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:

cns2008highlights@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- 0519951	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What is the name of the NSF Program Officer who originally made this award or who is currently your cognizant Program Officer?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
Foster research that will advance 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. *Please Note: 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.* ☒ Disciplinary or Interdisciplinary Research (Anything not covered by one of the 12 categories below.) ☐ International Collaborative Research ☐ CAREER ☐ Evaluation and Research to Improve STEM Education ☐ Discovery Research K-12 ☐ EPSCoR Program ☐ Centers for Analysis & Synthesis ☐ Centers for Chemical Innovation ☐ Engineering Research Centers ☐ Materials Research Science & Engineering Centers ☐ Nanoscale Science & Engineering Centers ☐ Science & Technology Centers ☐ Science of Learning Centers	Cultivate a world-class, broadly inclusive science and engineering workforce, and expand the scientific literacy of all citizens. ☐ K-12 Education ☐ Teacher Training ☐ Undergraduate Education ☐ Graduate Education ☐ Postdoctoral Fellowships, including International Postdoctoral Fellowships ☐ International Research Experiences for Undergraduate & Graduate Students ☐ Public Understanding of Science	Build the nation's research capability through critical investments in advanced instrumentation, facilities, cyber-infrastructure and experimental tools. *Please Note: 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.* ☐ Major Multi-User Facilities ☐ Research Instrumentation ☐ Cyberinfrastructure ☐ Research Resources and Tools (other than Cyberinfrastructure)

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
Foster research that will advance 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. *Please Note: 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.* ☐ Disciplinary or Interdisciplinary Research (Anything not covered by one of the 12 categories below.) ☐ International Collaborative Research ☐ CAREER ☐ Evaluation and Research to Improve STEM Education ☐ Discovery Research K-12 ☐ EPSCoR Program ☐ Centers for Analysis & Synthesis ☐ Centers for Chemical Innovation ☐ Engineering Research Centers ☐ Materials Research Science & Engineering Centers ☐ Nanoscale Science & Engineering Centers ☐ Science & Technology Centers ☐ Science of Learning Centers	Cultivate a world-class, broadly inclusive science and engineering workforce, and expand the scientific literacy of all citizens. ☐ K-12 Education ☐ Teacher Training ☐ Undergraduate Education ☐ Graduate Education ☐ Postdoctoral Fellowships, including International Postdoctoral Fellowships ☐ International Research Experiences for Undergraduate & Graduate Students ☐ Public Understanding of Science	Build the nation's research capability through critical investments in advanced instrumentation, facilities, cyber-infrastructure and experimental tools. *Please Note: 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.* ☐ Major Multi-User Facilities ☐ Research Instrumentation ☐ Cyberinfrastructure ☐ Research Resources and Tools (other than Cyberinfrastructure)

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 Technology (IT) equipment that connects to it consume from 1 to 3% of the total electricity consumed in the US. This sizeable percentage is expected to grow as more data centers are built and more advanced desktop computers, and other end devices such as set-top boxes, proliferate. Our research directly addresses how to reduce the energy consumption of network links and the end devices – such as desktop computers in the office and home – that connect to the Internet. The notion of "Green Computing" has become an urgent force in industry in only the past one to two years. Our research predates this industry focus on sustainability in IT and has, we believe, even been a driving force for it.

To address the increasing power consumption of faster Ethernet links, our research has found a way to reduce the speed of Ethernet links during periods of low use. There are literally billions of Ethernet links in operation in the world. Our ideas in Ethernet Adaptive Link Rate (ALR) are now being explored – and improved upon – by many major networking companies within the IEEE 802.3 standards organization (the IEEE 802.3 standards organization is responsible for standardization of Ethernet technologies). The ability to use ALR to achieve network slowdown has far reaching effects in how network equipment can now be designed and implemented to use less energy during periods of low utilization.

Our research is also exploring ways to power off end devices – such as desktop computers – more frequently and for longer periods of time without losing network connectivity. Indeed, we have found that network connectivity is often the reason that desktop computers in the office and at home are left powered-on 24/7 even if used for only a fraction of this time. We have proposed and are investigating ideas in low-power proxying where the network interface chip within a high powered PC can maintain network presence for key protocols and applications while the majority of the components – including the processor, bus, memory, disk, and video – in the PC are powered down.

Looking ahead, we see our continued research driving further energy efficiency into the future Internet by exploring how new notions of selective connectivity and network slowdown can be both enabled and exploited. We anticipate submitting a collaborative proposal for NSF-FIND with USF (Ken Christensen) and UF (Ann Gordon-Ross) to further pursue these new paradigms.

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**]:*

The most notable and important outcome of our project has been the formation of the IEEE 802.3az task force resulting from our work in Adaptive Link Rate (ALR). Many other people have been involved in the establishment of the standards effort and the now rapid progress towards standardization. Key individuals include Bruce Nordman and Mike Bennett at Lawrence Berkeley National Laboratory. ALR introduces an entirely new paradigm to networks - that of controlled network slowdown to save energy in a way that is not noticeable to the user.

Also very notable has been our impact on future EPA Energy Star specifications for PCs. The Energy Star program in its Tier 2 computer specification is scheduled to require proxying functionality in Energy Star-compliant desktop and notebook PCs beginning in 2009. Our work directly contributed to this new specification and the expected large impact in energy savings that this will result in.

If this highlight represents transformative research, please explain why.
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**]:

Our research has introduced two transformative notions to the networking community. They are:

1) The concept of selective connectivity (this term was coined by Mark Allman in a 2007 ACM HotNets paper titled: "Enabling an Energy-Efficient Future Internet Through Selectively Connected End Systems" by Allman, Christensen, Nordman, and Paxson). By selective connectivity we mean an end system that can choose to be connected or disconnected and knowingly manage the extent of its network connectivity. With selective connectivity an end system can be asleep (saving energy) and still maintain full network presence.

2) The concept of network slowdown whereby portions of a network can reduce its data rate in response to low utilization levels and achieve energy savings from both the links and from the equipment (routers, switches, etc.).

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***]:

Our project has funded one woman undergraduate student with a Research Experience for Undergraduates (REU) position. Rula Alnaser is working in the laboratory with the graduate students funded by this grant. Rula is exploring protocol implications for energy efficiency.

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. It is important for NSF to be able to provide examples of NSF-supported research that have or may have societal benefits.

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

Our project has significant long-term potential for energy and cost savings to the US and world economy. It is estimated that Energy Efficient Ethernet (IEEE 802.3az) standard - when it becomes a standard and is incorporated in future Ethernet products - will enable savings of hundreds of millions of dollars per year in the US alone. In addition to the economic savings are signficant reductions in CO2 emissions. These estimates were made by Bruce Nordman at Lawrence Berkely National Laboratory.

Our work in proxying and its potential for enabling much greater use of power management in end-devices has the potential for billions of dollars per year in energy savings.

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.

Image #1:

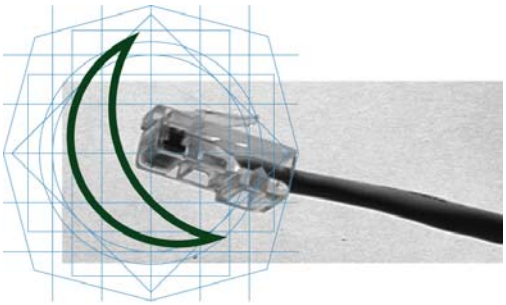

Image #1 Caption:

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).