	Americas Exchange Point
PacWave	Fox, Louis	CENIC	1451050	PacificWave Exchange Point
StarLight	Mambretti, Joe	Northwestern	1450871	StarLight Exchange Point

Active IRNC Awards in Special Areas				
Title	PI	Institution	Award#	Description
NSRC	Huter, Steven	U of Oregon	1451045	Global R&E Networking Training and Outreach
PRAGMA	Smallen, Shava	UCSD	1234983	Pac Rim Grid Middleware Collaboration
GRNOC	Jent, David	Indiana U.	1450934	Global R&E NOC
NetSage	Schopf, Jennifer	Indiana U.	1540933	Network Measurement