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Division of IT Convergence Engineering

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Green Networks: Reducing the Energy Consumption of Networks

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USF UNIVERSITY OF SOUTH FLORIDA

Keynote talk at ISITCE 2010 – Pohang, Korea

Thank you

Thank you to James Won-Ki Hong for inviting me to give this talk. I am very honored to be here in Korea for my first time.

Where do I come from?

University of South Florida and Tampa

47,000 students

Yes, we have lots of alligators

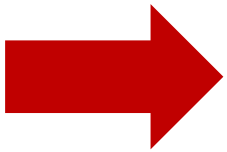
Acknowledging my students

Some of the work presented here was done by past and present students including,

- Chamara Gunaratne (PhD in 2008)
  - Early Proxying and Ethernet work
- Miguel Jimeno (PhD in 2010)
  - Proxying (especially for applications)
- Mehrgan Mostowfi (MS in 2010, continuing to PhD)
  - Recent Ethernet work

Why green networks?

One of the most urgent challenges of the 21st century is to investigate new technologies that can enable a transition towards a more sustainable society with a reduced CO_2 footprint.



We need to reduce energy consumption

The challenge to ICT

What role will ICT play in this grand challenge?

- Directly reduce energy consumed by ICT
- Enable energy savings in non-ICT

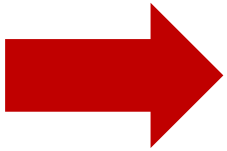
Notion of "comfortable conservation"

Two ways to consume less energy…

1) Have and do less = conservation

2) Improve performance = efficiency

> "I mean using less energy for identical performance, measured in whatever way the consumer wishes."
> - Richard Muller (Physics for Future Presidents, 2008)



In network speak, same QoS for less energy

Product lifecycle and green

Focus of this talk

Production → **Use** → **End-of-use**

- Production
  - Cleaner mining
  - Cleaner manufacturing
  - Use less toxic materials
  - Use less materials overall
  - Use less energy overall
- Use
  - Use less energy
  - Extend lifetime
- End-of-use
  - Recycle materials
  - Refurbish for reuse

1 kWh = $0.10

Energy consumed by a PC*
- Production = 2000 KWh
- Life (5 yrs) = 4200 KWh

* E. Williams, "Revisiting Energy Used to Manufacture a Desktop Computer: Hybrid Analysis Combing Process and Economic Input-Output Methods," *Proceedings of IEEE International Symposium on Electronics and the Environment*, pp. 80-85, 2004.

Roadmap of this talk

This talk has four major topics

- Quantifying the energy use of ICT
- Reducing direct energy consumption
- Reducing induced energy consumption (if time permits)
- Future challenges (if time permits)

Key definitions

Direct energy use

- Energy used by network links and equipment, but not hosts

Induced energy use

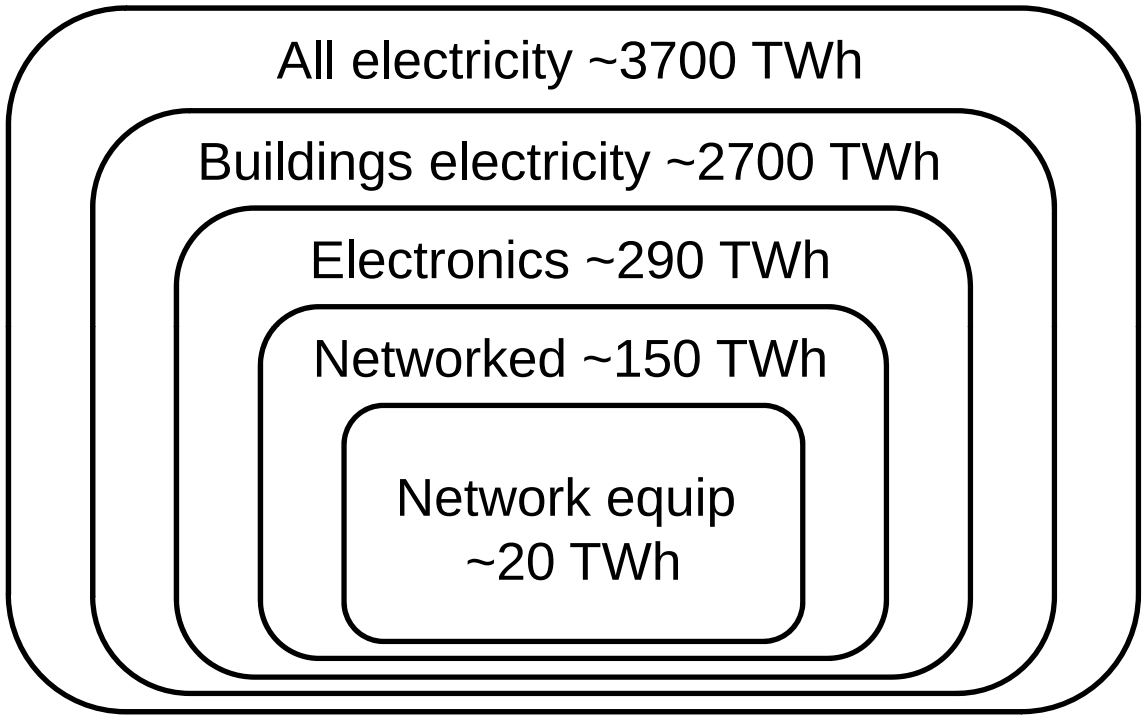
- Incremental additional energy used for a higher power state of hosts needed to maintain network connectivity

Quantifying the energy use of ICT

How much energy does ICT consume?

... the Internet is part of this

Electricity use in the USA – big picture



1 kWh = $0.10

$15 Billion

Where (exactly) is this electricity used?

How much of it is wasted?

How much can be saved?

From Bruce Nordman, LBNL, 2010.

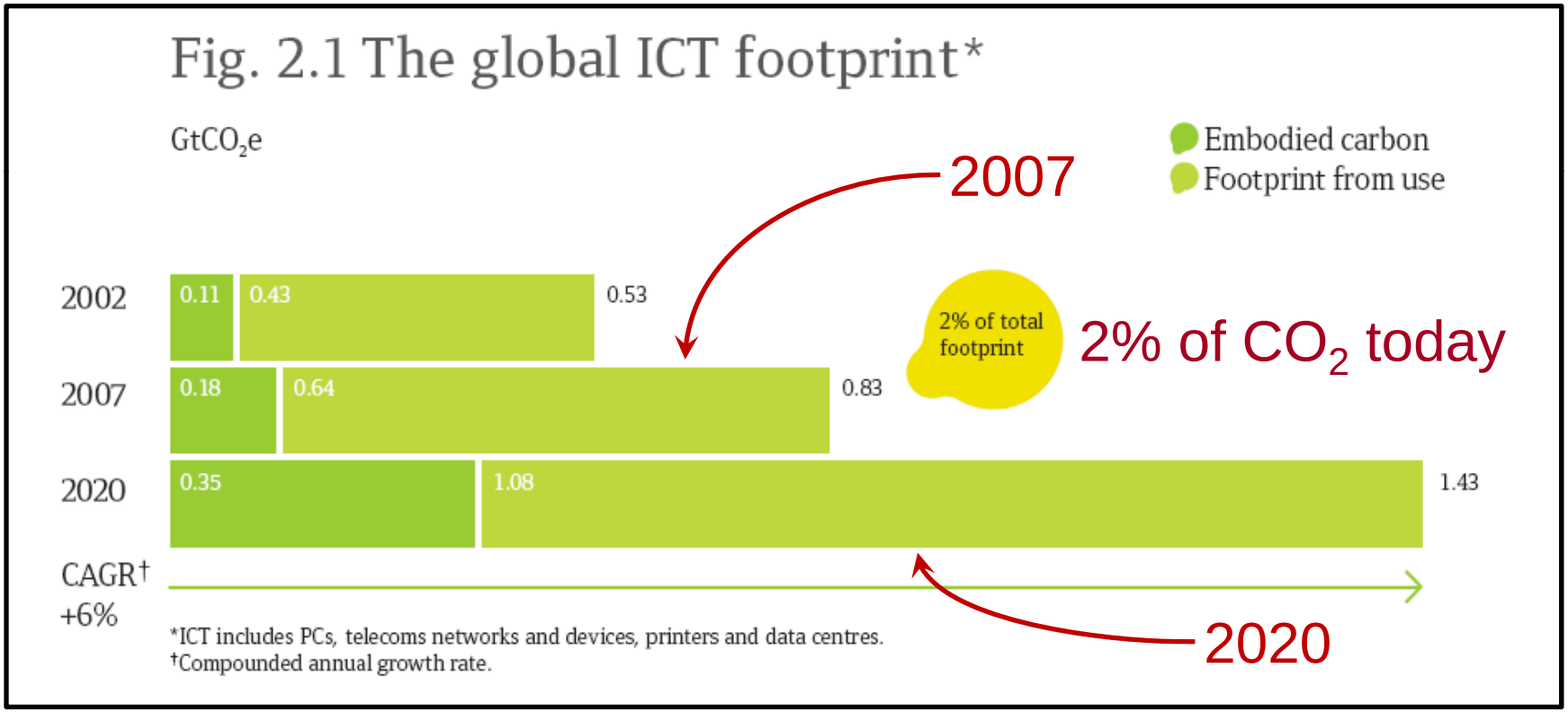
A view from the Climate Group

The SMART 2020 report

- Focus is on ICT's role in reducing greenhouse gases
  - Both of and by ICT
- A view of the world in 2020
  - Taking into account "likely" technology developments
- Supporting organizations
  - Include Cisco, Intel, HP, Sun, national telecoms, and telecom operators

Global ICT CO_2 footprint

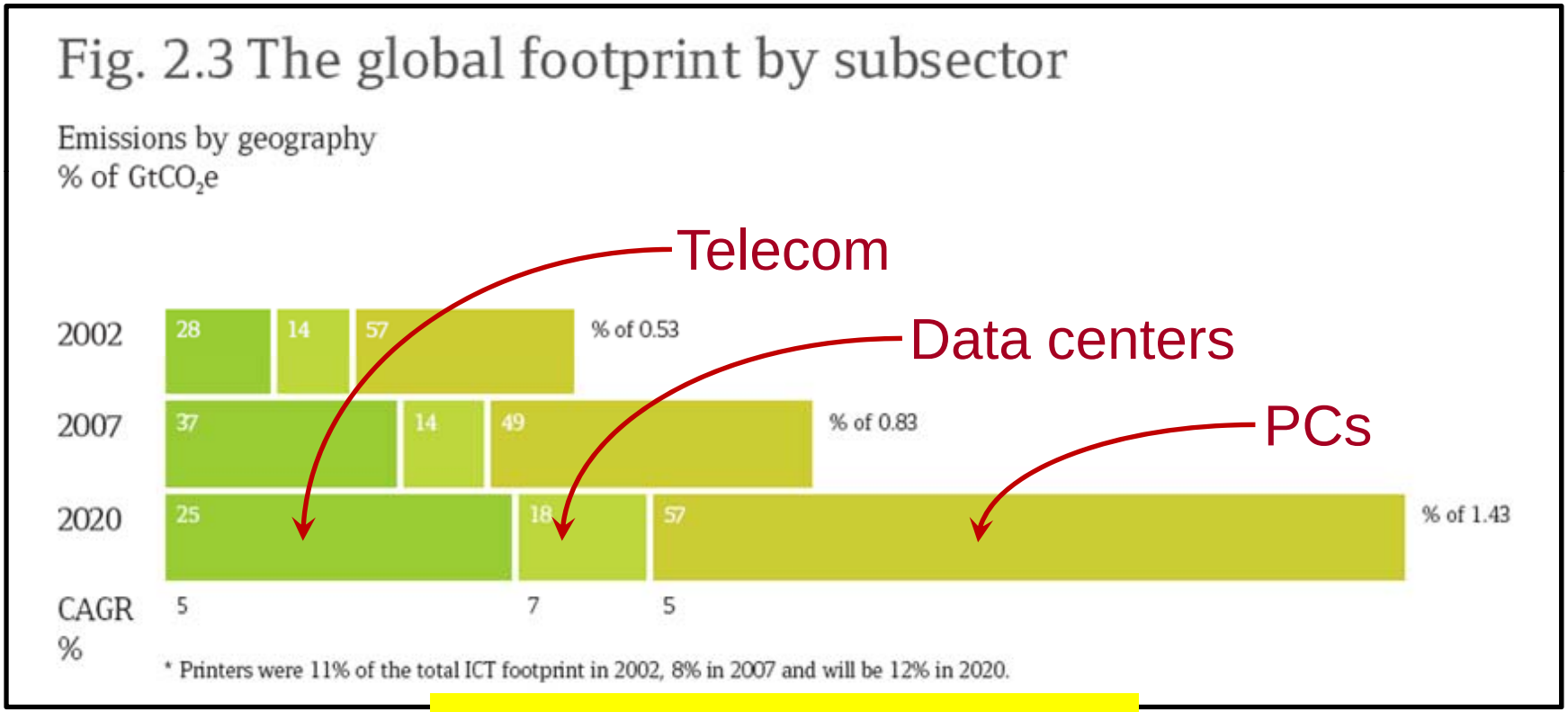
Today ICT is 2% of global CO_2



From SMART 2020 report

Global ICT CO_2 footprint continued

Telecom and PCs not data centers major contributors



Data centers are less than 15%

From SMART 2020 report

ICT CO_2 > Aviation CO_2

A very significant statistic…

> "The global information and communications technology (ICT) industry accounts for approximately 2 percent of global carbon dioxide (CO_2) emissions, a figure equivalent to aviation."
>
> - Gartner Group, Inc. (2007)

Most energy use is from the end user

More significant statistics…

> "Desktop computing accounts for 45 percent of global carbon emissions from information technology."
> - govtech.com

> "Most PC energy use in the US occurs when no one is there, and this is greater than the total energy use of all network equipment."
> - Bruce Nordman (LBNL)

Statistics from Italy – Broadband

17.5 million broadband users, overall population is 60 million

(A) 2015-2020 NETWORK FORECAST: DEVICE DENSITY AND ENERGY REQUIREMENTS IN THE BUSINESS-AS-USUAL CASE (BAU). EXAMPLE BASED ON THE ITALIAN NETWORK.

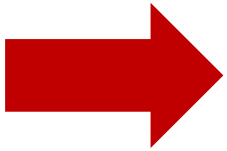
	power consumption [W]	*number of devices* [#]	*overall consumption* [GWh/year]
Home	10	17,500,000	1,533
Access	1,280	27,344	307
Metro/Transport	6,000	1,750	92
Core	10,000	175	15
		Overall network consumption	1,947

From: R. Bolla, R Bruschi, K. Christensen, F. Cucchietti, F. Davoli, and S. Singh, "The Potential Impact of Green Technologies in Next Generation Wireline Networks – Is There Room for Energy Savings Optimization?," to appear in *IEEE Communications*.

How much is wasted?

Most energy used in networks is wasted

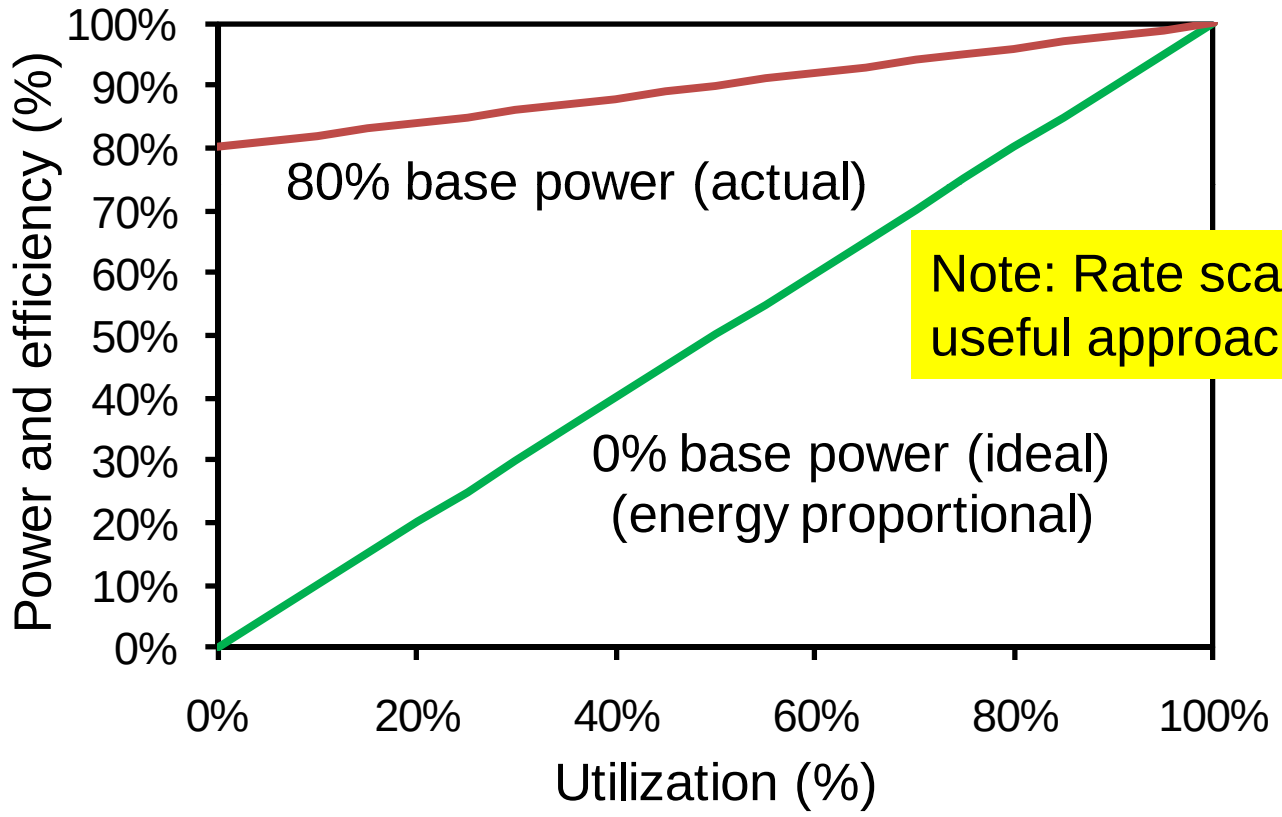
- Networks are lightly utilized
  - Over provisioned for peak and redundancy
  - 1% to 5% utilization typical at edges
- Network elements have high base power
  - Not energy proportional
  - 80% base power is typical for PCs, routers, links, etc.



Significant potential for large energy savings

Notion of energy proportional computing

Relationship of power use and utilization



Note: Rate scaling is not very useful approach for actual case

How do we move from the red line to the green line?

Notion of "doing nothing well"

Much of the time our systems are idle but on

- What we seek is the ability to do nothing well…

> "… but, the key starting point in conserving energy is: Do nothing well."
> - David Culler (UC Berkeley)

Because most of our systems are doing "nothing" most of the time

Summary of ICT energy use

ICT consumes and wastes a lot of energy

- ICT contributes about 2% of human emitted CO_2
  - About equal to aviation industry
  - Rapidly growing
- Most of this energy consumption comes from the edge
  - From edge networks, edge network equipment, and PCs
  - Not from data centers
- Most of the energy consumed is wasted
  - Due to provisioning for peak resulting in low average utilization
  - High base power

Reducing direct energy consumption

Can we reduce energy used by Ethernet?

... Energy Efficient Ethernet (EEE)

Reducing energy use of Ethernet

Key observations:

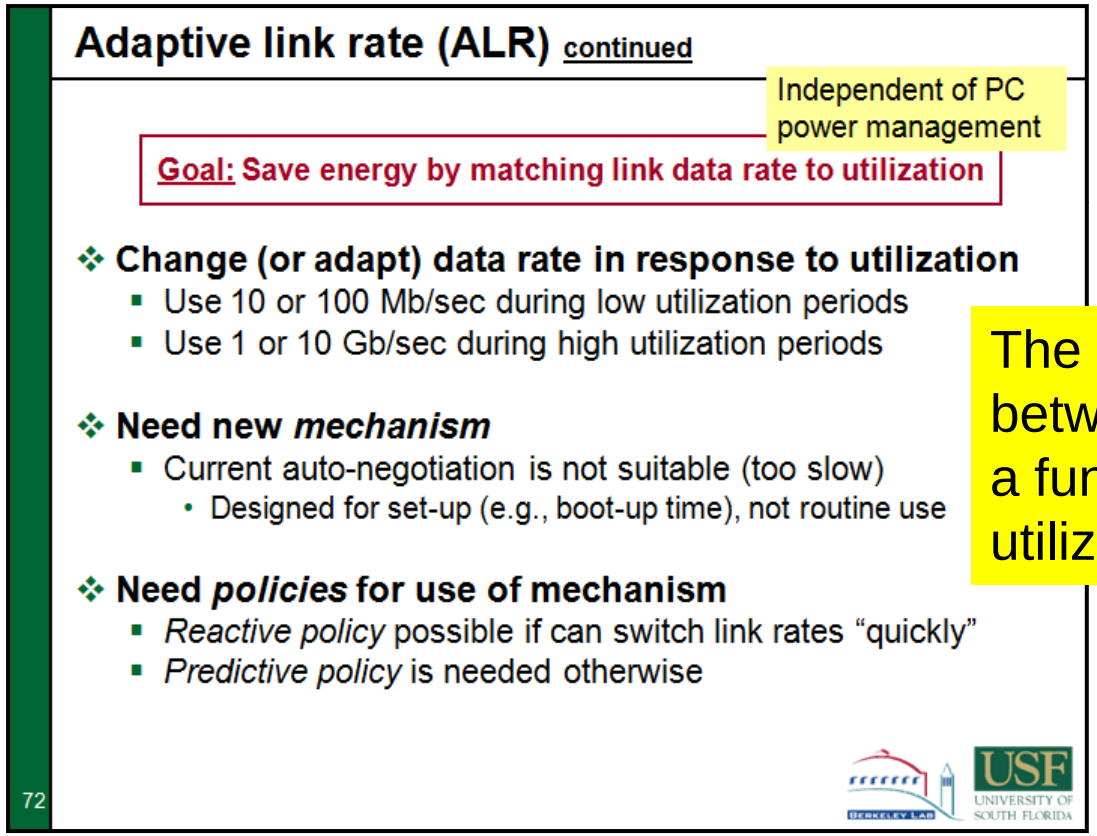
- Most Ethernet links are lightly utilized (1% to 5%)
  - Majority of links are desktop to wiring closest
- Ethernet power consumption independent of utilization

Can we adapt power use to utilization?

- First idea: Adaptive Link Rate (ALR)
- Better idea: Low Power Idle (LPI)

Adaptive Link Rate (ALR)

Proposed in 2005 by Nordman and Christensen

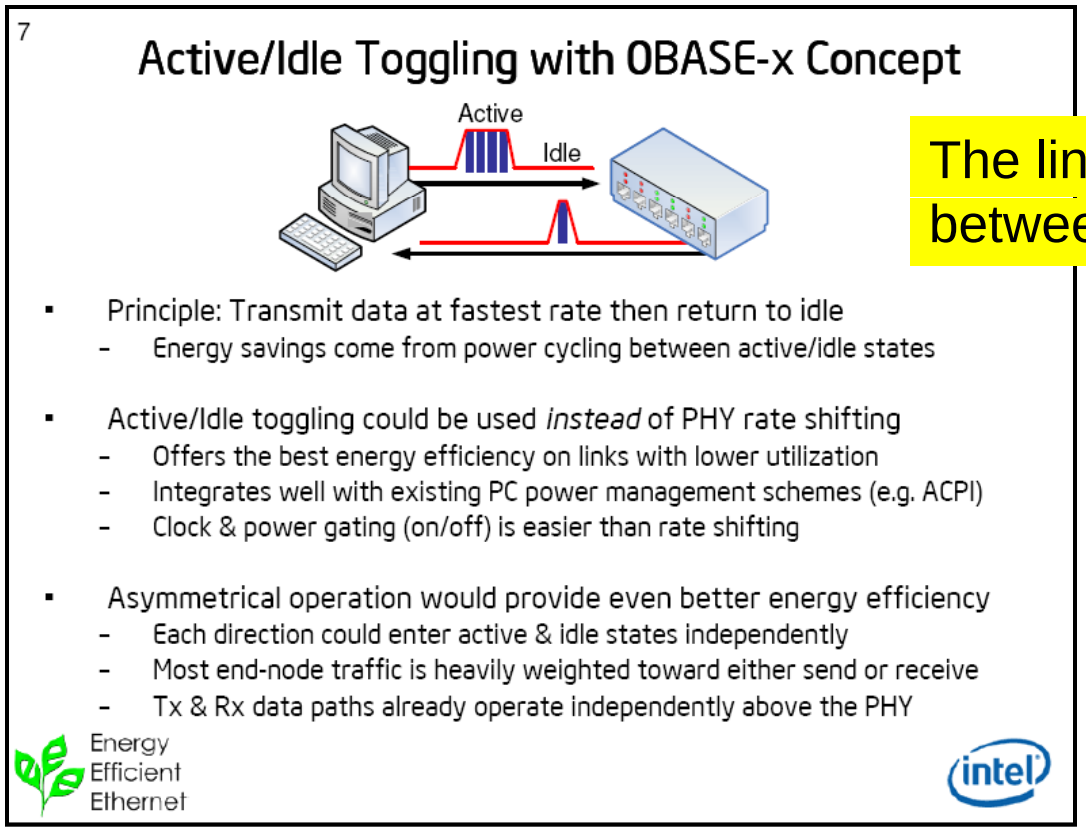


The link switches between rates as a function of link utilization

From Bruce Nordman and Ken Christensen, "Reducing the Energy Consumption of Networked Devices," IEEE 802.3 tutorial, July 19, 2005 (San Francisco).

Low Power Idle (LPI)

Proposed in 2007 by Intel



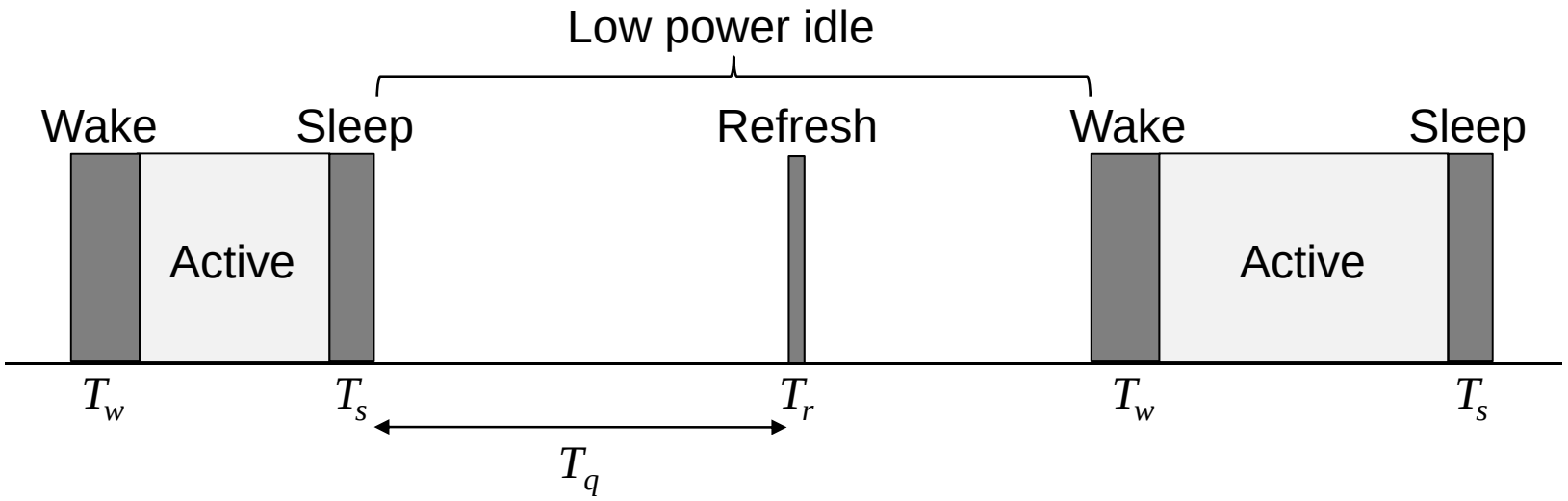
The link sleeps between packets

From Robert Hays, "Active/Idle Toggling with 0BASE-x for Energy Efficient Ethernet," presentation to IEEE 802.3az Task Force, November 2007.

How LPI works

PHY goes to sleep between packets

- Sleep is idle = about 10% of full power
  - Periodic refreshes to keep synchronized
  - Has wake-up and sleep transitions
    - » First packet after an idle incurs a wake-up transition (T_w)
    - » After last packet in a burst a go to sleep transition (T_s)



Effect of LPI overhead

Efficiency for single packet case

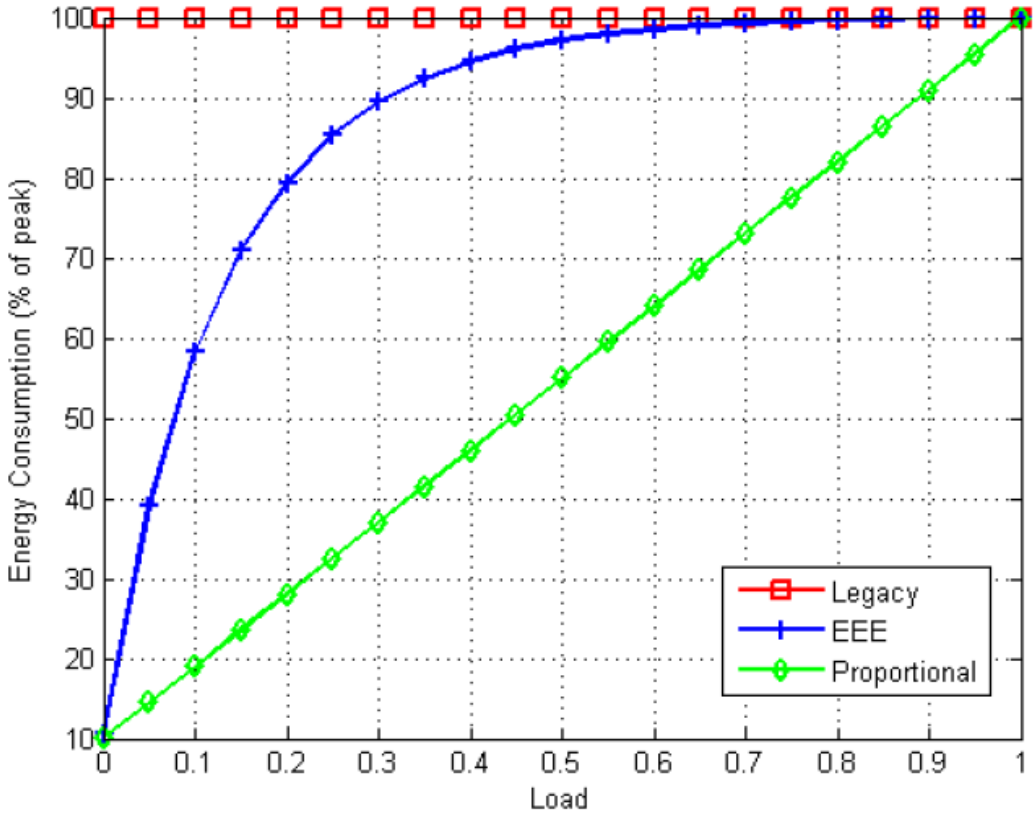
$$Efficiency = \frac{T_{Frame}}{T_{Frame} + T_w + T_s}$$

Protocol	Min T_w (μs)	Min T_s (μs)	T_{Frame} (1500B) (μs)	Frame eff.	T_{Frame} (150B) (μs)	Frame eff.
100Base-Tx	30	100	120	48%	12	8.5%
1000Base-T	16	182	12	5.7%	1.2	0.6%
10GBase-T	4.16	2.88	1.2	14.6%	0.12	1.7%

From P. Reviriego, J. Hernandez, D. Larrabeiti, and J. Maestro, "Performance Evaluation of Energy Efficient Ethernet," *IEEE Communications Letters*, Vol. 13, No. 9, pp. 1-3, September 2009.

Effect of LPI overhead continued

Efficiency for 10 Gb/s (Poisson arrivals)



Simulation. Fixed length 1250 byte packets.

There is potential for improvement!

From P. Reviriego, J. Hernandez, D. Larrabeiti, and J. Maestro, "Performance Evaluation of Energy Efficient Ethernet," *IEEE Communications Letters*, Vol. 13, No. 9, pp. 1-3, September 2009.

Packet coalescing to improve EEE

Addressed EEE improvements in recent paper

IEEE 802.3az: The Road to Energy Efficient Ethernet

Authors: K. Christensen, P. Reviriego, B. Nordman, M. Bennett, M. Mostowfi, and J.A. Maestro

- Explored coalescing of packets at transmitter
  - Reduce overall wake and sleep overhead
  - Trade-off energy savings for delay
- Paper to appear in special issue on Green Communications in *IEEE Communications* magazine

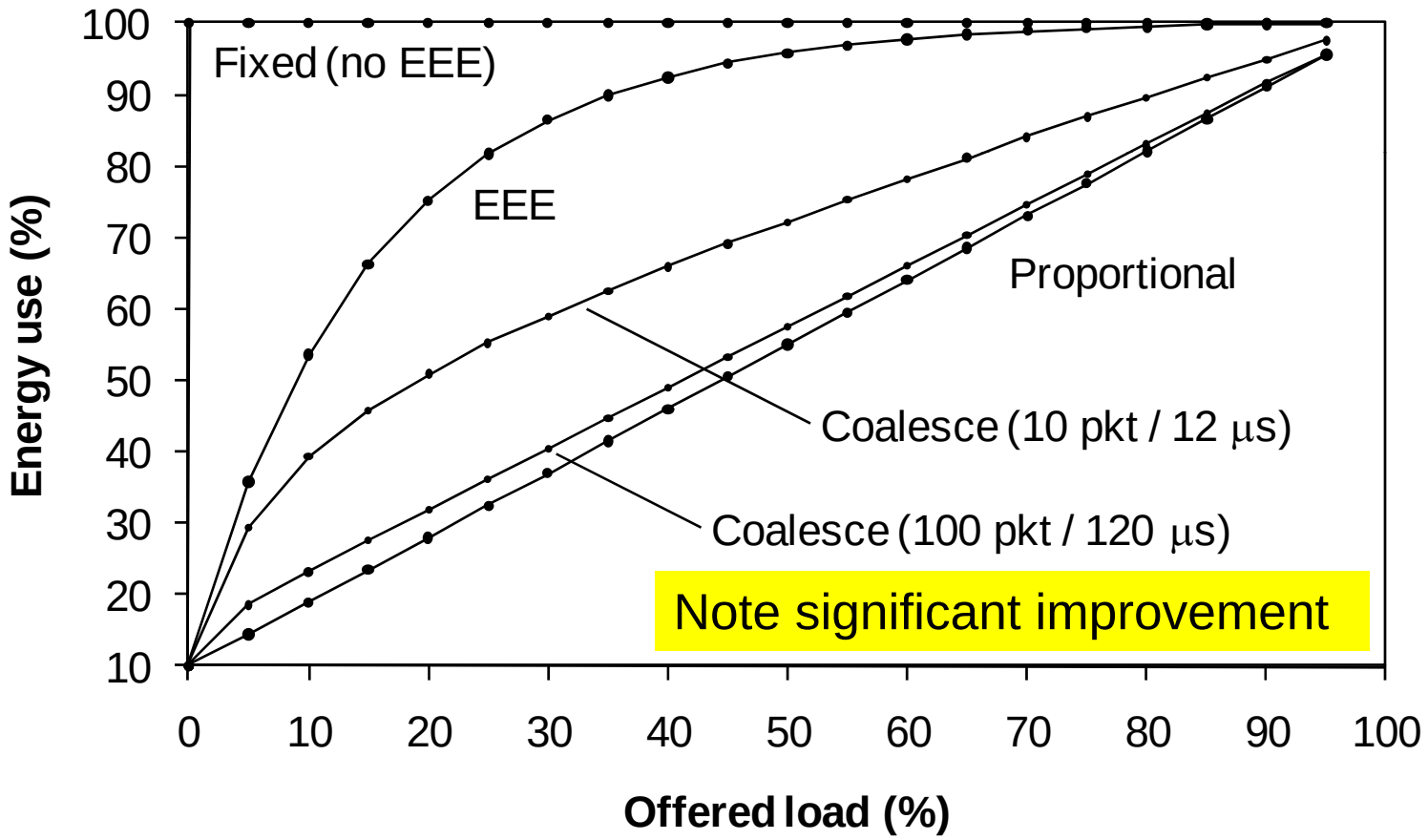
Reproduced previous 10 Gb/s experiment

Key parameter values for simulation model

- EEE parameter values
  - T_WAKE = 4.16 μs
  - T_SLEEP = 2.88 μs
  - For 1250 byte packet service time = 1.0 μs
- Coalescing parameter values
  - max = 10 packets or $t_{coalese}$ = 12 μs
  - max = 100 packets or $t_{coalese}$ = 120 μs
- Assume that idle power use is 10% of full power use
- Vary offered load from 0% to 95%
  - Poisson arrivals, fixed length packet

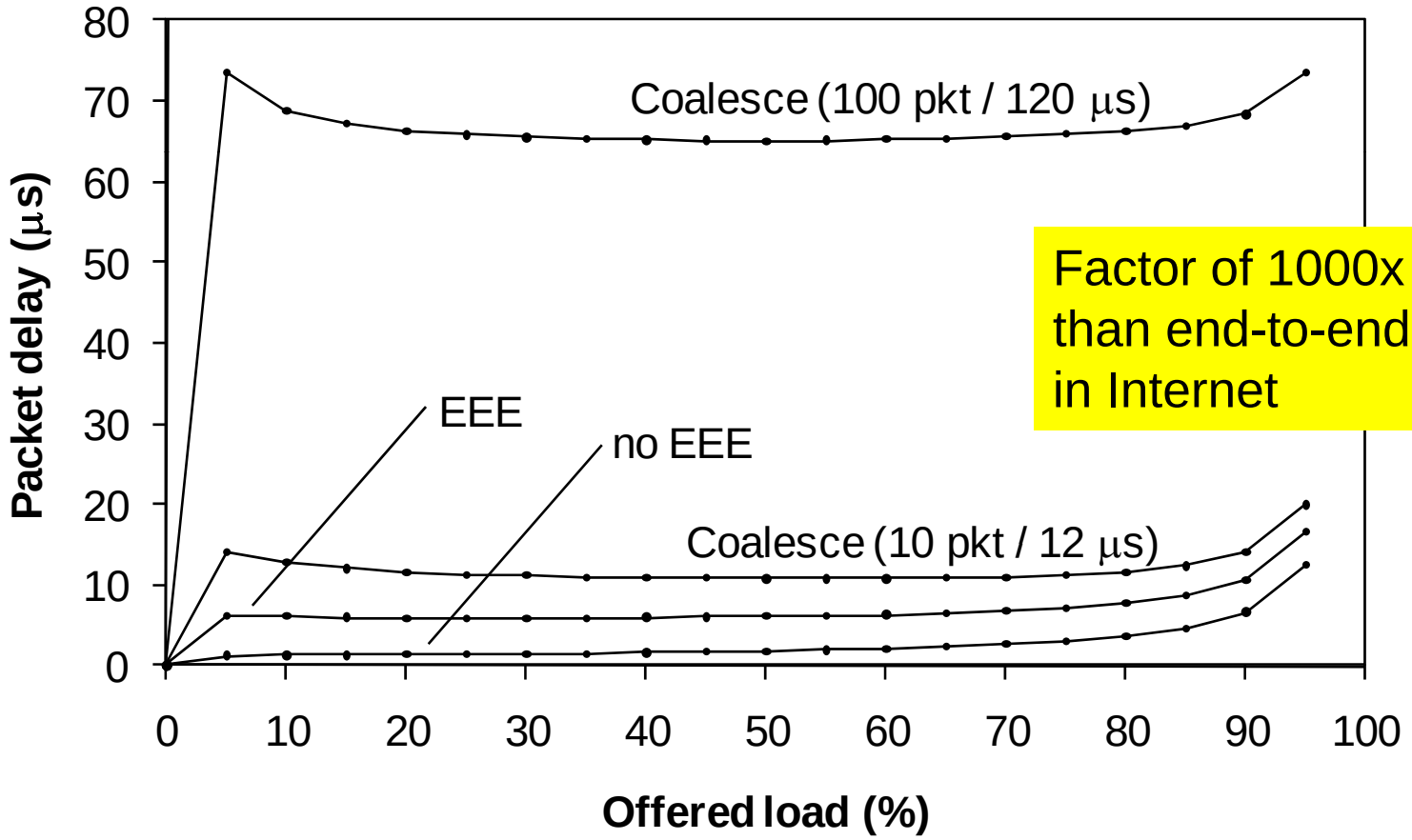
EEE with coalescing results

Efficiency of 10 Gb/s with coalescing



EEE with coalescing results continued

Packet delay for 10 Gb/s with coalescing



Factor of 1000x less than end-to-end delay in Internet

Future work for coalescing

Need to consider effects of added delay

- What are effects of coalescing on TCP?
  - ACK compression?
- Are there other system-wide effects?

Expected savings

Energy savings have been estimated for USA

- Assume 2008 stock of Ethernet links as the “future”
  - Assume all interfaces support EEE
  - 250 million 1 Gb/s and 65 million 10 Gb/s
  - Per link savings of 1 W for 1 Gb/s and 5 W for 10 Gb/s
  - Get efficiency values from simulation graphs

⇒ EEE savings per year in the USA = $410 million

⇒ Additional savings from coalescing = $80 million

History of IEEE 802.3az

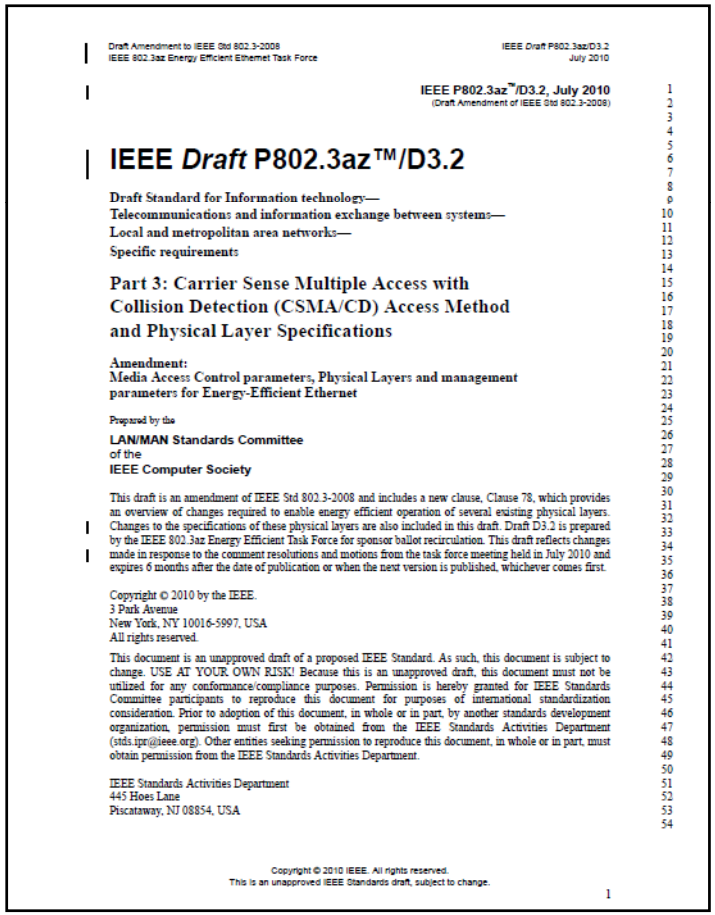
- Opportunity for energy savings to IEEE 802.3 in 2005
  - Presented idea of ALR
  - A Study Group was formed
  - Mike Bennett from LBNL became the chair
- Became “Energy Efficient Ethernet”
  - IEEE 802.3az task force

- ALR became RPS, which then became LPI
- Standard based on LPI to be ratified in September 2010
- Vendors are now sampling products (based on LPI)
  - Broadcom and Realtek

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

The IEEE 802.3az standard

The IEEE Draft P802.3az/D3.2 standard



Draft Amendment to IEEE Std 802.3-2008
IEEE 802.3az Energy Efficient Ethernet Task Force

IEEE Draft P802.3az/D3.2
July 2010

IEEE P802.3az™/D3.2, July 2010
(Draft Amendment of IEEE Std 802.3-2008)

IEEE *Draft* P802.3az™/D3.2

**Draft Standard for Information technology—
Telecommunications and information exchange between systems—
Local and metropolitan area networks—
Specific requirements**

Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications

**Amendment:
Media Access Control parameters, Physical Layers and management parameters for Energy-Efficient Ethernet**

Prepared by the

LAN/MAN Standards Committee
of the
IEEE Computer Society

This draft is an amendment of IEEE Std 802.3-2008 and includes a new clause, Clause 78, which provides an overview of changes required to enable energy efficient operation of several existing physical layers. Changes to the specifications of these physical layers are also included in this draft. Draft D3.2 is prepared by the IEEE 802.3az Energy Efficient Task Force for sponsor ballot recirculation. This draft reflects changes made in response to the comment resolutions and motions from the task force meeting held in July 2010 and expires 6 months after the date of publication or when the next version is published, whichever comes first.

IEEE Standards Activities Department
445 Hoes Lane
Piscataway, NJ 08854, USA

1

- "… adds changes required to enable energy efficient operation of several existing Physical Layers."
- Mike Bennett (LBNL) is chair
- Expected to be ratified in September 2010

Summary of EEE

IEEE 802.3az improves energy efficiency of Ethernet

- Ethernet links typically have low utilization
- EEE = Energy Efficient Ethernet
  - Based on Low Power Idle (link sleeps between packets)
  - Sleep and wake overhead may be an issue to savings
  - Estimated savings are $100s of million per year in the US
- Packet coalescing can improve EEE savings
  - Trade-off of reduced energy use for added delay
  - Added delay is in 10s of microseconds – probably not an issue for end-to-end delay in an Internet connection

Reducing induced energy consumption

Can we reduce energy used by hosts?

... Proxy to maintain network presence

Reducing energy use of network hosts

Key observation

- "Today, billions of dollars' worth of electricity are used to keep Ethernet (and other) connected devices fully powered on at all times only for the purpose of maintaining this connectivity." (Bruce Nordman, 2007)

- The need for network presence is driving PCs to be left fully powered-on at all times

Defining "network presence" is a key challenge

Network Connectivity Proxy

How can we maintain network presence?

- Two possible approaches
  1) Redesigning protocols and applications
  2) Encapsulating intelligence for maintaining network presence in an entity other than the core of the network devices

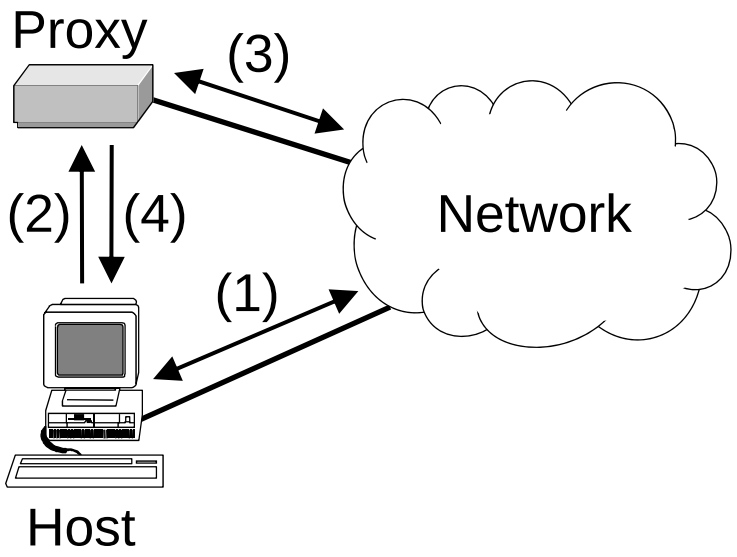
- Approach (2) best in the near-term

- A proxy is “an entity that maintains full network presence for a sleeping device”
  - Host appears to other devices as fully operational

High level view of a proxy

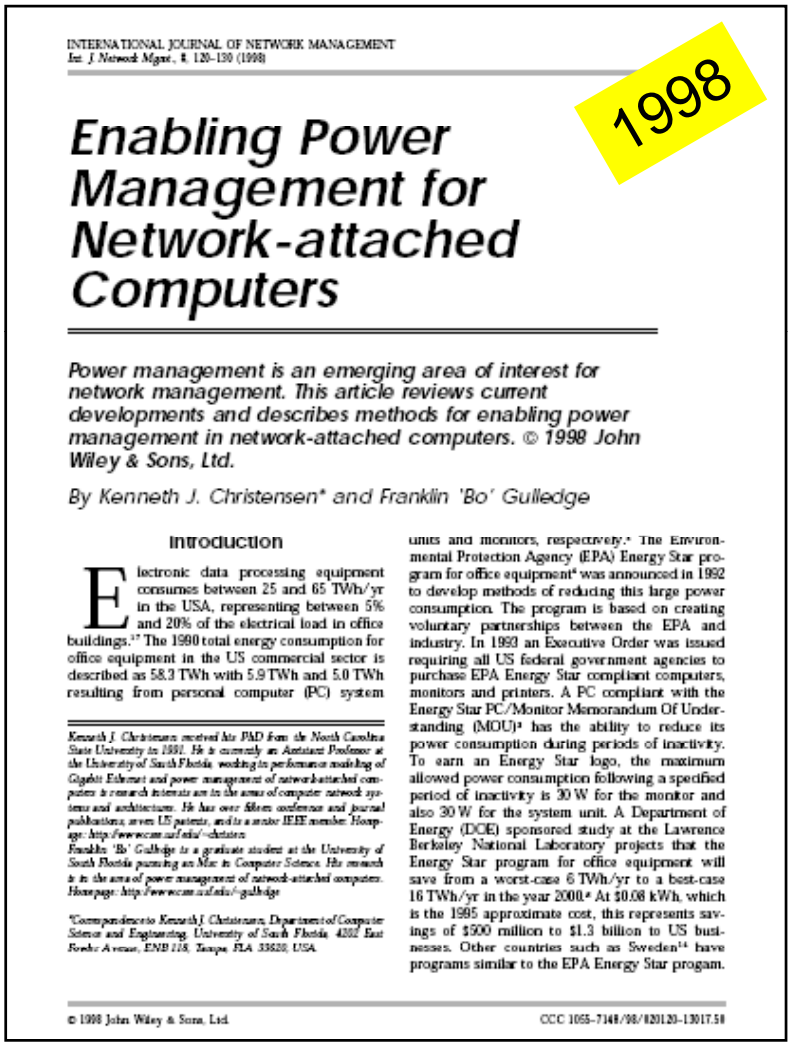
Operation of a proxy

1) Host awake; becomes idle
2) Host transfers state to proxy on going to sleep
3) Proxy responds to routine traffic for sleeping host
4) Proxy wakes up host as needed



Proxy can be in separate entity, or within host NIC

The first work on proxying



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

1998

Enabling Power Management for Network-attached Computers

Power management is an emerging area of interest for network management. This article reviews current developments and describes methods for enabling power management in network-attached computers. © *1998 John Wiley & Sons, Ltd.*

By Kenneth J. Christensen and Franklin 'Bo' Gulledge*

Introduction

Electronic data processing equipment consumes between 25 and 65 TWh/yr in the USA, representing between 5% and 20% of the electrical load in office buildings.[1,2] 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 units and monitors, respectively.[3] The Environmental Protection Agency (EPA) Energy Star program for office equipment[4] was announced in 1992 to develop methods of reducing this large power 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. His 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' Gulledge 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/~gulledge

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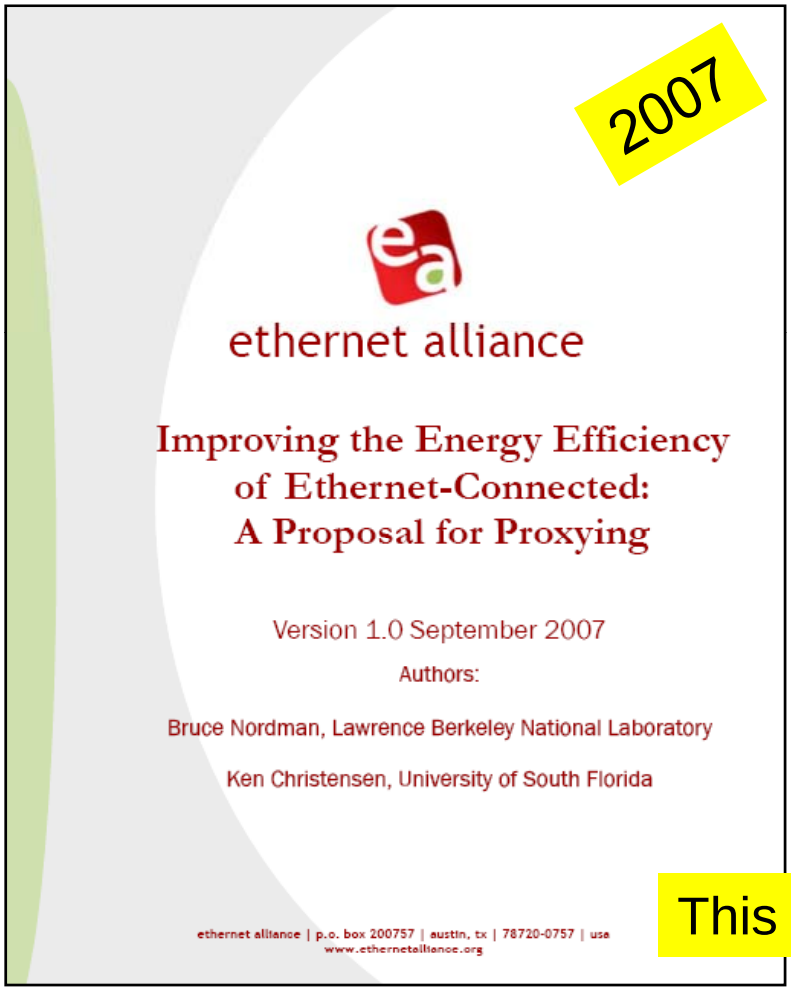
CCC 1055–7148/98/020120–13$17.50

- Described proxying for ARP and TCP keep-alives
- Described a centralized proxy covering for many hosts on a shared Ethernet LAN

Describing proxying to industry



- A whitepaper to bring proxying to industry folks
  - Industry folks do not read academic papers
- High-level view of proxying
  - Why we need it
  - How it might work
  - Next steps
  - FAQ

This was the first step to a standard

Early work: A prototype ARP/SYN proxy

Emulated proxy to allow a web server to sleep

From K. Christensen, P. Gunaratne, B. Nordman, and A. George, "The Next Frontier for Communications Networks: Power Management," *Computer Communications*, Vol. 27, No. 18, pp. 1758-1770, December 2004.

Recent work: A proxy for SIP phones

IP phones are a new energy consumer

- IP phones need to maintain network presence
  - In order to receive a “ring” signal on incoming call
- IP phone draws about 10 to 20 W (so, $10 to $20 per year)
- Can also use a PC to make a “soft phone”
  - PC then needs to remain powered-up at all times

The Magic Jack product

A new product to replace landline telephone service

- USB device to plug an analog phone into a PC
  - Then use a SIP-based IP telephony service
  - Uses your Broadband service “for free”

Millions sold

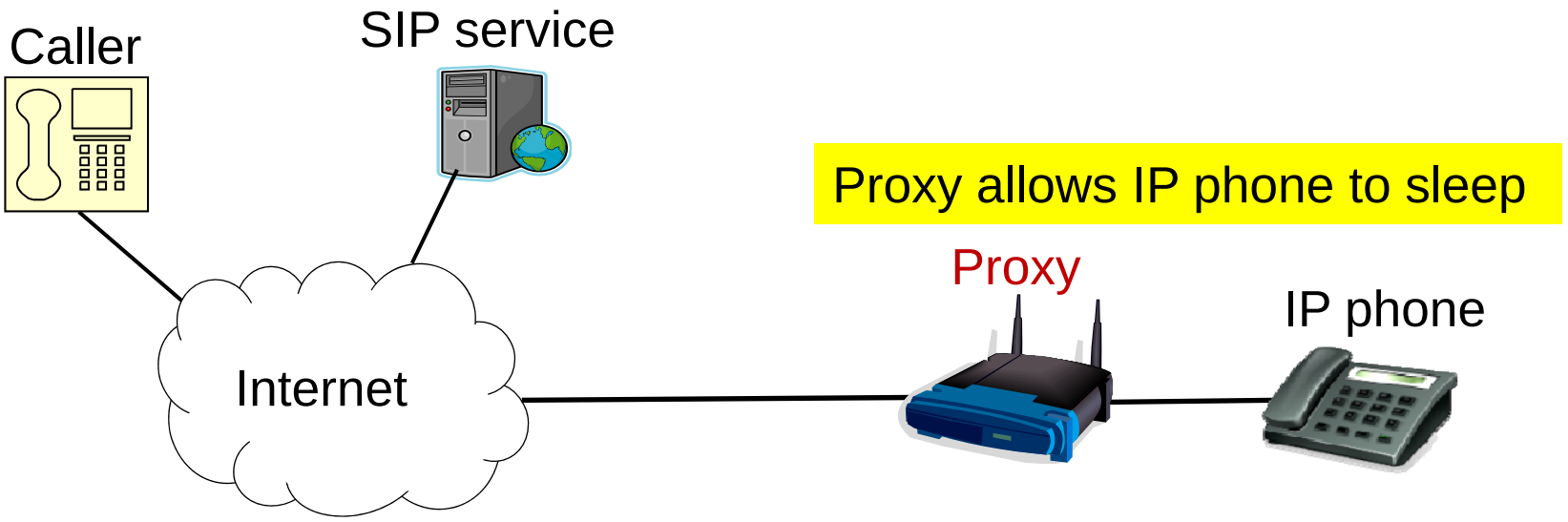
Requires PC to be fully powered-on to be able to participate in SIP protocol

Power costs can exceed savings from canceling landline service

The “SIP catcher” – system view

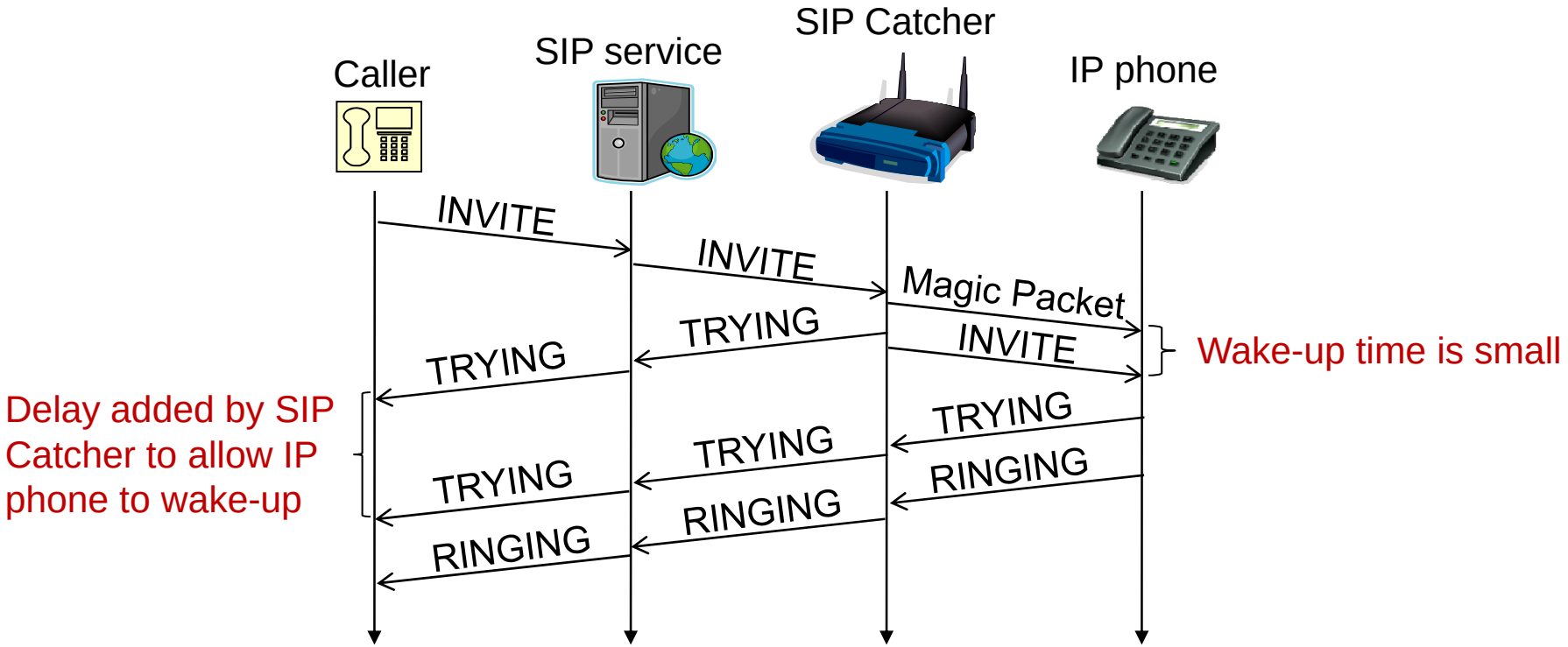
Developed a proxy within a Linksys router

- Knows sleep/wake state of a soft phone PC or IP phone
- Handles SIP protocol and wakes IP phone as needed



The “SIP catcher” – packet flow view

Key steps:
1) Wakes up phone when call detected (incoming INVITE)
2) Responds on behalf of phone (TRYING)
3) Forwards INVITE to phone when it is awake

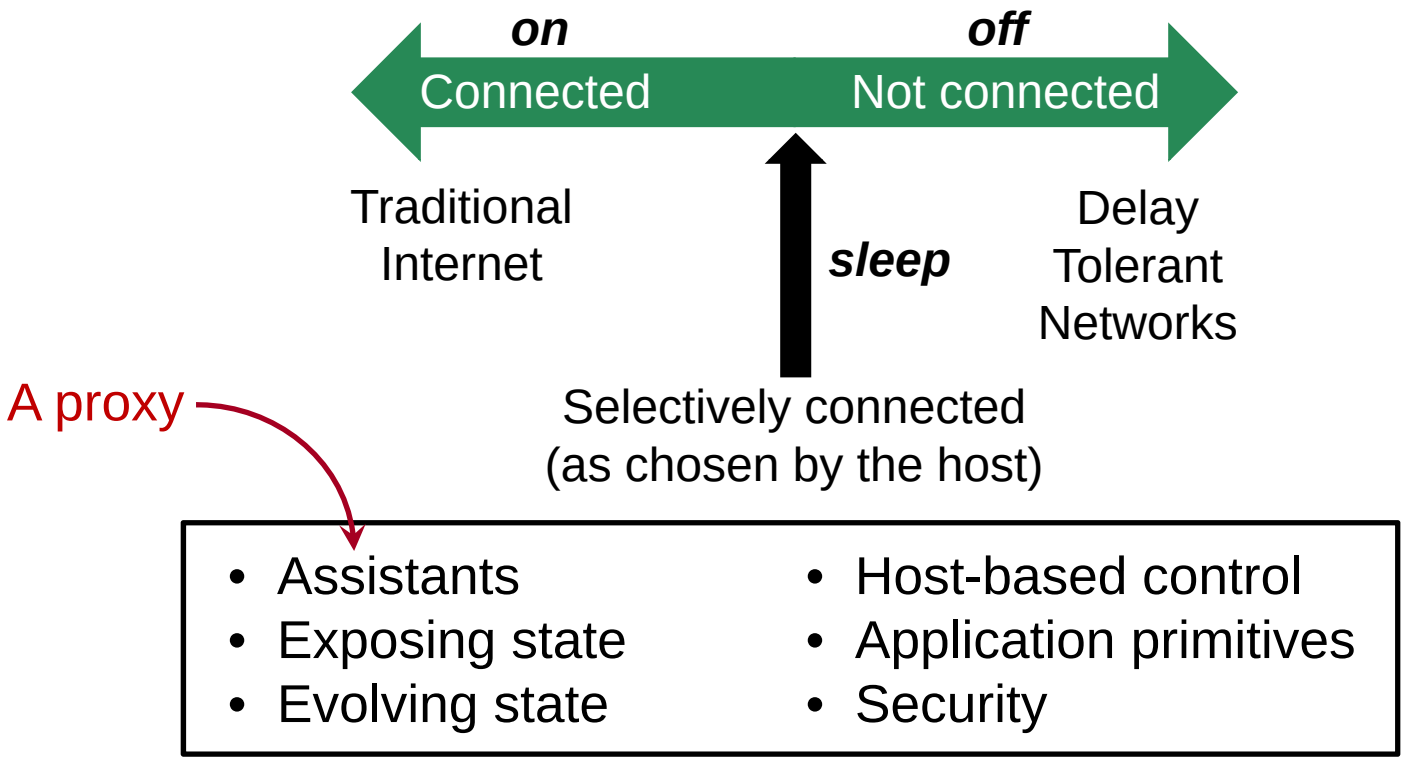


Full 8 minute version on YouTube

The “SIP catcher” – a demonstration

Future work for proxying

Explore selective connectivity as an architecture

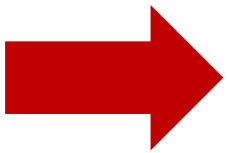


From M. Allman , K. Christensen, B. Nordman, and V. Paxson, "Enabling an Energy-Efficient Future Internet through Selectively Connected End Systems," *Sixth Workshop on Hot Topics in Networks (HotNets-VI)*, November 2007.

Expected savings

Energy savings have been estimated for USA

- For desktop PCs most time is spent as on and idle
- Proxying could save more than half of energy used by these products



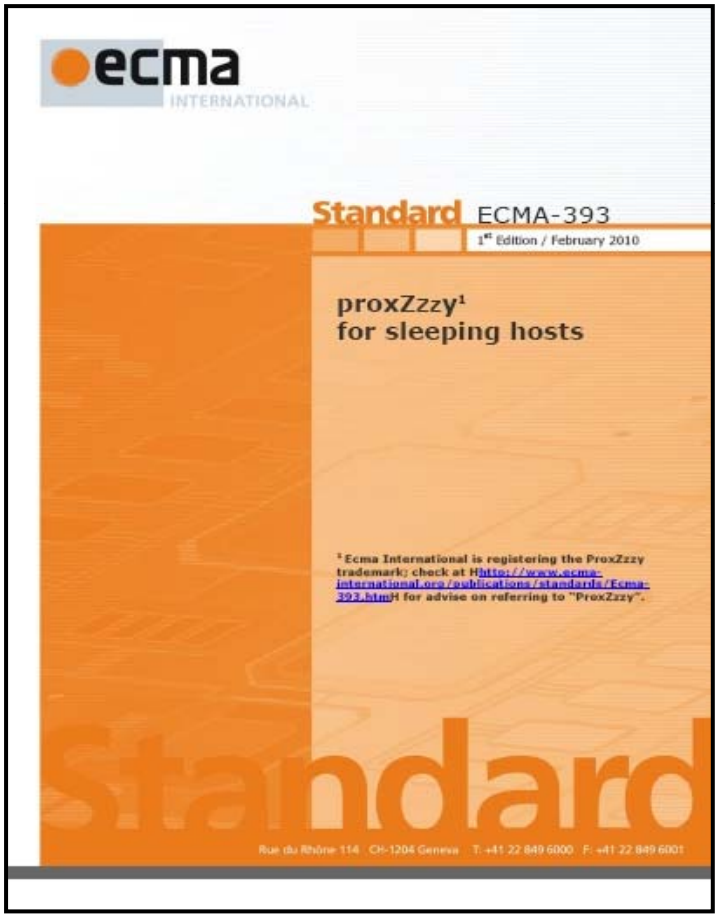
Savings potential for desktop PCs = $0.8 to $2.7 billion

History of Proxying

- Discussions toward a standard started in 2007 to 2008
  - To address IPv4 and IPv6 “lower layers”
    - » Layers below applications
- Starting of Ecma effort in 2008 to 2009
  - Bruce Nordman led the effort
- Standard approved in February 2010
- Standard referenced in EPA Energy Star
  - Will drive adoption of proxying

The Ecma proxying standard

Ecma-393 ProxZzzy for sleeping hosts



- "… maintenance of network connectivity and presence by proxies to extend the sleep duration of hosts"
- Satisfies EPA Energy Star "platform-independent industry standard"
- Approved in February 2010

Does not include proxying for applications (e.g., P2P)

Proxying in EPA Energy Star

EPA Energy Star for Computers, Version 5.0

- "Proxying refers to a computer that maintains Full Network Connectivity as defined in Section 1 of this specification. 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.“*

The Ecma standard is key to this

From ENERGY STAR® Program Requirements for Computers, Version 5.0, EPA, 2009.

Proxying in products

Apple Snow Leopard

- "Wake on Demand. This is Apple's name for a new networking feature that lets a Snow Leopard Mac go to sleep while a networked base station continues to broadcast Bonjour messages about the services the sleeping computer offers."*

Bonjour Sleep Proxy, supports ARP, file and print serving, and SSH login initiation.

From "Wake on Demand lets Snow Leopard Sleep with One Eye Open," MacWorld, August 28, 2009

Summary of Proxying

Ecma ProxZzzy reduces induced energy use of hosts

- Hosts usually idle but connected to maintain “presence”
- Idea of a network connectivity proxy
  - Based on low-power hardware covering for high-power hardware
  - Supporting applications is a challenge
  - Estimated savings are on the order of $1 billion per year in the US
- Future work in addressing applications
  - Including P2P in all forms
- Future work in Selective Connectivity architecture
  - A future view of the Internet as not “always on”

Future challenges

Where do we go from here?

… energy savings of and by ICT

Future challenges in green networks

Future challenges in four areas

1) General
2) Network core and edge
3) Network hosts
4) Distributed applications

Future challenges continued

General

- Metrics
  - How do we measure energy-performance trade-offs?
- Models
  - How do we model energy-performance trade-offs?
- Exposing power and usage state
  - Need to be able to remotely determine power/use state
  - How to know when something is idle?
- Architectures for selective connectivity
  - Need mechanisms/protocols for selective connectivity
  - Includes notions of proxying

Future challenges continued

Network core and edge

- Energy efficient routers and switches
  - Support sleep states and rate adaptation
- Energy efficient links
  - Adapt link rates to load
- Traffic shaping
  - Shape traffic for short-term sleep during idle periods
- Traffic engineering
  - Consolidate routes for long-term sleep of idle routes
- Data caching
  - Cache popular data to reduce load on network and servers

Future challenges continued

Network hosts

- Discovery of devices, capabilities, content, and services
  - Need to be able to discover low-power substitutes

Distributed applications

- Move computing work to where power is cheapest
  - "Follow the moon" for data center activity
- P2P, multiplayer games, and virtual worlds
  - When idle should sleep
- Webcams and sensors everywhere (Internet of things)
  - When idle should sleep

Future challenges continued

My thoughts on the "best" challenges

- I think that the biggest challenges are at the edge
  - Most energy use there
  - Most opportunity for making changes
- Need applications and protocols that allow for and enable hosts and network equipment to sleep
  - Notion of selective connectivity
- Be careful to not work on problems already solved
  - Much has now been solved (the "low hanging fruit")
  - Always be able to quantify expected savings and argue that they are sufficient to be of interest

Conclusions

- ICT has large and growing energy use
  - Estimated to be 2% of human generated CO_2
- EEE will reduce direct energy use
  - Hundreds of millions of dollars per year in US expected
- Packet coalescing can improve efficiency of EEE
  - Tens of millions of dollars per year saving in US possible
- Proxying will reduce induced energy use by hosts
  - Potential for billions of dollars per year savings in the US
- There are future challenges to be addressed

Any questions?

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