

# US National Science Foundation and the Future Internet Design

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## Introduction

In spite of the current Internet's overwhelming success, there are growing concerns about its future and its robustness, manageability, security, openness to innovation, and scalability. As the Internet has become the largest human-made system ever deployed will we retain the ability to understand or manage it? Will we find ways to secure the current Internet or will we lose the security arms race to hackers and even state-supported attackers as they become more pervasive and sophisticated? Will the Internet continue to incorporate the thousands of new wireless networks currently added daily or encompass millions of embedded sensor systems that are expected to connect to the Internet in the future? There are also increasing societal concerns such as ensuring that an Internet maintains support for an open society, a balance of accountability and privacy, and continued economic viability. Will Internet companies continue to create new services and capabilities for the current Internet or will economic factors result in "network ossification" as some researchers fear?

These are questions that concern networking and social science researchers around the world. In the United States, the National Science Foundation (NSF) has challenged the US research community to take a fresh look at the Internet by participating in the Future Internet Design (FIND) part of the Networking Technology and Systems (NeTS) program in the Division of Computer and Network Systems.

## NSF's Future Internet Design (FIND)

Creating bold new research challenges is part of NSF's mission and NSF is a leader among national and international agencies for funding high-impact computer

and information science research. Within NSF, the Directorate for Computer Information Science and Engineering (CISE) "supports investigator initiated research in all areas of computer and information science and engineering" ([www.cise.nsf.gov](http://www.cise.nsf.gov)) and constitutes about 85% of current Federal funding in basic research for U.S. academic computer science and engineering.

Networking Technology and Systems (NeTS) supports the networking research community at a funding level of approximately \$40 million per year. It supports four large areas of networking research, three of which, Wireless Networks (WN), Networks of Sensor Systems (NOSS), and Networking Broadly Defined (NBD) focus on the current Internet and emerging networks. NeTS continues to support research on the current Internet, but also considers the possibility that simply placing band-aids on the current system will not work, but must get researchers to think about how to design a new Internet if they could take what they have learned from the current Internet to design a new network system that meets the needs of the twenty-first century.

Future Internet Design was created in 2006 to empower the research community to design and implement a new Future Internet that builds on knowledge and wisdom about current networks, but is not constrained by the current Internet. FIND enables the US academic networking research community to take a clean-slate design approach, submit research proposals that address architectural design components and issues, and work together to design new Internet architectures that meet tomorrow's requirements of being secure, robust, manageable, flexible, scalable, capable of including billions of wireless and sensor networks and supportive of new applications and services as well as being economically viable. FIND provides funding for the research community and a forum for discussion and collaboration through its FIND meetings that are held three times per year.

The intellectual scope of FIND<sup>1</sup> is broad and supports research that addresses questions such as:

- How can we design a network that is fundamentally more secure and available than today's Internet? How would we define and solve

the security problems if we could start from scratch?

- How might such functions as information dissemination, location management or identity management be addressed into a new network architecture?
- What will be the long-term impact of new technologies such as advanced wireless and optics?
- How will economics and technology interact to shape the overall design of a future network?
- How do we design a network that fosters a free and open society?

### Three Phases of FIND

There are three phases to FIND with the duration of the phases dependent upon the progress of the research. The current expectation is that each phase will last about three years while retaining the opportunity of researchers to submit proposals appropriate for earlier phases if they have new and exciting ideas. This iterative aspect of FIND is intended to continue to refresh FIND and to educate new researchers on how to design, build and deploy new large-scale architectures and systems.

The first phase projects primarily focus on components or parts of an architecture such as new schemes for security, naming, or routing. FIND is in its second year of its first phase and is now at the stage of selecting new projects for funding. The 2007 projects will be added this summer to the 2006 projects on the FIND community's website [www.nets-find.net](http://www.nets-find.net).

FIND will continue soliciting component projects, but the program will enter its second phase of the program during which researchers will be asked to form teams and propose overarching network architectures using research and knowledge gained from the first phase. NSF, with input from the FIND research community, is in the initial planning stage for this phase of FIND with active discussions, for example, about the best way to develop full scale Future Internet architectures and what the evaluation criteria for architecture-design proposals should entail.

The third phase of FIND involves implementing overarching research network architectures, creating code and testing them first through emulation and simulation and then by experimenting with them on national-scale network infrastructures with real users and real data. In addition, there is an expectation that in the future there will be a federation of national scale infrastructures, for example with wide-area network infrastructure facilities in the US joined with those in the EU and Asian countries.

### The FIND Portfolio

The current FIND portfolio includes a variety of research topics in twenty-six funded projects. The following is only a very high-level sample of some of the projects in FIND. The complete project descriptions are at [www.nets-find.net](http://www.nets-find.net). At one end of the spectrum, FIND includes technology projects that focus on new ideas and capabilities for optical, wireless, and sensor networks and their potential impacts on an overall new architecture--a challenge that FIND is only beginning to explore. At the other end of the spectrum are proposals that advocate the possibility that virtualization may become the new network architecture. One virtualization project proposes a new "layer 2+" hour glass that would support multiple networks above it, and another looks at new end-to-end services with virtual nodes and links that form an architecture with multiple hour glasses.

In between the extremes of simply looking at lower layer or edge technologies and new hour glasses that support multiple networks are projects that propose new approaches to architectural components such as new naming (e.g., handles, naming for small devices,) addressing, routing (e.g., user controlled routes), and service schemes. FIND projects also explore architecture building principles such composable architectural building blocks and a recursive network architecture using a single, tunable protocol for different layers of the protocol stack.

In addition to projects mentioned above that focus on a new national- or global-scale Future Internet, FIND funded delay tolerant network architectures including a network, which relies on role-based addressing and anycast, that can be composed use ad hoc networks during disasters and a cache and forward network particularly suited for transporting large files to communication limited edge nodes.

There are also several overarching or meta-network projects that explore management mechanisms such as in routing systems and model-based diagnosis of the knowledge plane. One seeks to build-in security with least-privilege and default-off, whereby users may access only hosts that have explicitly granted them privileges. Another project explores packet attribution with privacy preservation. There are other projects that focus on economics and market-enabled architectures.

### Success Criteria

Efforts like FIND should not be judged against a single criterion but against a variety of success criteria. For example, FIND will be successful if the research it supports produces a new generation of young researchers who think more creatively, understand how to design and build large scale systems, and create new applications and services.

FIND research will be a success if it has an impact on the current Internet much the way IPv6 has challenged and changed IPv4 without itself as yet being widely deployed. For example, new ways of thinking about security for the Future Internet might result in the development of technologies that could be adapted in the current Internet and result, for example, in more secure critical network components such as routers, middleboxes, BGP (Border Gateway Protocol) or DNS (Domain Name Service). FIND research that improves usability or creates new applications and services that run on both a new network architecture and on the current Internet would be additional examples of success.

If virtualization actually works and the research community creates one or more new architectures that run in parallel with the current Internet--for example, creating a separate highly secure and robust real-time network for supporting critical infrastructure such as the power grid--that would be a success. Important research in the FIND portfolio expands the scope and scale of the ways in which different parts of the network might be "virtualized" and then managed to run simultaneously.

Finally, FIND would be a success if it created new architectures that resulted in a new Internet that was so compelling that it replaced the current Internet. But this last scenario, the most challenging and perhaps most unlikely, is not necessary for success or the ultimate goal of FIND. FIND does not have to build a new Internet that totally replaces the current Internet to have a major impact on improving networking in the world.

## **FIND and GENI**

Crucial to the third phase of FIND, as mentioned above, is the existence of a national-scale networking research facility for the deployment, experimentation and testing of Future Internet architectures resulting from the FIND research program. The National Science Foundation in partnership with the research community has launched an

initiative, called the Global Environment for Networking Innovations (GENI)<sup>2</sup>, to create such a national-scale research facility. This facility will be a powerful resource on which to deploy and experiment with a large range of computer science and engineering research projects, including FIND projects. A description of GENI is expected to be a subject of a future CCR article.

## **Industrial and International Collaboration**

NSF and others around the world realize that it is important to be part of an international effort that engages governments, academics, and industry. There are an increasing number of efforts to work together on Future Internet projects. The FIND community has issued two calls for white papers as a way to identify and invite researchers who are currently working in FIND-like projects at universities and industry in the US and from other nations to join the FIND researchers in creating new network architectures. As a result researchers from four industrial projects, three from Europe, attended the March 2007 FIND meeting. Additional invitations resulting from a May call for white papers will be issued for the June 2007 FIND meeting. Future white papers calls will be posted at [www.nets-find.net](http://www.nets-find.net). The NSF program officers and FIND researchers are talking to researchers from industry and academia from the EU and Asia about similar programs and related research. An INFOCOM 2007 panel entitled, "Clean Slate Designs for a Future Internet", discussed examples of programs from the US, EU, Japan, and Korea. The April 2007 Computer Communications Review featured an article about the EU perspective on Future Internet Research<sup>3</sup>, which extended an invitation for international cooperation and partnerships.

These first efforts toward building an international community are important developments in the world of Internet research. And they are significant steps toward conceiving and building a Future Internet for the twenty-first century.

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[http://www.nsf.gov/publications/pub\\_summ.jsp?ods\\_key=nsf07057](http://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf07057) for the NeTS program announcement

<sup>2</sup> [www.nsf.gov/cise/cns/geni/](http://www.nsf.gov/cise/cns/geni/)

<sup>3</sup> J. da Silva. Future Internet Research: The EU framework. In CCR, 37 (2): 85-88.