



Request for NSF Highlight

National Science Foundation Computer and Information Science and Engineering Directorate (CISE) Computer and Network Systems Division (CNS)

Each year, NSF program officers are asked to provide descriptions of program accomplishments, or "highlights," about the outcomes of NSF awards. This activity is a requirement of the Government Performance and Results Act (GPRA). As a recipient of a NSF-CISE award, you are asked to provide the information outlined in this form.

Please save a copy of this form (and the completed version of the form) with a **file name** formed by concatenating your proposal number with your last name as:

Your NSF proposal number your last name.doc
(For example: 0599999Smith.doc)

Please return the completed form as an attachment to an email message you send to:

cnshighlights@nsf.gov

*Please note: This form is a Word Form. Please use the **TAB key** to move through the form. Other keys (such as the ENTER key) are likely to cause spurious behavior.*

Your Last Name:	Christensen
First Name:	Ken
Your Institution:	University of South Florida
Your email address:	christen@csee.usf.edu
Telephone Number:	813 974 4761

Your Project's Title:

Collaborative Research (NeTS-NBD): Increasing the Energy Efficiency of the Internet with a Focus on Edge Devices

Please enter your **NSF/CISE/CNS Award Number**: [Please note – If you are describing a collaborative award, please enter the proposal numbers for **all** of the affiliated awards]

NSF- 0520081	NSF-	NSF-	NSF-	NSF-
NSF-	NSF-	NSF-	NSF-	NSF-

What is the name of the NSF Program Officer who originally made this award or who is currently your cognizant Program Officer?

Fisher, Darleen

Select Primary (and Secondary) Strategic Outcome Goal

Included below are two tables – titled **Primary Strategic Outcome Goal** and **Secondary Strategic Outcome Goal**.

All NSF projects have “Primary” strategic outcome goals and they *may also have* “Secondary” strategic outcome goals. In the PRIMARY strategic outcome goal table please decide on **one category** (i.e., one column: Discovery, Learning or Research Infrastructure) that BEST DESCRIBES your project’s highlight. Within that column, please check one or more boxes that apply. If your project also has clear Secondary strategic outcome goals, decide on the appropriate column in the *second table* labeled “Secondary Strategic Outcome Goals and check as many boxes within that column that describe your project. So, for example, if your Primary Strategic Outcome Goal was Discovery, your Secondary Goal may be Learning.

Primary Strategic Outcome Goal

Decide whether your project’s *Primary Strategic Outcome* goals address Discovery, Learning **or** Research Infrastructure. For whichever of the three that captures your project’s focus, please check one or more boxes *within that column* that best describe your project.

Discovery	Learning	Research Infrastructure
<p>Fostering research that advances the frontiers of knowledge, emphasizing areas of greatest opportunity and potential benefit and establishing the nation as a global leader in fundamental and transformational science and engineering.</p>	<p>Defined in the NSF Strategic Plan 2006-2011 as "Cultivate a world-class, broadly inclusive science and engineering workforce, and expand the scientific literacy of all citizens."</p>	<p>Defined in the NSF Strategic Plan 2006-2011 as "Build the nation's research capability through critical investments in advanced instrumentation, facilities, cyber-infrastructure and experimental tools."</p>
<p>Please Note: If you are reporting an outcome from an EPSCoR Research Infrastructure Improvement grant, or a research grant co-funded with the EPSCoR Program, please check the EPSCoR box under DISCOVERY, as well as the box that represents the area of science, engineering, or education for the project. 2) If you are reporting an outcome of research conducted at an NSF-funded large facility and check a category under Discovery for the PRIMARY goal, please also check the Major Multi-User Facilities category under Research Infrastructure for the SECONDARY goal.</p>	<p>Please Note: 1) If you are reporting an outcome from an EPSCoR Research Infrastructure Improvement grant, or a research grant co-funded with the EPSCoR Program, please check the EPSCoR box under DISCOVERY, as well as the box that represents the area of science, engineering, or education for the project.</p>	<p>Please Note: 1) If you are reporting an outcome from an EPSCoR Research Infrastructure Improvement grant, or a research grant co-funded with the EPSCoR Program, please check the EPSCoR box under DISCOVERY, as well as the box that represents the area of science, engineering, or education for the project. 2) If you are reporting an outcome of research conducted at an NSF-funded large facility and check the Major Multi-User Facilities category under Research Infrastructure for the PRIMARY goal, please also check the appropriate category under Discovery for the SECONDARY goal.</p>
<p>Research Grants</p> <ul style="list-style-type: none"> <input type="checkbox"/> Biological Sciences <input checked="" type="checkbox"/> Computer & Information Science and Engineering <input type="checkbox"/> Cyberinfrastructure (excluding Shared Cyberinfrastructure Tools; see Research Infrastructure) <input type="checkbox"/> Engineering Research <input type="checkbox"/> Small Business Innovation Research/Small Business Technology Transfer <input type="checkbox"/> Geosciences: Earth, Atmosphere, and Ocean Sciences 	<ul style="list-style-type: none"> <input type="checkbox"/> K-12 Education <input type="checkbox"/> Teacher Education and In-service Professional Development <input type="checkbox"/> Undergraduate Education and Undergraduate Student Research <input type="checkbox"/> Graduate Education and Graduate Student Research <input type="checkbox"/> International Research Experiences for Undergraduate & Graduate Students <input type="checkbox"/> Postdoctoral Education, including International Postdoctoral Fellowships <input type="checkbox"/> Public Understanding of Science and Lifelong Learning <input type="checkbox"/> Broadening Participation to Improve Workforce Development <input type="checkbox"/> Promoting CyberLearning Strategies to Enhance STEM Education <input type="checkbox"/> Professional and Career Development (i.e., ADVANCE, Course, Curriculum, and Laboratory Improvement (CCLI)) 	<p>Major Multi-User Facilities</p> <ul style="list-style-type: none"> <input type="checkbox"/> Academic Research Fleet <input type="checkbox"/> ATLAS - A Toroidal Large Angle Spectrometer <input type="checkbox"/> CMS - Compact Muon Solenoid <input type="checkbox"/> Cornell Electron Storage Ring <input type="checkbox"/> Gemini Observatory <input type="checkbox"/> IRIS - Incorporated Research Institutes for Seismology <input type="checkbox"/> Integrated Ocean Drilling Program <input type="checkbox"/> Large Hadron Collider

<input type="checkbox"/> Mathematical & Physical Sciences <input type="checkbox"/> Social, Behavioral, & Economic Sciences <input type="checkbox"/> Polar Sciences: Arctic and Antarctic Research <input type="checkbox"/> CAREER: Faculty Early Career Program <input type="checkbox"/> EPSCoR: Experimental Program to Stimulate Competitive Research <input type="checkbox"/> International Collaborative Research <input type="checkbox"/> Education Research and Evaluation to Improve STEM Learning and Teaching NSF Centers <input type="checkbox"/> Centers for Analysis & Synthesis <input type="checkbox"/> Centers for Chemical Innovation <input type="checkbox"/> Engineering Research Centers <input type="checkbox"/> Materials Research Science & Engineering Centers <input type="checkbox"/> Nanoscale Science & Engineering Centers/Networks <input type="checkbox"/> Science & Technology Centers <input type="checkbox"/> Science of Learning Centers	Program, & Advanced Technological Education (ATE Program)	<input type="checkbox"/> Laser Interferometer Gravitational Wave Observatory (LIGO) <input type="checkbox"/> MREFC Projects: ALMA, Earthscope, IceCube Neutrino Observatory, SODV (Scientific Ocean Drilling Vessel), South Pole Station Modernization, NEON, OOI, ARRV, ATST <input type="checkbox"/> National Astronomy and Ionosphere Center (NAIC) <input type="checkbox"/> National Center for Atmospheric Research (NCAR) <input type="checkbox"/> National High Magnetic Field Laboratory <input type="checkbox"/> National Nanofabrication Infrastructure Network <input type="checkbox"/> National Optical Astronomy Observatory (NOAO) <input type="checkbox"/> National Radio Astronomy Observatory (NRAO) <input type="checkbox"/> National Solar Observatory <input type="checkbox"/> National Superconducting Cyclotron Laboratory <input type="checkbox"/> Network for Earthquake Engineering Simulation (NEES) <input type="checkbox"/> Polar Facilities & Logistics <input type="checkbox"/> Major Research Instrumentation (MRI) Program <input type="checkbox"/> Shared Cyberinfrastructure Tools <input type="checkbox"/> Other Infrastructure and Research Resources
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Secondary Strategic Outcome Goal

Complete this table **only** if your project has clear *Secondary Outcome goals*. So, for example, if your Primary Strategic Outcome Goal was Discovery, then your Secondary Strategic Outcome Goal can be either Learning or Research Infrastructure. Please check one or more boxes within that column that describe your project's Secondary Strategic Outcome goals:

Discovery	Learning	Research Infrastructure
<p>Fostering research that advances the frontiers of knowledge, emphasizing areas of greatest opportunity and potential benefit and establishing the nation as a global leader in fundamental and transformational science and engineering.</p> <p>Please Note: If you are reporting an outcome from an EPSCoR Research Infrastructure Improvement grant, or a research grant co-funded with the EPSCoR Program, please check the EPSCoR box under DISCOVERY, as well as the box that represents the</p>	<p>Defined in the NSF Strategic Plan 2006-2011 as "Cultivate a world-class, broadly inclusive science and engineering workforce, and expand the scientific literacy of all citizens."</p> <p>Please Note: 1) If you are reporting an outcome from an EPSCoR Research Infrastructure Improvement grant, or a research grant co-funded with the EPSCoR Program, please check the EPSCoR box under DISCOVERY, as well as the box that represents the area of science, engineering, or education for the project.</p>	<p>Defined in the NSF Strategic Plan 2006-2011 as "Build the nation's research capability through critical investments in advanced instrumentation, facilities, cyber-infrastructure and experimental tools."</p> <p>Please Note: 1) If you are reporting an outcome from an EPSCoR Research Infrastructure Improvement grant, or a research grant co-funded with the EPSCoR Program, please check the EPSCoR box under DISCOVERY, as well as the box that represents the</p>

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Enter Highlight

NOTE: Insert only text in the box. **Do not try to paste in images.** An option for inserting images will appear later in the form.

Please write the highlight with sufficient information to describe the research, its significance, and its results in terms that the general public can understand. Technical information is useful, but please avoid jargon and explain any acronyms that you use.

Your lead-in sentence should “engage” the reader and relate the major impacts of your project. You may identify the project’s PI and institution in the narrative. However, please avoid lengthy lists of other project participants and institutions if your award is part of a large collaborative group.

Be clear and concise. Describe the problem that motivated your research. What were the key knowledge gaps? Describe the scope of your project.

REQUIRED. Please enter your Highlight text here [*Note: This form limits you to about 400 words*]:

One of the most urgent challenges of the 21st century is to investigate new technologies that can enable us to move towards a more sustainable society with reduced energy consumption at all levels. The Internet and the Information Communications Technology (ICT) equipment that connects to it consume about 3% (or possibly more) of the total electricity used in the US. This sizeable percentage is expected to grow as electronic devices of all kinds proliferate and connect to the Internet. Our research directly addresses how to reduce the direct energy consumption of network links and the induced energy consumption of end devices that connect to the Internet. The notion of “Green Computing” and “Green Networking” have become an urgent force in industry in only the past few years. Our research predates this industry focus on sustainability in IT and has, we believe, been a major influence in defining the problem space and possible solutions for it. This project has funded research in two primary areas which are:

1) Reduction of direct energy use of Ethernet links by adapting link rate to link utilization. This work has led directly to the founding of the IEEE 802.3az Energy Efficient Ethernet task group that is standardizing ideas that have evolved from original research in this project. A key collaborator has been Bruce Nordman at LBNL.

2) Reduction of induced energy use of PCs and other end devices by a concept of “Network Connectivity Proxy” (NCP) that can cover for an end device and allow it to sleep (and save energy) much of the time. This work has led to the founding of Ecma TC32-TG21 - Proxying Support for Sleep Modes. Again, a key collaborator has been Bruce Nordman at LBNL.

In the timeframe of March 2008 to January 2009 we have been focused primarily on (2) above. The founding of Ecma TC32-TG21 occurred in this time. Defining work, including prototyping of proxy functions for various protocols and applications, was completed in this time resulting in several publications and direct input to Ecma TC32-TG21. The electricity savings from (1) and (2) above will be in the hundreds of millions of dollars per year in the US alone when adopted and deployed. The standards efforts – and the direct inclusion of proxying in the EPA Version 5.0 Energy Star Specification for Computers – makes the likelihood of these large savings very high. We were also invited to give a presentation at a Cisco Green Research Symposium allowing for even greater spread and cross-pollination of our ideas.

In terms of *intellectual merit*, why is this research outcome notable and/or important? What was achieved that expanded the frontiers of knowledge or contributed to learning or workforce development?

REQUIRED. Please describe what is notable/important about your project here [Note: The form limits your description to about **100 words**]:

Our work has pioneered the area of green networking – our publications show clearly that we were among the first to identify the need for, and opportunities in, energy use reduction in networks. We are the first to have introduced the notion that networks induce energy use in end devices (that is, the energy use increment of an end device increases when connected to a network), and that this induced energy use can be reduced by the idea of a network connectivity proxy. Many other researchers (for example, at Intel and Microsoft Research) are now working in the area of green networks. Many green networking workshops have been and are being organized (Christensen is one of four organizers of GreenComm'09 at ICC 2009).

In terms of *broader impacts*, why is this outcome notable and/or important? How well does the activity advance discovery and understanding while promoting teaching, training and learning? How well does the proposed activity broaden the participation of underrepresented groups (e.g., gender, ethnicity, disability, geographic, etc.)? To what extent will it enhance the infrastructure for research and education, such as facilities, instrumentation, networks and partnerships? Will the results be disseminated broadly to enhance scientific and technological understanding? What may be the benefits of the proposed activity to society?

REQUIRED. In the context of Broader Impacts as described above, Please describe what is notable/important about your project here. [Note: The form limits your description to about **100 words**]:

Our work is expected to have a major beneficial impact to society in terms of reduced energy use of buildings where ICT equipment is a growing percentage of the overall building energy consumption. Energy savings estimates made by Lawrence Berkeley National Laboratory show expected savings of hundreds of millions of dollars per year in the US alone. For these savings to occur, the ideas need to be refined, adopted, and deployed. Inclusion of both Energy Efficient Ethernet and Proxying in the EPA Energy Star specification for computers will do much to drive such adoption and deployment. EPA Energy Star Version 5 now says, "For a system to qualify under the proxying weightings above, it must meet a non-proprietary proxying standard that has been approved by the EPA and the European Union as meeting the goals of ENERGY STAR." This is a significant contribution.

Does this highlight represent transformative or potentially transformative research? If so, please explain why. **Please check one.**

Yes No

The National Science Board has defined transformative research as "Research that has the capacity to revolutionize existing fields, create new subfields, cause paradigm shifts, support discovery, and lead to radically new technologies."

OPTIONAL. Please describe the "Transformative" aspects of your project here [Note: The form limits your description to about **100 words**]:

Transformative is the notion that network connectivity can be defined at different levels - these levels can then allow for energy savings. This notion is being fully developed in cooperation with researchers at ICSI and LBNL (as funded by 0721858 for Christensen and 0721933 for Allman, Paxson, and Nordman).

Does this highlight represent Broadening Participation? If so, please explain why. **Please check one.**

Yes No

If this highlight represents Broadening Participation, please explain why.

The concept of broadening participation includes: *individuals* from underrepresented groups, certain types of *institutions* of higher education, *geographic areas* (e.g. EPSCoR states), and *organizations* whose memberships are composed of institutions or individuals underrepresented in STEM or whose primary focus is on broadening participation in science and engineering. It is important to note that underrepresented groups vary within scientific fields.

OPTIONAL. Please describe your project's Broadening Participation aspects (if any) here [Note: The form limits your description to about **100 words**]:

A woman undergraduate student (Rula Alnaser) was funded through an REU supplement. The student is currently exploring options for continuing her education.

Are there existing or potential societal benefits of this research? It is important for NSF to be able to provide examples of NSF-supported research that have societal benefits, including benefits to the U.S. economy. **Please check one.**

Yes No

If there are any existing or potential societal benefits, including benefits to the U.S. economy, of this research of which you are aware, please describe in the space below.

OPTIONAL. Please enter your project's societal benefits (if any) here [Note: The form limits your description to about **100 words**]:

As a restatement of the project Broader Impacts: Our work is expected to have a major beneficial impact to society in terms of reduced energy use of buildings where ICT equipment is a growing percentage of the overall building energy consumption. Energy savings estimates made by Lawrence Berkeley National Laboratory show expected savings of hundreds of millions of dollars per year in the US alone. For these savings to occur, the ideas need to be refined, adopted, and deployed. Inclusion of both Energy Efficient Ethernet and Proxying in the next EPA Energy Star Specification for Computers will do much to drive such adoption and deployment. This work has been done in collaboration with Bruce Nordman of LBNL and his Energy Efficient Digital Networks project (<http://efficientnetworks.lbl.gov/>).

NSF Investments (Existing and Proposed) -- select as many as apply: The purpose of identifying one or more NSF investments is to provide guidance for NSF staff selecting highlights for publication in the annual budget, the annual performance report, and other public documents. These investments represent major cross-foundation initiatives.

REQUIRED:

- Adaptive Systems Technology
- American Competitiveness Initiative (ACI)
- Climate Change
- Cyber-enabled Discovery and Innovation (CDI)
- Cyberinfrastructure
- Environment (including the importance of fresh water and dynamics of water processes)
- Homeland Security
- Human and Social Dynamics
- International Polar Year (IPY)
- National Nanotechnology Initiative (NNI)
- Networking and Information Technology Research Development (NITRD)
- Science and Engineering Beyond Moore's Law
- Science of Science and Innovation Policy (SciSIP)
- Sensor Research
- Understanding Complex Biological Systems (including the interfaces of life, physical, and computational sciences)
- None Applicable

Add Image(s)

Why are images important?

NSF highlights and images are for illustration in the Foundation's annual Budget Requests, performance reports, and other documents.

Clear, colorful images (photos, pictures, graphs, charts, etc.) greatly enhance the value of highlights and often tell a story by themselves.

- Resolution should be **72 dpi or higher**.
- Files must be **GIFs or JPEGs**.
- Images must be the size you want them to appear. Recommended maximum width and height are **240 pixels**.
- A **descriptive caption** must be provided.

Insert your image(s) here. For each image, **please provide a caption**. If you have difficulty including your image, formatted as described above, you may attach it to the email that you send back with this form.

Image #1:

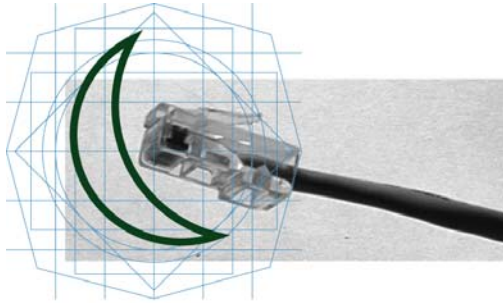


Image #1 Caption:

This is a graphic view of our project showing the IEEE 1621 standard symbol for "sleep" and an Ethernet connector. This graphic summarizes our goal of reducing the energy used by Ethernet networks. The graphic is originally from Bruce Nordman at LBNL (full permission for use granted by Bruce Nordman via email dated January 29, 2007).

Image #2:



Image #2 Caption:

This graphic symbolizes the green benefits of an energy efficient Ethernet. The graphic is originally from Glen Kramer at Teknovus, Inc. (full permission for use granted by Glen Kramer via email dated January 27, 2007).