Some slides are from a presentation given at Cisco by Ken Christensen.

An Energy Efficient Internet: Some Ongoing Work

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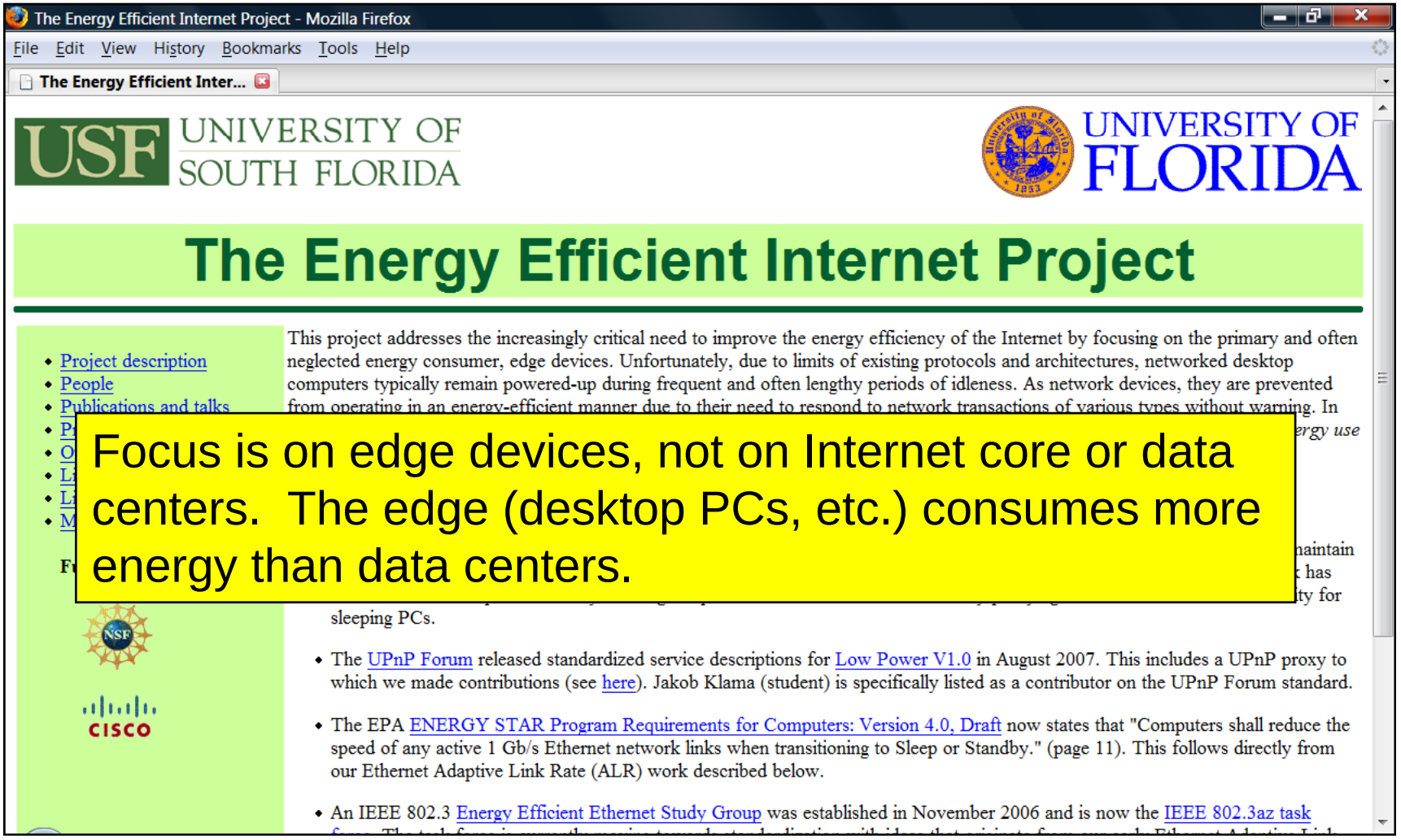
This material is based upon work funded by the National Science Foundation under grant CNS-0520081.

Thank you

- **Thank you for inviting me to this brown bag lunch**
- **I am a graduate student at the University of South Florida**
- **My advisor is Ken Christensen**
  - http://www.csee.usf.edu/~christen/christen.html
- **We work extensively with Bruce Nordman at LBNL**

Our project

http://www.csee.usf.edu/~christen/energy/main.html



Where this short talk is going

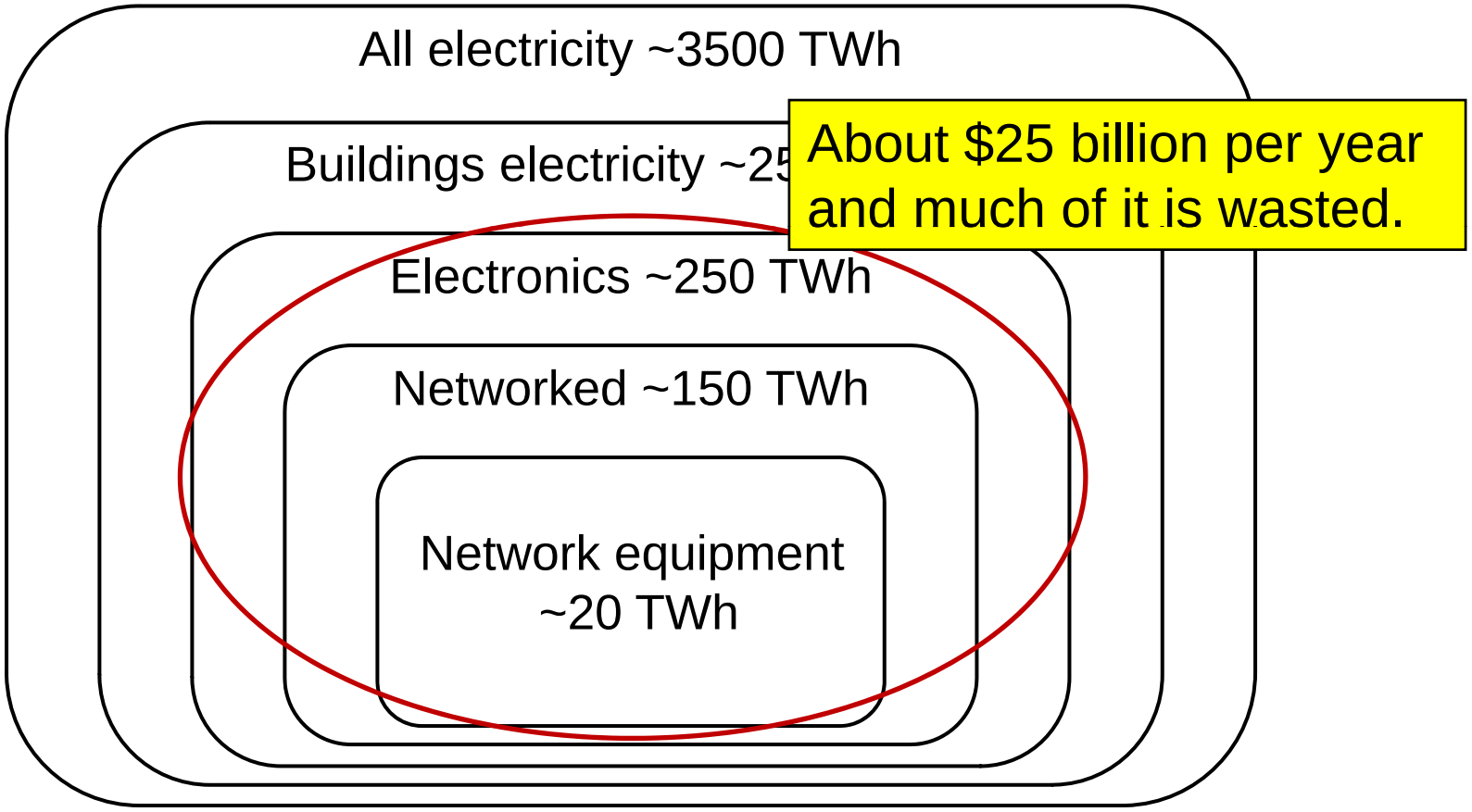
- **Energy usage by IT equipment**
- **Reducing induced energy use**
- **Reducing direct energy use**
- **Additional efforts at USF**

Electricity production and costs

- **Let's set the stage…**
  - 1 kWh ≅ $0.10 (average US residential cost for electricity)
  - 1 Wyr = $0.88 ≅ $1.00
  - 1 TWh = $100 million
  - 1 TWh = 0.75 million tons of CO_2

Electricity use in the USA

- **2006 US electricity usage*** (not to scale)



* B. Nordman, "Networks, Energy, and Energy Efficiency," presentation at *Cisco Green Research Symposium*, March 2008.

Electricity use by IT equipment today

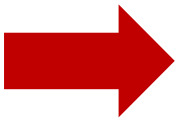
- **How much electricity do PCs consume?**
  - EPA estimates about 2% of all electricity consumed*
- **How much electricity do data centers consume?**
  - About 1.5% of all electricity consumed in US**
    - Doubled since 2000
- **How much electricity does the Internet consume?**
  - "The Internet accounts for 5% of all the power we consume – in a couple of years, that figure will be 10%." ***

This might be too high?

* "EPA Announces New Computer Efficiency Requirements," Release date: 10/23/2006, Contact: Enesta Jones.
** Jon Koomey quoted in http://gigaom.com/2008/06/25/structure-08-data-center-power-guru-jonathan-koomey/
*** Institute for Energy Efficiency, UC Santa Barbara, 2008.

PC energy impact

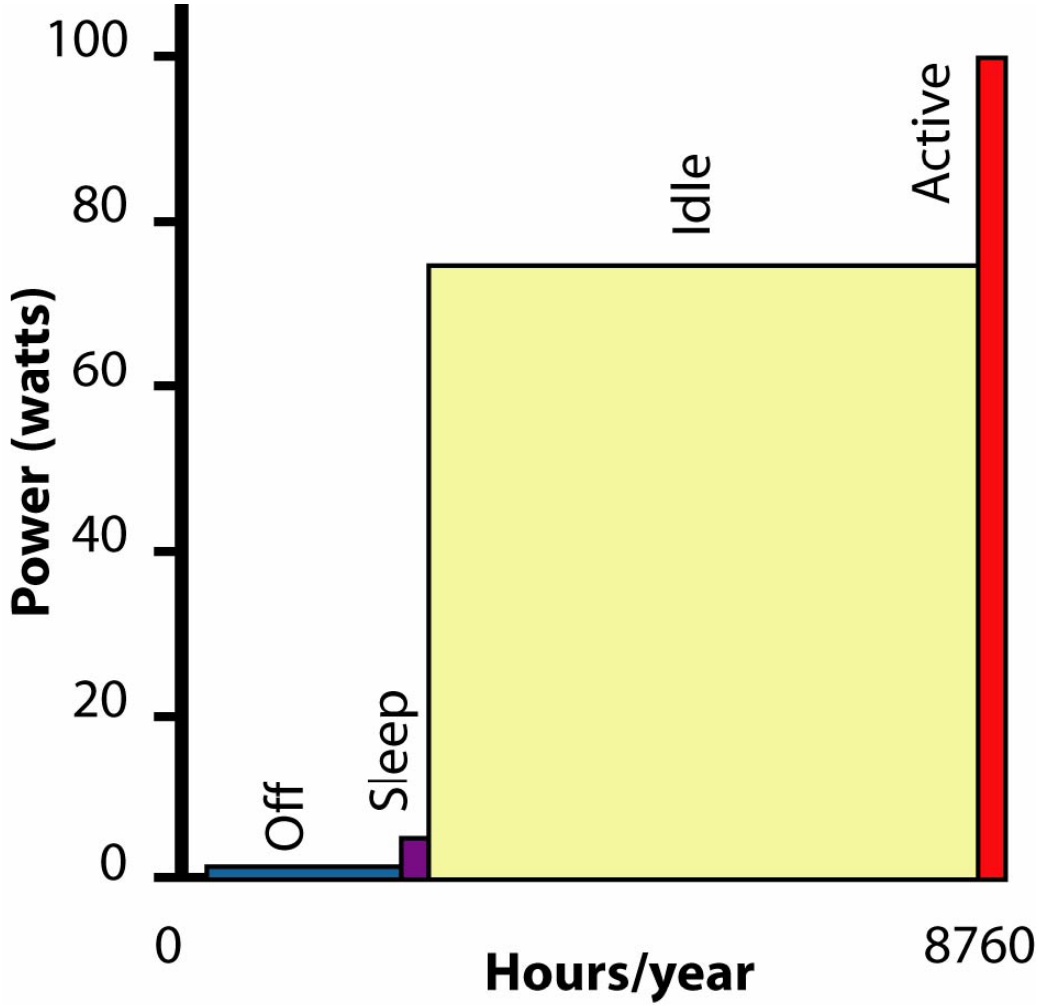
- **The typical US home consumes 10,654 kWh/yr***
- **One 100W PC on 24/7 for one year is…**
  - 876 kWh/yr
  - This is 8.2% of entire home consumption



Each PC adds about 8% to your power bill!

* Energy Information Administration, "U.S Household Electricity Report," July 2005.

Typical commercial PC energy use



$$P_{on} >> P_{sleep}$$

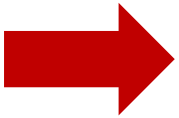
$$P_{sleep} \simeq P_{off}$$

Consumption is driven by on time, not by usage

From http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/computer/TierII_Network_Issue_Slides.pdf

PC energy use is “induced”

- **Why is the typical PC fully powered on when idle?**
  - For usability reasons?
  - For network connectivity reasons?



This is induced energy use

Where this talk is going

- **Energy consumption by IT equipment**
- **Reducing induced energy use**
- **Reducing direct energy use**
- **Additional efforts at USF**

Reducing energy use of edge devices

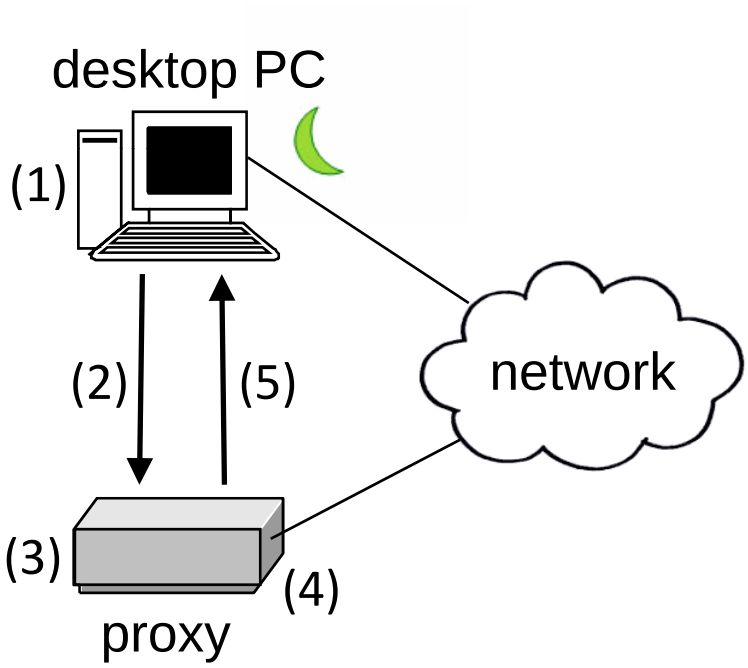
- **Observation: Devices are often left fully powered-on to maintain network connectivity or presence**
  - Usually devices are not in active use

- **Idea: A low-power network connectivity proxy**
  - Maintains *full network connectivity* for a sleeping device
  - Enable devices to sleep more often
  - Not related to existing Wake-on-LAN

- **Key issues: Lots of issues…**
  - Definition of "connectivity"
  - Wake-ups (not too many, not too few)
  - Packet loss (during wake-up)

Network connectivity proxy

- **Proxy covers for sleeping device**
  - Proxy could be in local NIC or in the network



Steps:

1) PC determines it is time to sleep

2) PC state transferred to proxy

3) PC sleeps, proxy maintains presence

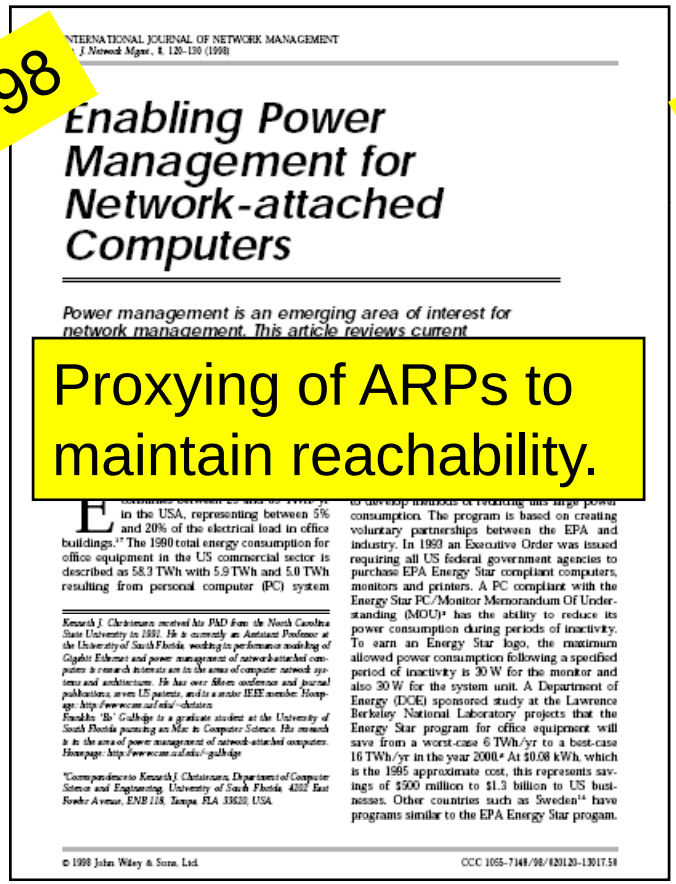
4) Proxy determines need to wake-up PC

5) PC awakes and proxy state transferred

Proxying for reducing energy use

- **Started to think about proxying 10 years ago**
  - Now hoping to define a direction towards a standard

1998



INTERNATIONAL JOURNAL OF NETWORK MANAGEMENT
Int. J. Network Mgmt., 8, 120–130 (1998)

Enabling Power Management for Network-attached Computers

Power management is an emerging area of interest for network management. This article reviews current

Proxying of ARPs to maintain reachability.

in the USA, representing between 5% and 20% of the electrical load in office buildings.[1] The 1990 total energy consumption for office equipment in the US commercial sector is described as 58.3 TWh with 5.9 TWh and 5.0 TWh resulting from personal computer (PC) system

consumption. The program is based on creating voluntary partnerships between the EPA and industry. In 1993 an Executive Order was issued requiring all US federal government agencies to purchase EPA Energy Star compliant computers, monitors and printers. A PC compliant with the Energy Star PC/Monitor Memorandum Of Understanding (MOU)[3] has the ability to reduce its power consumption during periods of inactivity. To earn an Energy Star logo, the maximum allowed power consumption following a specified period of inactivity is 30 W for the monitor and also 30 W for the system unit. A Department of Energy (DOE) sponsored study at the Lawrence Berkeley National Laboratory projects that the Energy Star program for office equipment will save from a worst-case 6 TWh/yr to a best-case 16 TWh/yr in the year 2000.[4] At $0.08 kWh, which is the 1995 approximate cost, this represents savings of $500 million to $1.3 billion to US businesses. Other countries such as Sweden[14] have programs similar to the EPA Energy Star progam.

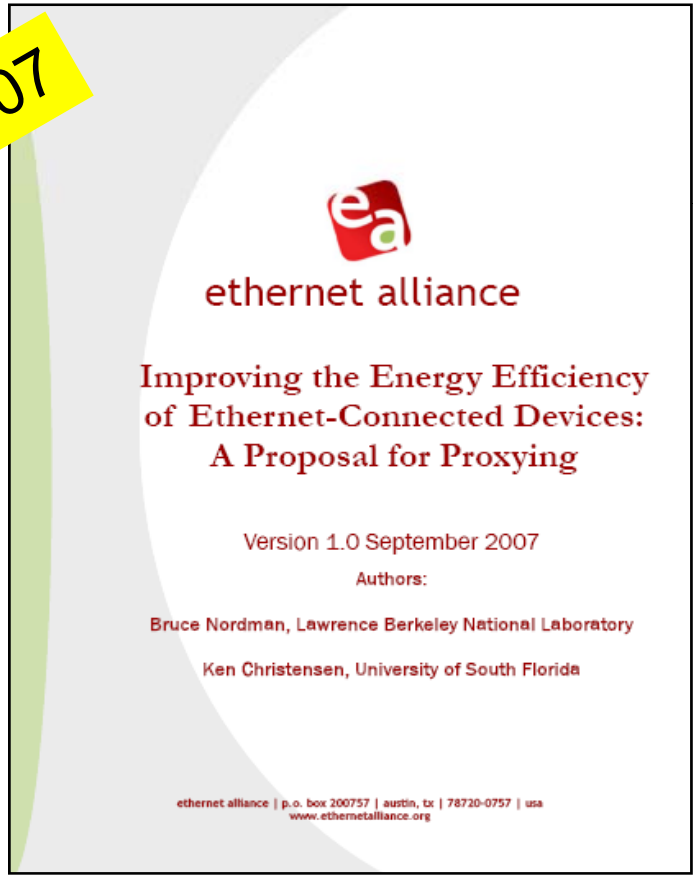
Kenneth J. Christensen received his PhD from the North Carolina State University in 1991. He is currently an Assistant Professor at the University of South Florida working in performance modeling of Gigabit Ethernet and power management of network-attached computers in research interests are in the areas of computer network systems and architectures. He has over fifteen conference and journal publications, seven US patents, and is a senior IEEE member. Homepage: http://www.csee.usf.edu/~christen

Franklin 'Bo' Gulbrigt is a graduate student at the University of South Florida pursuing an MSc in Computer Science. His research is in the area of power management of network-attached computers. Homepage: http://www.csee.usf.edu/~gulbrigt

Correspondence to Kenneth J. Christensen, Department of Computer Science and Engineering, University of South Florida, 4202 East Fowler Avenue, ENB 118, Tampa, FLA 33620, USA.

CCC 1055-7148/98/020120-13$17.50

2007



ethernet alliance

Improving the Energy Efficiency of Ethernet-Connected Devices: A Proposal for Proxying

Version 1.0 September 2007

Authors:

Bruce Nordman, Lawrence Berkeley National Laboratory

Ken Christensen, University of South Florida

ethernet alliance | p.o. box 200757 | austin, tx | 78720-0757 | usa
www.ethernetalliance.org

Key protocols that proxying might cover

- **Layers 1 and 2**
  - Already covered by PHY/MAC
- **Layer 3**
  - ARP, ND, ICMP, IGMP, IPSec, etc.
- **Layer 4**
  - TCP connection request (SYN)
  - TCP connections (keep-alives)
- **Higher layers including applications**
  - NetBIOS, SMB, DHCP, SNMP, SSDP, VPN, SSH, etc.
  - Application semantics

Network connectivity from the EPA

- **Future EPA Energy Star Program Requirements**
  - Version 5.0, Draft 1 Comment Sumary* (for computers)

"Full Network Connectivity: The ability of the computer to maintain network presence while in sleep and intelligently wake when further processing is required. Maintaining network presence may include obtaining and/or defending an assigned interface or network address, responding to requests from other nodes on the network, or sending periodic network presence messages to the network all while in the sleep state. In this fashion, presence of the computer, its network services and applications is maintained even though the computer is in sleep. (Note: More information on this can be found at: http://efficientnetworks.lbl.gov/enet-proxying.html)

* From http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/computer/Defs_Summary_Computer_Comment_Resp.pdf

Proxying next steps…

- **Progress is being made with**
  - Definition
  - Trace analysis
  - Prototyping
  - Use case
- **Involvement with several companies to do above**
  - Work being done is mostly not by us
- **Plan to approach to Ecma to host/develop standard**
  - Bruce Nordman (LBNL) driving this

Where this talk is going

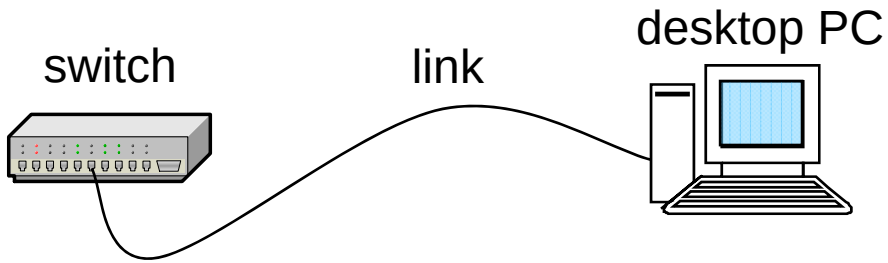
- **Energy consumption by IT equipment**
- **Reducing induced energy use**
- **Reducing direct energy use**
- **Additional efforts at USF**

Reducing energy use of links

- **Observation #1: Most edge links are lightly utilized**
  - 1% to 5% on average
- **Observation #2: Higher rates consume more power**
  - About 2 to 4 W for 1 Gb/s versus 100 Mb/s
  - Much more for 10 Gb/s versus 1 Gb/s
- **Idea: Match link data rate with utilization**
- **Key issue: Time to change between data rates**
  - Can buffer overflow occur during transition?
  - What impact might this packet loss have?

Ethernet Adaptive Link Rate (ALR)

- **Two parts to the problem**
  1) *Mechanism* for how to switch link rate
  2) *Policy* for when to change link rate



Save energy in MAC/PHY at each end
(potential for deeper savings)

Ethernet ALR publications

- **We published the idea and some results**
  - From a 2005 paper and a 2006 whitepaper

2005

INTERNATIONAL JOURNAL OF NETWORK MANAGEMENT
Int. J. Network Mgmt 2005; 15: 297–310
Published online in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/nem.565

Managing energy consumption costs in desktop PCs and LAN switches with proxying, split TCP connections, and scaling of link speed

By Chamara Gunaratne, Ken Christensen*† and Bruce Nordman

The IT equipment comprising the Internet in the USA uses about $6 billion of electricity every year. Much of this electricity use is wasted on idle, but fully powered-up, desktop PCs and network links. We show how to recover a large portion of the wasted electricity with improved power management methods that are focused on network issues. Copyright © 2005 John Wiley & Sons, Ltd.

1. Introduction

A growing expense and impact of the Internet is its energy use. Current estimates are that 2% of electricity consumption in the USA goes to powering the Internet.[1] In Germany it is estimated that energy consumption by IT equipment will be between 2% and 5% in 2010.[2] The 2% estimate for the USA totals more than 74 TWh/year or $6 billion per year. It is predicted that energy use of IT equipment is growing faster than energy use of any other type within buildings.[3] Much of this energy use is wasted. Energy use by IT equipment is not proportional to utilization of the equipment. A recent study by Lawrence Berkeley National Laboratory (LBNL) showed that 60% of all desktop PCs in commercial buildings remain fully powered-on during nights and weekends[4] with existing power management almost always disabled. Beyond the PC are the Ethernet link and workgroup switch. At present, these energy consumers have almost no means of power management. Existing Internet protocols including discovery and routing are also 'energy unaware'; future protocols need to be made energy aware. For existing protocols that cannot be changed, methods of accommodating current operation must be developed. In previous work we have shown that there exists the potential for savings of *billions of dollars per year* in the USA alone.[5–7] These savings are summarized in Section 6 of this paper. Energy costs are a part of the total cost of ownership of an IT operation. Savings in these costs are of interest to IT managers and companies are beginning to respond with network management products (such as Verdiem with its centralized power management controller[8]) to address this need.

An efficient device consumes energy proportional to its output or utility. Thus, an idle or lightly utilized PC or Ethernet link should not consume the same energy as one that is highly utilized. In this paper, we develop several new methods to reduce energy consumption of PCs,

Chamara Gunaratne is a graduate student in the Department of Computer Science and Engineering at the University of South Florida.

Ken Christensen is an Associate Professor in the Department of Computer Science and Engineering at the University of South Florida.

Bruce Nordman is a Principal Research Associate in the Energy Analysis Department, Environmental Energy Technologies Division, of Lawrence Berkeley National Laboratory Berkeley, California.

*Correspondence to: Ken Christensen, Department of Computer Science and Engineering, University of South Florida, Tampa, FL 33620, USA
†E-mail: christen@csee.usf.edu

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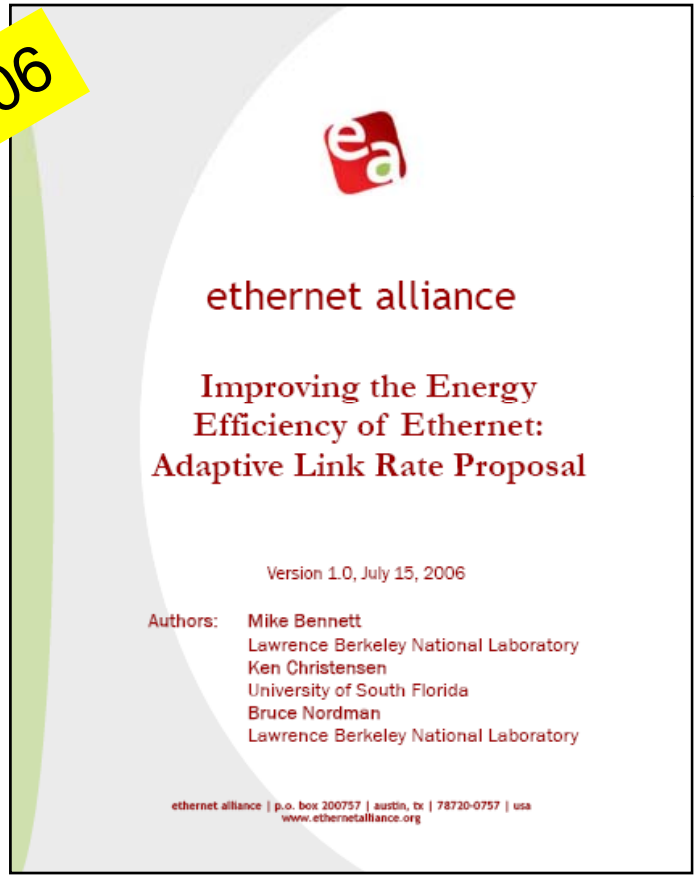
2006



ethernet alliance

Improving the Energy Efficiency of Ethernet: Adaptive Link Rate Proposal

Version 1.0, July 15, 2006

Authors: Mike Bennett
Lawrence Berkeley National Laboratory
Ken Christensen
University of South Florida
Bruce Nordman
Lawrence Berkeley National Laboratory

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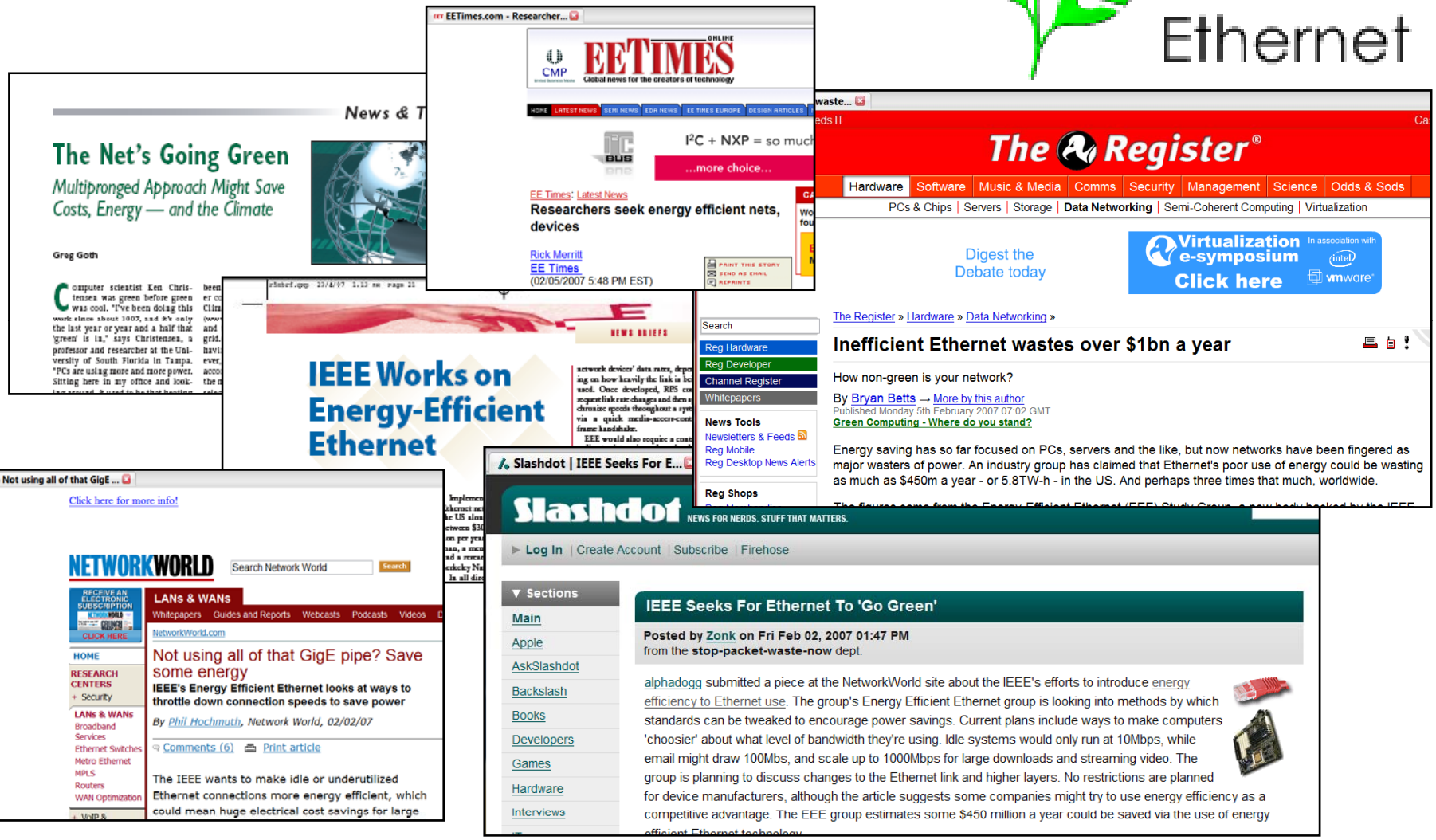
www.ethernetalliance.org

Where is EEE now…

- **IEEE 802.3az Task Force**
  - Mike Bennett from LBNL is chair
- **Moving forward to becoming a standard**
  - 2009 timeline for completion
  - Is in EPA Energy Star Version 5.0 Draft 1 for computers
- **Current proposal is for "Active-Idle" approach**
- **Active-Idle idea is from Intel**
  - Use a low-power idle between packets
  - Switch to high data rate when a packet is queued
  - About *10 microseconds* to transition out of low-power idle

Some press and a logo…

Energy * Efficient Ethernet



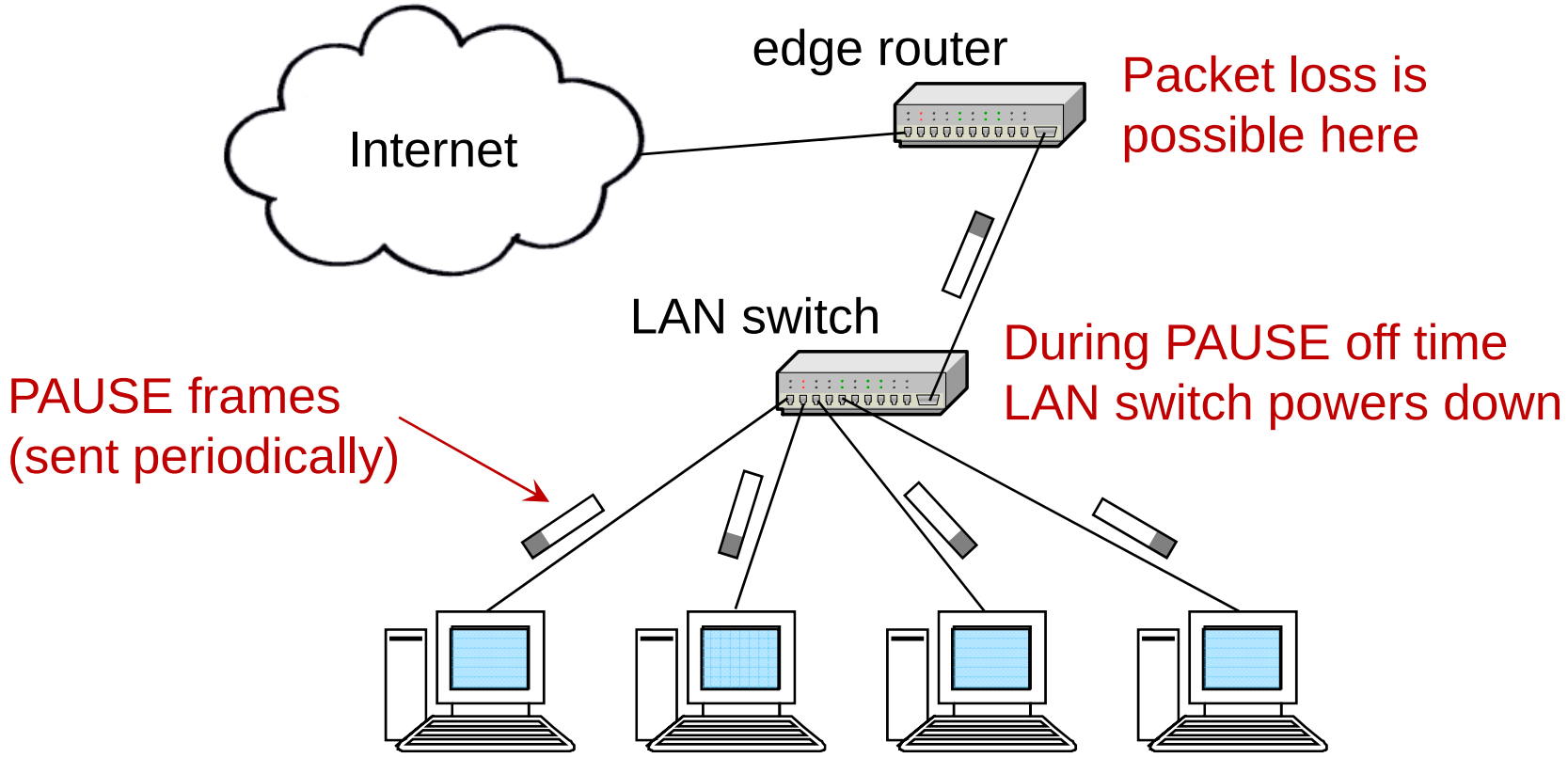
* Logo by Glen Kramer of Teknovus, Inc. (full permission for use granted via email dated January 27, 2007)

What is next?

- **EEE requires both ends to participate**
  - Full EEE deployment is still many years off
- **Can we do something simpler?**
  - Something backwards compatible?
- **Idea: PAUSE Power Cycle (PPC)**
  - Use PAUSE to proactively cycle links on and off
  - During link off time power-down LAN switch

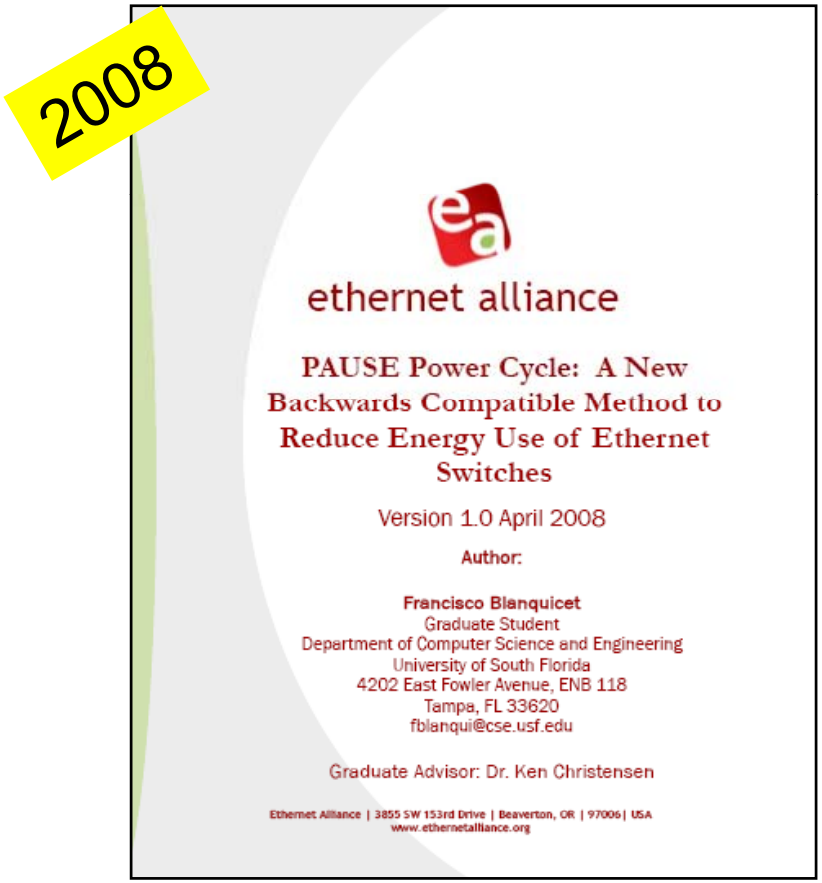
PAUSE Power Cycle (PPC)

- **Basic idea is to periodically send PAUSE frames**
  - Power “stuff” down during PAUSE interval



PPC publications

- **Winner of Ethernet Alliance white paper contest**
  - Shown at EA booth in Interop 2008 at Las Vegas



Where this talk is going

- **Energy consumption by IT equipment**
- **Reducing induced energy use**
- **Reducing direct energy use**
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SNMP Power MIB

- **We want to expose and control power state**
- **Can we use SNMP to do this?**
- **Developing a Power MIB for desktop PC**
  - Power management capabilities
  - Power management settings
  - Total time for idle, busy, and sleep
  - Current elapsed time for idle, busy, or sleep
  - Statistics on wake-up events (network, user, etc.)
  - Statistics on sleep events
  - Actual power and energy use if metering is implemented

SNMP Power MIB continued

NAME	SYNTAX	ACCESS	DESCRIPTOR	UNITS
totalOffTime:1	Integer	Read-Only	Total time in off state	seconds
totalSleepTime:2	Integer	Read-Only	Total time in sleep state	seconds
totalOnTime:3	Integer	Read-Only	Total time in on state	seconds
totalInactiveTime:4	Integer	Read-Only	Total time in inactive state	seconds
totalActiveTime:5	Integer	Read-Only	Total time in active state	seconds
lastOfftime:6	Integer	Read-Only	Duration of last off time period	seconds
lastSleepTime:7	Integer	Read-Only	Duration of last sleep time period	seconds
lastOnTime:8	Integer	Read-Only	Duration of last on time period	seconds
lastInactiveTime:9	Integer	Read-Only	Duration of last inactive time period	seconds
lastActiveTime:10	Integer	Read-Only	Duration of last active time period	seconds
goToSleepCount:11	Counter	Read-Only	Counts number of transitions to sleep state	number
lastGoToSleepType:12	String	Read-Only	Describes what caused last transition to sleep	System/User
goToOffCount:13	Counter	Read-Only	Counts number of transitions to off state	number
lastGoToOffType:14	String	Read-Only	Describes what caused last transition to off	System/User
currentPowerState:15	String	Read-Write	Current state the system is in	Off/Sleep/On
powerSource:16	String	Read-Only	Current power source	AC/Battery
totalTimeACSource:17	Integer	Read-Only	Total time on AC power	seconds
totalTimeBattSrc:18	Integer	Read-Only	Total time on battery power	seconds
lastACTime:19	Integer	Read-Only	Duration of last time period on AC power	seconds
lastBattTime:20	Integer	Read-Only	Duration of last time period on battery power	seconds
powerLevel:21	Gauge32	Read-Only	Current power consumption level	Watts
energyConsumption:22	Gauge32	Read-Only	Total energy used	Watt-hours
energyLeft:23	Gauge32	Read-Only	Energy left (if on battery)	Hours
utilization:24	Guage32	Read-Only	Current utilization	percentage
inactivityOffTimer:25	Integer	Read-Write	Inactivity time-out to go to Off state	seconds
inactivitySleepTimer:26	Integer	Read-Write	Inactivity time-out to go to Sleep state	seconds
currentInactivityVal:27	Integer	Read-Only	Current inactivity timer value	seconds
acpiSupportStates:28	String	Read-Only	ACPI supported states	ACPI defined states
acpiEnabledStates:29	String	Read-Only	ACPI enabled states	ACPI defined states
acpiCurrentState:30	String	Read-Only	ACPI current state	ACPI defined states
acpiLastState:31	String	Read-Only	ACPI last state	ACPI defined states

Adaptive power management for PCs

- **PC operating systems use inactivity time-out**
  - For example, to put system to sleep
  - Use a fixed value for time-out
- **Can we do better with an adaptive time-out?**
  - Greater energy savings and less user annoyance
- **Have experimented with using past activity history**
  - Adaptively set the time-out value based on prediction
  - No conclusive results yet
  - Need to do more characterization of PC users

Lots of potential here!

Summary

- **Energy savings can be achieved**

  - **Induced energy savings**
    - Letting devices sleep without losing network presence

    ➡ How can we enable this for all end devices?

  - **Direct energy savings**
    - Matching link data rate to link utilization

    ➡ How can we exploit this for deeper savings?

Microsoft involvement

- **Need more Microsoft involvement in proxying standard**
  - Contact Bruce Nordman (bnordman@lbl.gov)
    - He will be in Redmond area on July 7th through 9th
- **Need funding to continue work in adaptive time-out**
  - Contact Ken Christensen (christen@csee.usf.edu)
  - Working with Ann-Gordon Ross at UF on this

My advisor said to always ask for money ☺.

Acknowledgments

- **Folks who have contributed…**
  - Bruce Nordman
  - Francisco Blanquicet
  - Miguel Jimeno
  - Jakob Klamra
  - Jeremy Blackburn
  - Many others

Students in the group

Thank you!

Questions?

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Key links

- **USF project website**
  - http://www.csee.usf.edu/~christen/energy/main.html
- **LBNL project website**
  - http://efficientnetworks.lbl.gov/
- **Project publications and invited talks**
  - http://www.csee.usf.edu/~christen/energy/pubs.html
- **ALR whitepaper at Ethernet Alliance**
  - http://www.ethernetalliance.org/technology/white_papers/alr_v10.pdf
- **Proxying whitepaper at Ethernet Alliance**
  - http://www.ethernetalliance.org/technology/white_papers/Proposal_for_Proxying_edit.pdf
- **IEEE 802.3az taskforce**
  - http://www.ieee802.org/3/az/index.html
- **UPnP Forum Low Power V 1.0**
  - http://www.upnp.org/specs/lp.asp