Green Networks: Opportunities and Challenges

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The Grand Challenge

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

Here is one reason why…

Sea level in 2100 under "high emissions" scenario

I live here

From U.N. Intergovernmental Panel on Climate Change

The challenge to ICT

What role will ICT play in this grand challenge?

1) To directly reduce energy use of ICT

2) To enable energy savings in non-ICT

→ "Green Computing"

Green = sustainable

"Sustainability: Development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

- "Our Common Future" (Brundtland Report 1987 UN report)

One way to be "green"…

Just have less and do less

- No houses, no cars, no travel, no PCs, no Internet, etc.

North Korea at night.
A model green society?
I don't think so…

From http://strangemaps.wordpress.com/2007/12/16/218-koreas-dark-half/

Notion of comfortable conservation

"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

Lifecycle of "stuff" (including ICT equipment)

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 energy use of ICT
- Reducing energy use of PCs
- Reducing energy use of Ethernet
- Future challenges

Quantifying the energy use of ICT

How much energy does ICT use?

... the Internet is part of this.

USF UNIVERSITY OF SOUTH FLORIDA

A quick look at power and energy

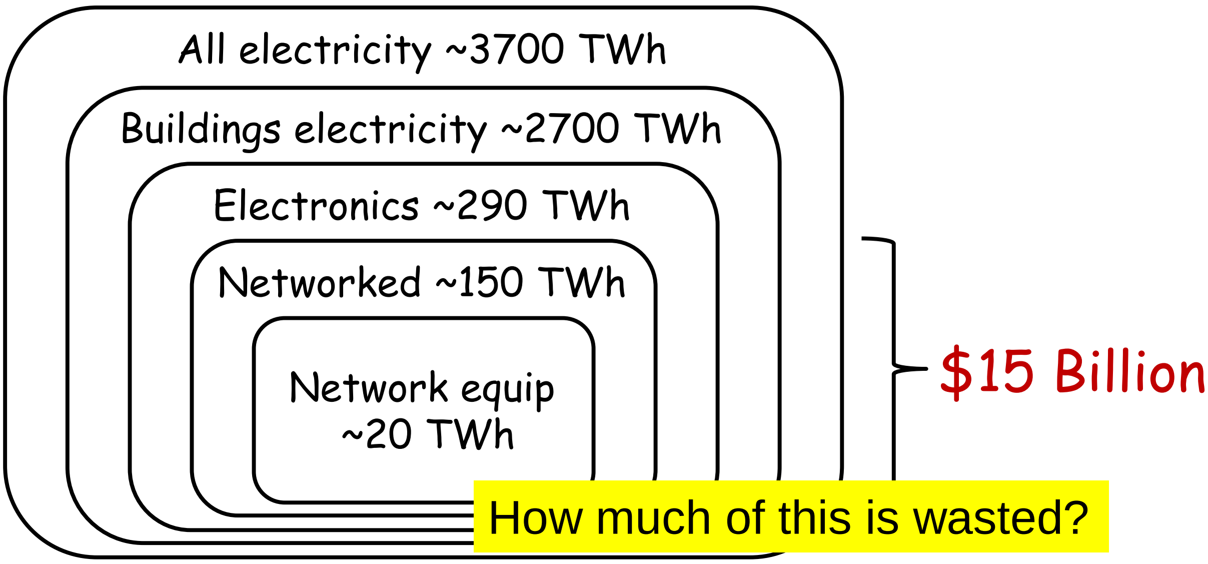
Energy is power multiplied by time

- Power is Watts (W) and Energy is Watt-hours (Wh)
- A kWh is about $0.10
- So, a TWh is about $100 million

St Lucie, Florida
(about 11 TWh/year)

Electricity use – big picture

Electricity use in the USA (2006, from LBNL)

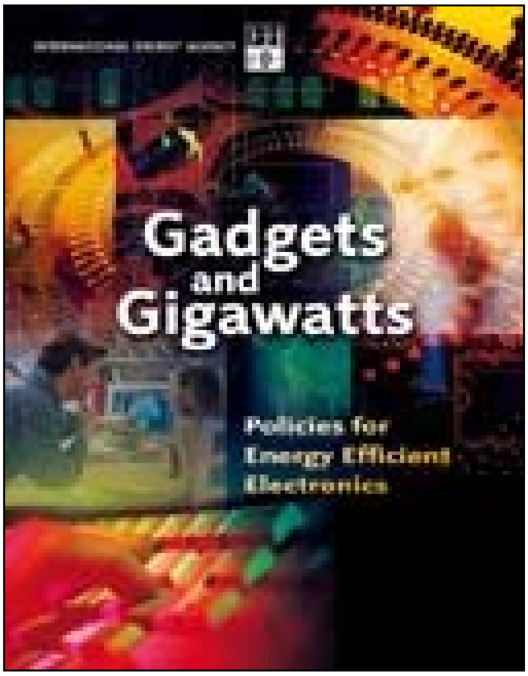


How much of this is wasted?

How much can be saved?

A view from the IEA

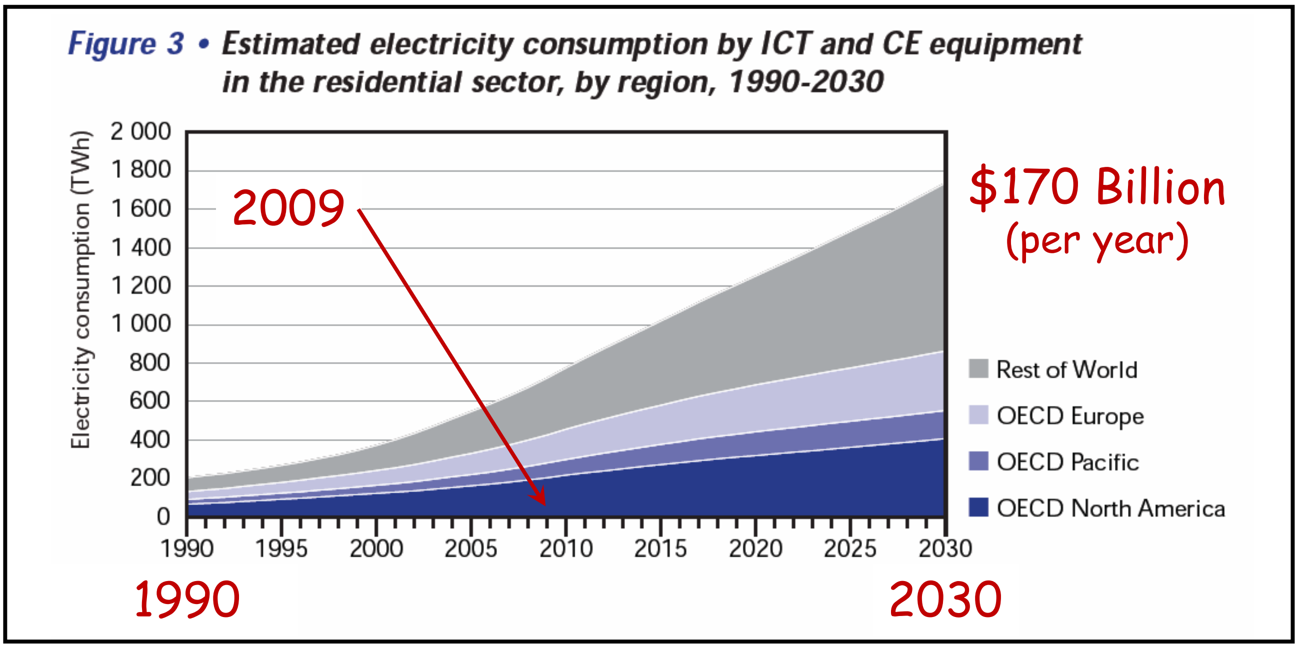
The Gadgets and Gigawatts book



- Focus is on policies for energy efficient electronics
- ICT and CE energy use is about 15% of household use
  - Growing very rapidly
- ICT and CE blur together at some point

ICT electricity use – it is growing

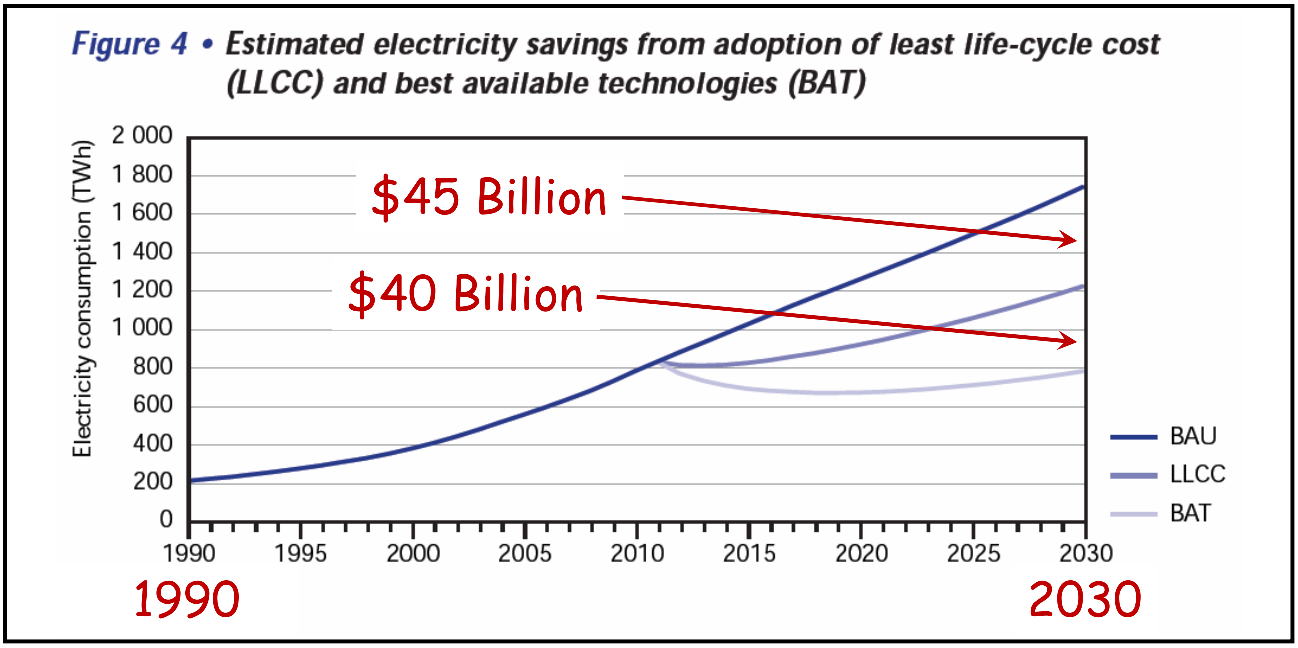
Electricity consumption estimates from IEA



From "Gadgets and Gigawatts," IEA, 2009.

ICT electricity use – possible savings

Electricity savings estimates from IEA



From "Gadgets and Gigawatts," IEA, 2009.

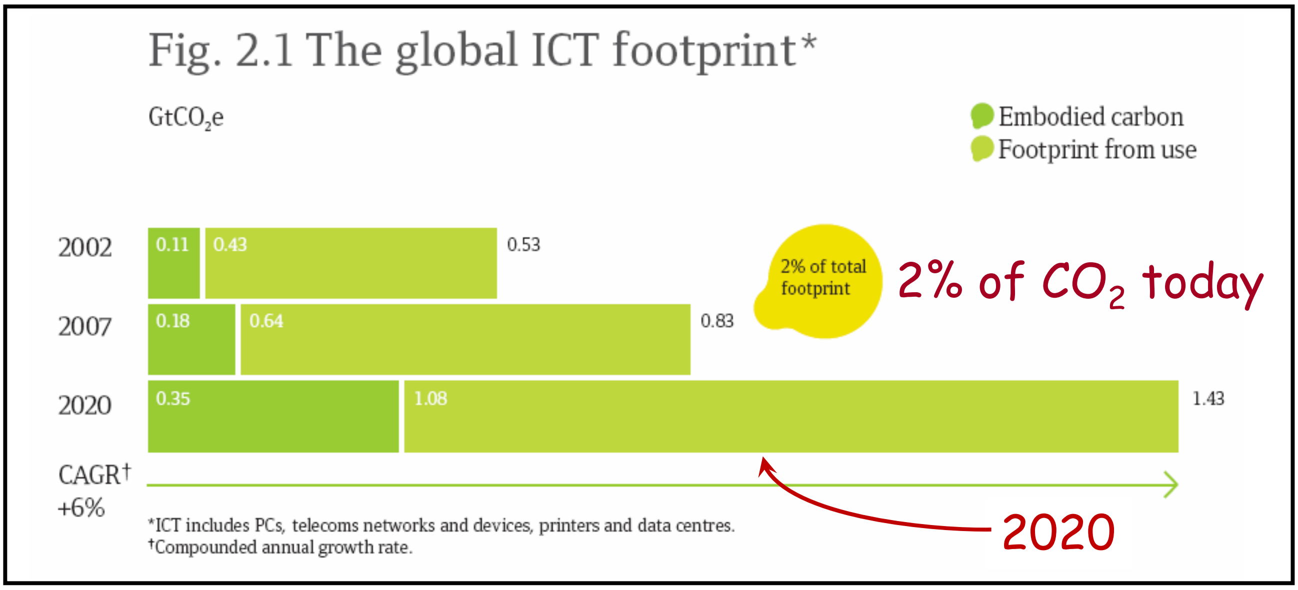
A view from the Climate Group

The SMART 2020 report

- Focus is on ICT's role in reducing greenhouse gases
- 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

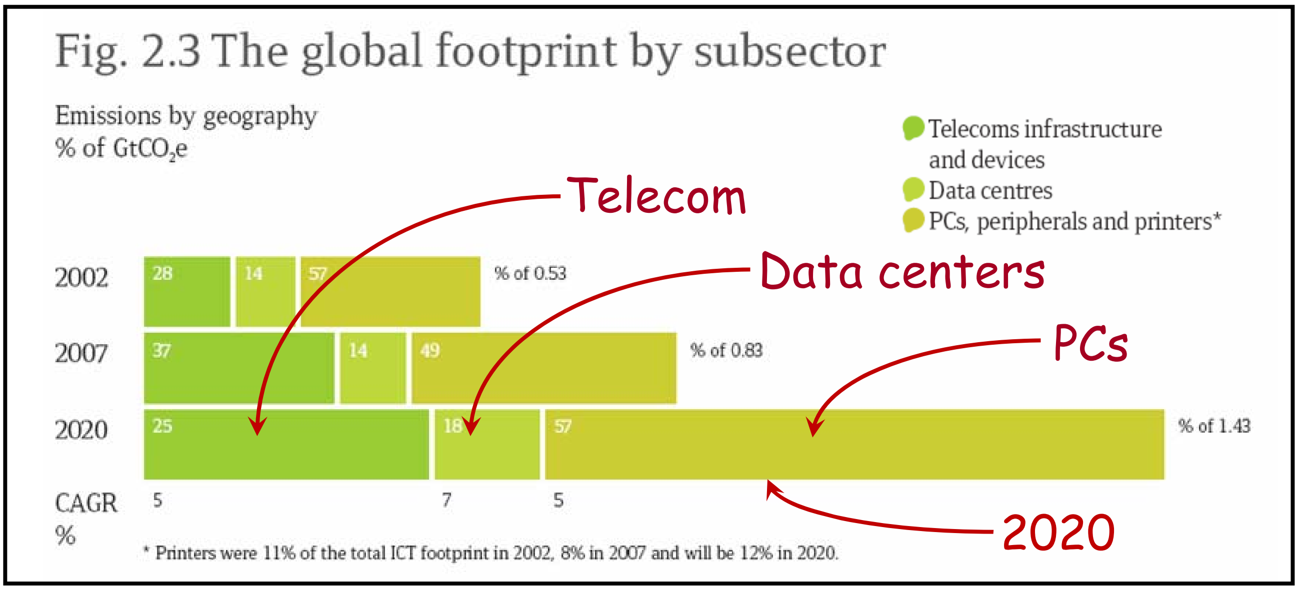
Today ICT is 2% of global CO_2



From SMART 2020 report

Global ICT CO_2 footprint continued

PCs (not data centers) are major CO_2 contributor



From SMART 2020 report

ICT CO_2 > Aviation CO_2

"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)

- ICT use growing faster than airline traffic
- Greater impact by "fixing" ICT than airplanes

ICT electricity use – more numbers

- **In the USA**
  - –2% of total electricity used is from PCs (EPA)
  - –1.5% is from data centers (Congressional report)
- **In the UK**
  - –About 10% from IT equipment (Public Policy, Sun UK)
- **In Italy**
  - –Energy consumption of Telecom Italia is about 1% of total Italian energy demand (Telecom Italia)

ICT energy use – small scale

Let's add one new PC to a household

- Average US household is 10,700 kWh per year
  - Much higher than in EU
- One PC at 80 W fully on 24/7 is 700 kWh per year
  - P2P and other applications are driving 24/7 fully-on

➡ One PC adds 6.6% to the yearly power bill

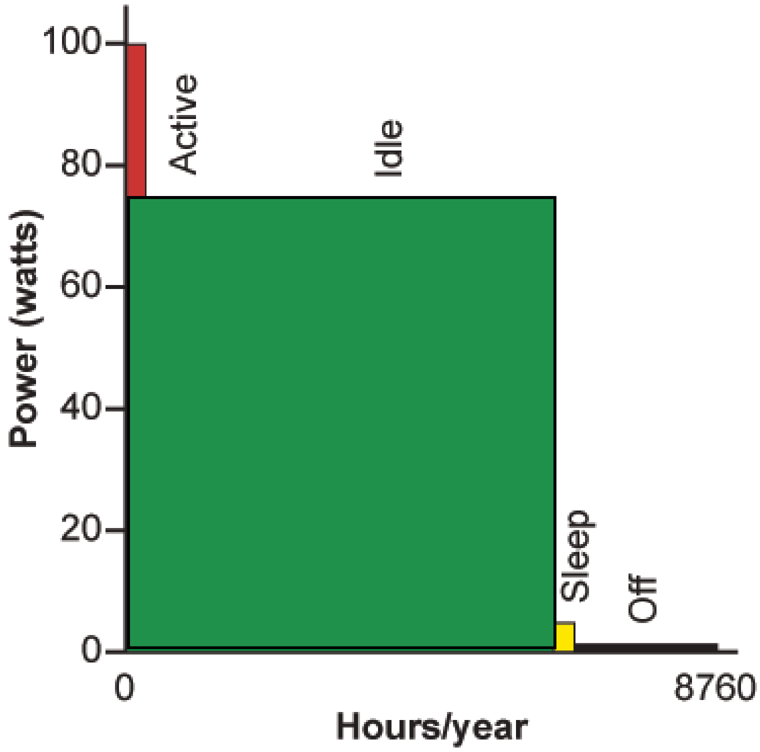
ICT energy use – the PC

The end user PC is the biggest consumer

"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)

Typical commercial PC energy use



From Bruce Nordman (LBNL)

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

$P_{sleep} \cong P_{off}$

Consumption is driven by on time, not by usage

The energy savings potential

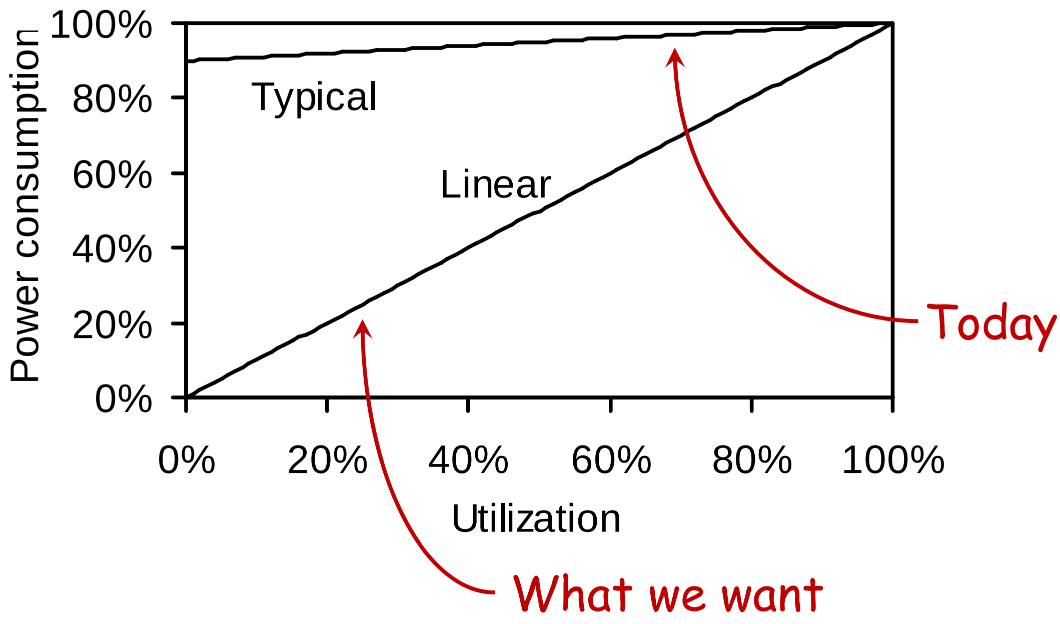
To achieve a savings there must be waste

- Low utilization levels
- Power use not proportional with utilization

Our goal is energy-proportional computing

Energy-proportional computing

Power use today is a function of capacity



Reducing energy use of PCs

Can we reduce energy used by PCs?

... this is a networking problem.

Just a few lines of code?

PASSPORT | RICKS | DREZNER | WALT | ROTHKOPF | LYNCH | THE CABLE | NET EFFECT | S

FP Foreign Policy

PASSPORT

A blog by the editors of FOREIGN POLICY

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The New ForeignPolicy.com
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Microsoft could save 45 million tons of CO2 emissions with a few lines of computer code

Wed, 11/15/2006 - 2:59pm

Here's a memo to **Bill Gates** and **Steve Ballmer**:

It is estimated there are **660 million computers** in use worldwide, the majority of which run some iteration of a Microsoft operating system. Generating the electricity needed to power those computers requires hundreds of power plants that produce billions of tons of CO2 emissions. Many of those machines sit idle for 12 to 16 hours per day, burning electricity, but not doing any work, because businesses habitually leave their computers running overnight.

Microsoft has already announced that they will build **aggressive, energy-saving technology** into their next operating system, **Vista**. But that's not enough. These days, most computers are networked and can accept software upgrades

Basic approaches to saving energy

Four basics approaches:

1) Slowdown
2) Sleep/stop
3) Substitute
4) Send/compute less

The four S's

Across multiple time and distance scales

➡ What are effects on application QoS/QoE?

➡ What reduced functionality is essential?

Why are PCs fully on 24/7?

Reasons to not sleep a PC:

Wake-up annoyance is being fixed in new OSes

1)To reduce wake-up annoyance

2)For remote access (e.g., management, remote use)

3)To share its resources (e.g., P2P)

Induced energy use by networks

Notion of network presence

If a host is not "present" on a network it loses functionality. To be present a host must be responsive to requests and be able to maintain connections.

For example, P2P keeps TCP connections open

Network presence for IPv4 is…

To maintain network presence a host must:

- Maintain host-level reachability (respond to ARP requests)
- Maintain its IP address (if DHCP is used)
- Maintain its manageability (respond to ICMP such as ping)
- Support name resolution (e.g., for NetBIOS)
- Maintain application-level reachability (respond to TCP SYN)
- Preserve application state associated with network state
  - Maintain TCP connections
  - Respond to application-level requests and heartbeat message
- Wake-up only when its full resources are needed

Commercial offerings for PCs

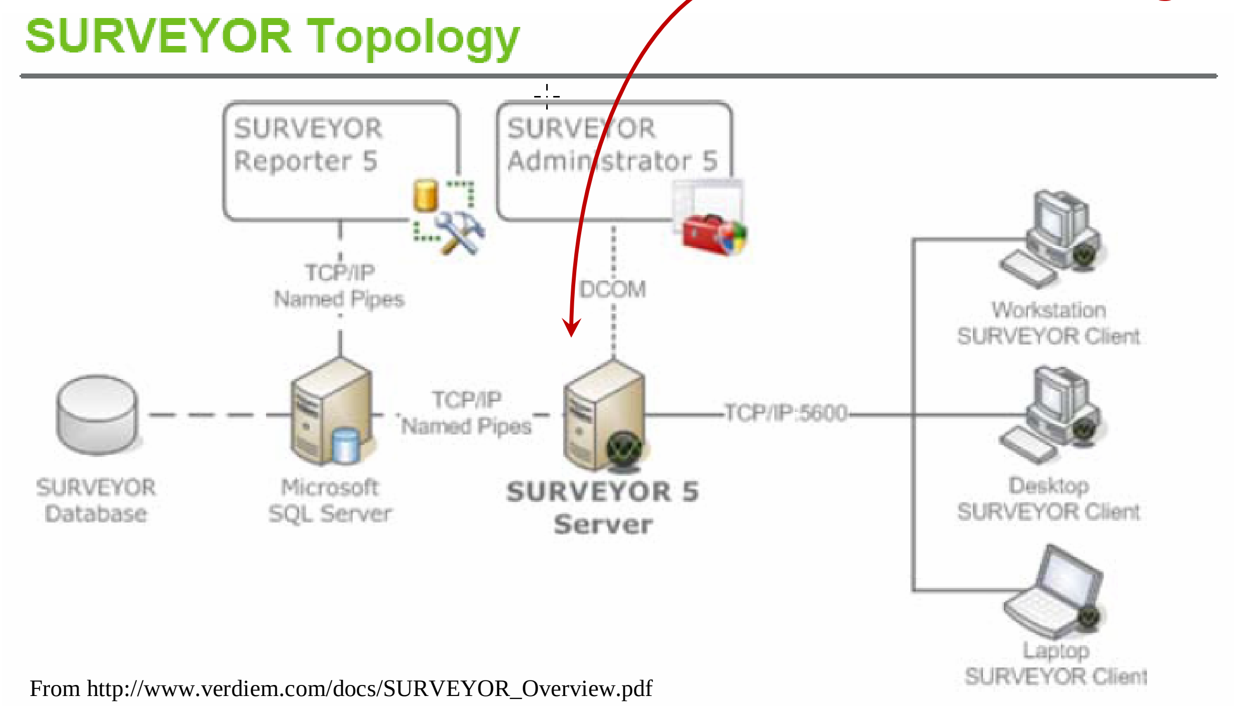
Use a global (enterprise wide) controller

1)To control PC power management settings

2)"Magic Packet" to wake-up PCs for management

Verdiem Surveyor

Centralized manager



From http://www.verdiem.com/docs/SURVEYOR_Overview.pdf

We need to go beyond point solutions

Seek a more general solution to network presence

1)Distributed

2)Does not require new software

3)Standard

4)Architecturally clean

Notion of a proxy to cover for a sleeping host

Addressing Network Presence

An entirely new view of connectivity*

on — Connected | *off* — Not connected

Traditional Internet

sleep

Delay Tolerant Networks

Selectively connected
(as chosen by the host)

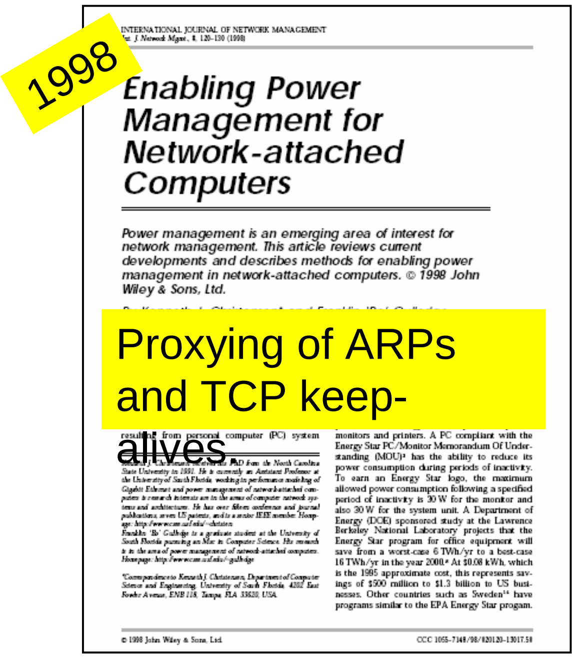
A proxy

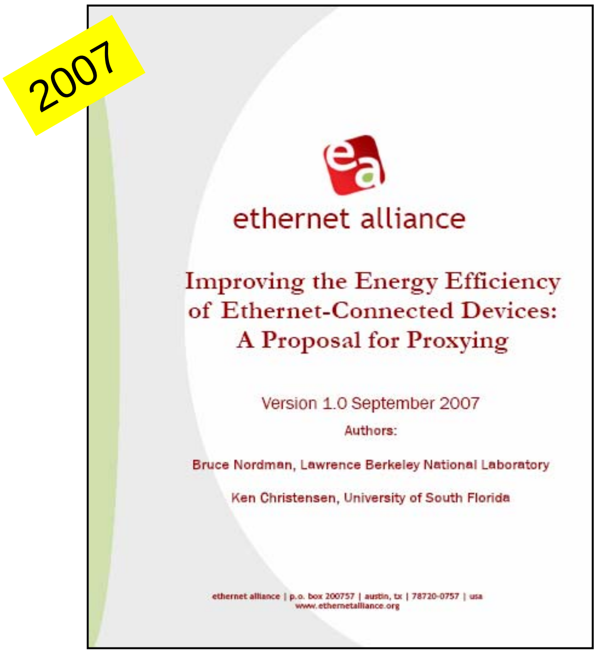
- Assistants
- Exposing state
- Evolving state
- Host-based control
- Application primitives
- Security

* 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.

Notion of a proxy – covers for a host

Network connectivity proxying goes back 10+ years

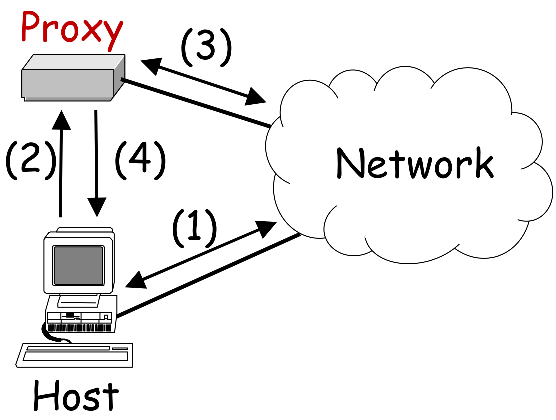




High-level view of a proxy

Functional steps:

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

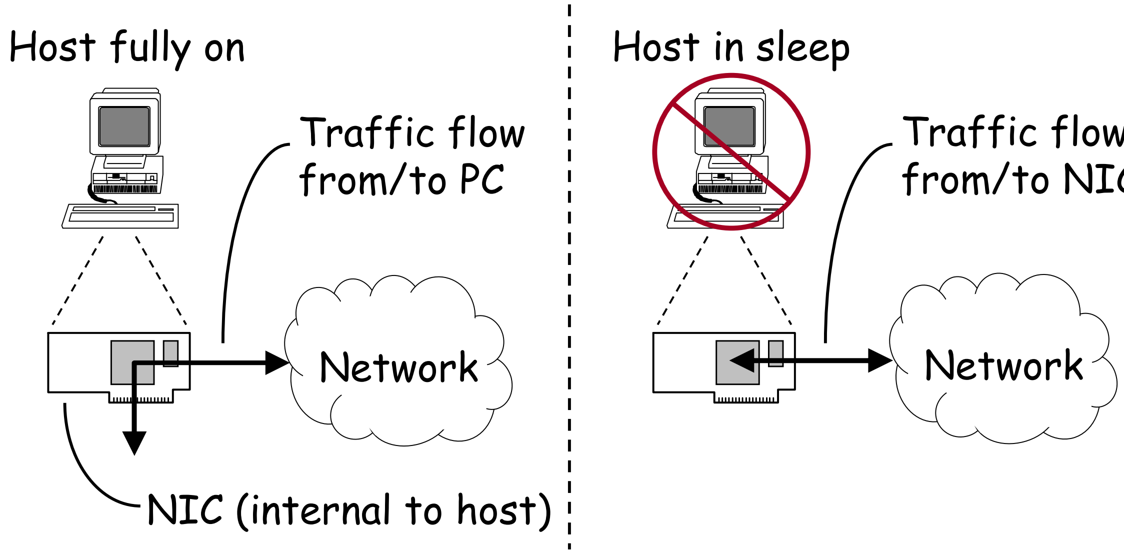


Proxy can be in separate entity, or within host NIC

Proxy in a SmartNIC

The proxy could be integrated into a NIC

- When host is sleeping, NIC is still powered-up
- Same MAC and IP address in all cases



Some work in the lab

Proxy for ARP and wake-up on valid TCP SYN

- Early 2000s*

* 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.

More recent work

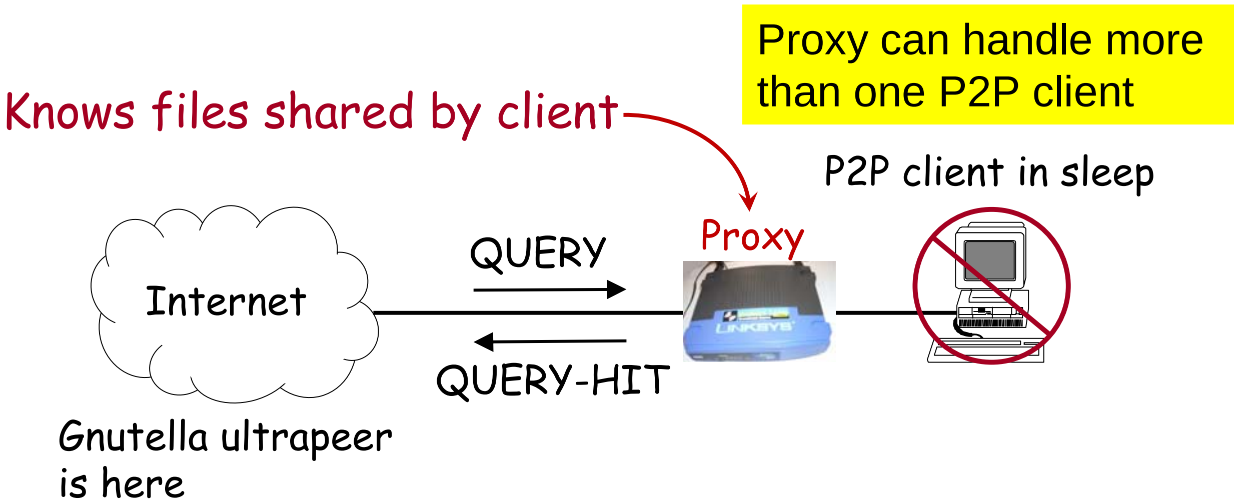
Proxying for TCP connections

- Linksys WRT54G SOHO router with OpenWRT
- Maintains TCP connections using a modified SOCKS
- Listens for messages from host
  - Two messages: "Going to sleep" and "Now awake"

Even more recent work

Proxying for Gnutella P2P connections

- Uses TCP connection proxy
- Handles QUERY messages (sends QUERY-HIT)



Most recent work

The "SIP Catcher" allowing SIP phones to sleep

From the lab of other folks

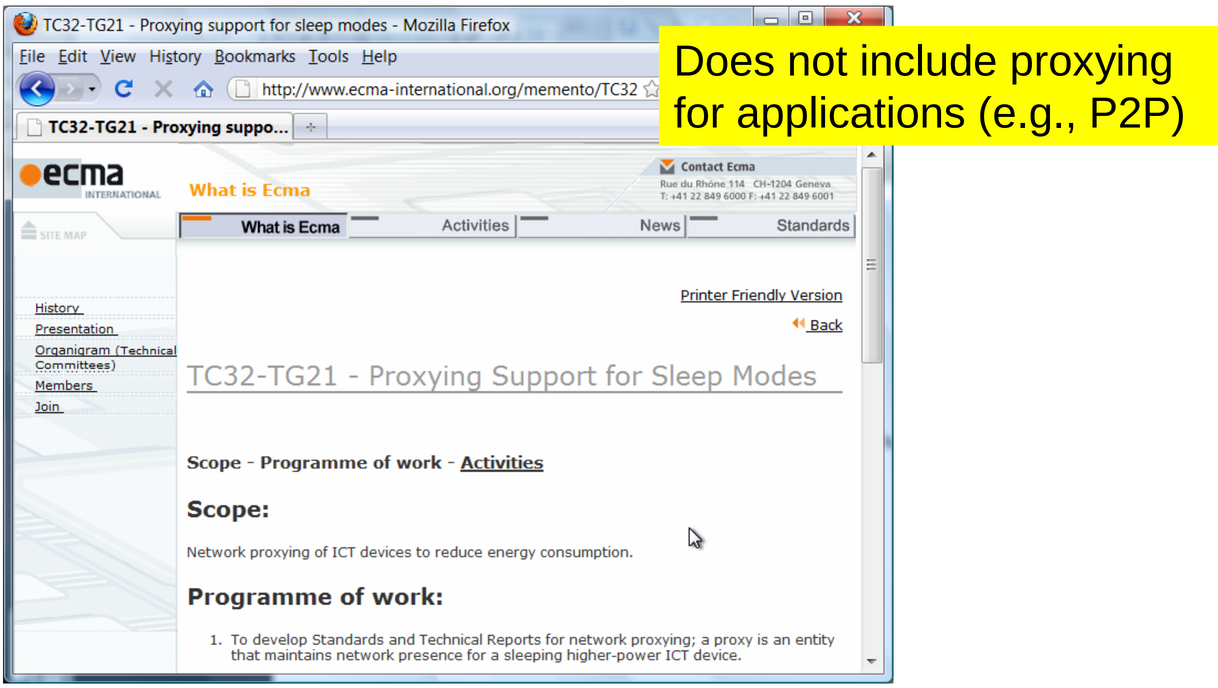
Somniloquy (Yuvraj Agarwal, UCSD)

- "Small USB-connected hardware and software plug-in system that allows a PC to remain in sleep mode while continuing to maintain network presence and run well-defined application functions"*

* From "Sleep Talking PCs Save Energy and Money," 2009. URL: http://www.jacobsschool.ucsd.edu/news/news_releases/release.sfe?id=840

Proxying as a standard

Ecma TC32-TG21 – Proxing Support for Sleep Modes



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."*

ENERGY STAR

The Ecma standard is key to this

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

Proxying in new 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

Reducing Energy use of Ethernet

Can we reduce energy used by Ethernet?

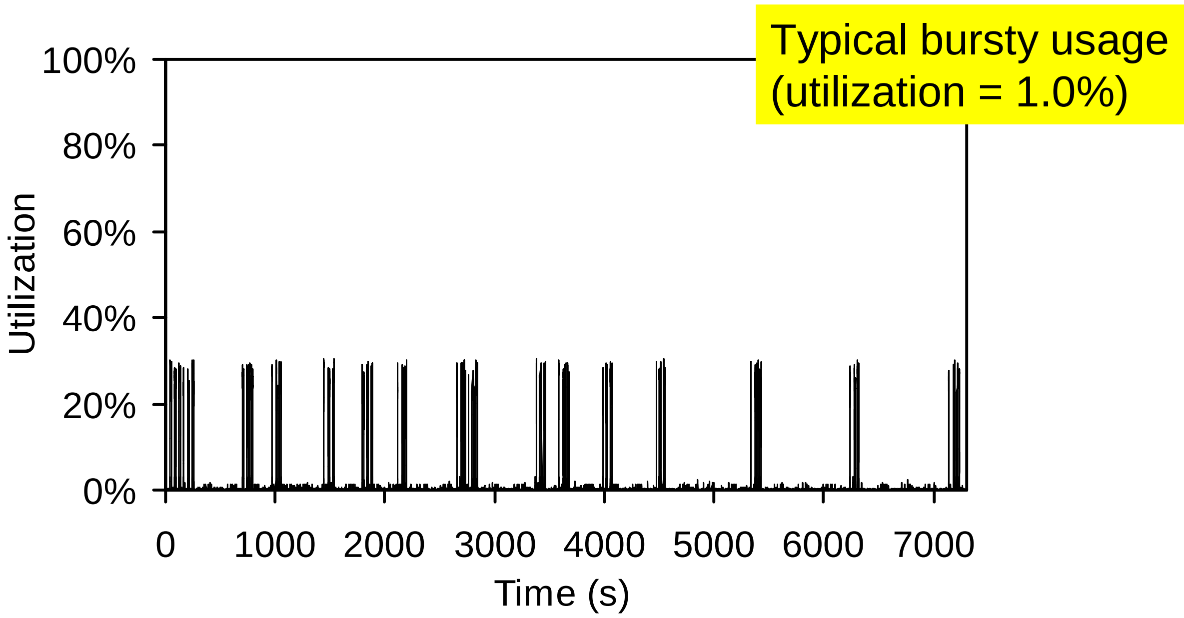
... this is Energy Efficient Ethernet.

Some observations and an idea

- **Observation #1: Most edge links lightly utilized**
  - About 1% on average
- **Observation #2: Higher rates use more power**
  - About 2 to 4 W per link 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**

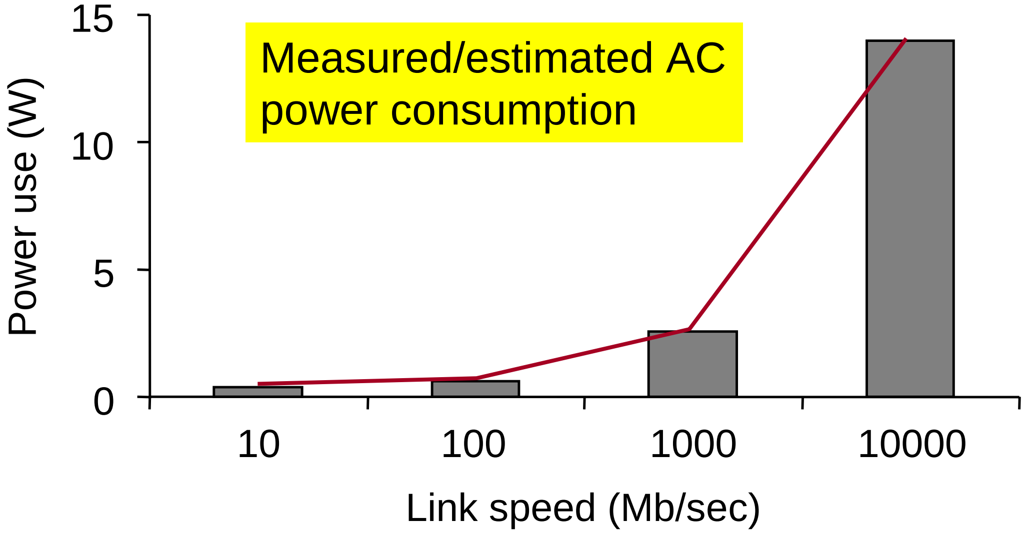
Edge links are lightly utilized

Focus on the last hop link
- Bursty and low utilization (trace from Portland State)



Higher rates use more power

As data rate increases, so does power use
- 10 Gb/s Ethernet is a concern



The general idea

Can we switch to a lower link rate (and save energy) during periods of low utilization?

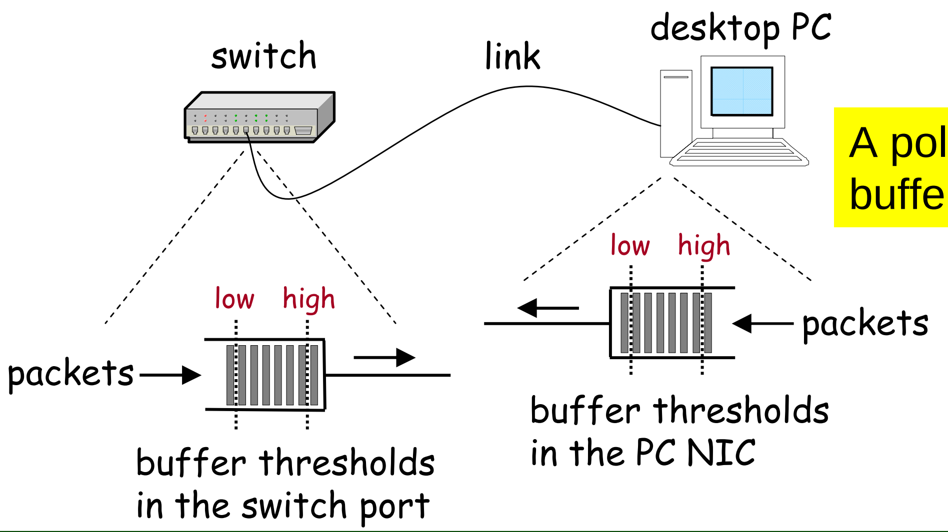
➡ Big issue is time to switch between rates

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



A policy based on buffer thresholds

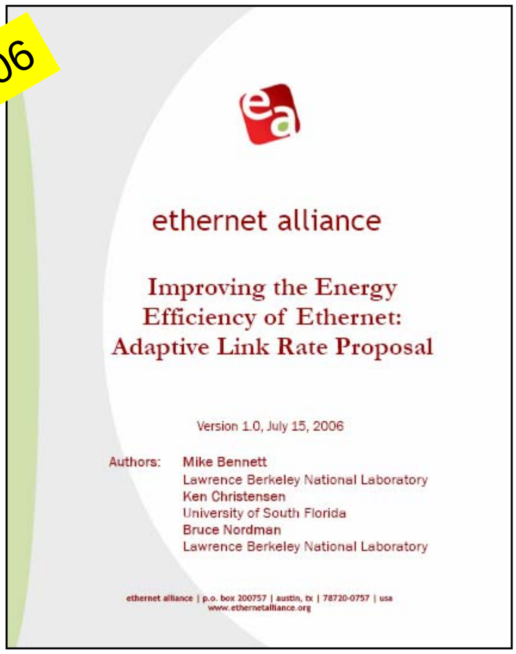
Some early publications

We published the idea and some results

- From a 2005 journal paper and a 2006 whitepaper

2005

2006



Work done by other people…

- **ALR was proposed to IEEE 802.3**
  - A Study Group was formed
  - Mike Bennett from LBNL is the chair
- **Became "Energy Efficient Ethernet"***
  - IEEE 802.3az task force
- **ALR renamed to Rapid PHY Selection (RPS)**
- **Much discussion on switching times**
- **Work done on mechanisms and policies**

Energy Efficient Ethernet

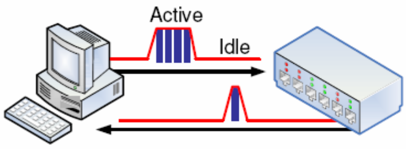
* Logo by Glen Kramer of Teknovus, Inc. (full permission for use granted via email dated January 27, 2007)

A better idea than ALR/RPS

Slide from November 2007 IEEE 802.3az meeting…

7

Active/Idle Toggling with 0BASE-x Concept



- Principle: Transmit data at fastest rate then return to idle
  - Energy savings come from power cycling between active/idle states
- Active/Idle toggling could be used *instead* of PHY rate shifting
  - Offers the best energy efficiency on links with lower utilization
  - Integrates well with existing PC power management schemes (e.g. ACPI)
  - Clock & power gating (on/off) is easier than rate shifting
- Asymmetrical operation would provide even better energy efficiency
  - Each direction could enter active & idle states independently
  - Most end-node traffic is heavily weighted toward either send or receive
  - Tx & Rx data paths already operate independently above the PHY

Energy Efficient Ethernet

intel

The low power idle approach

Low power idle is better in at least two ways:

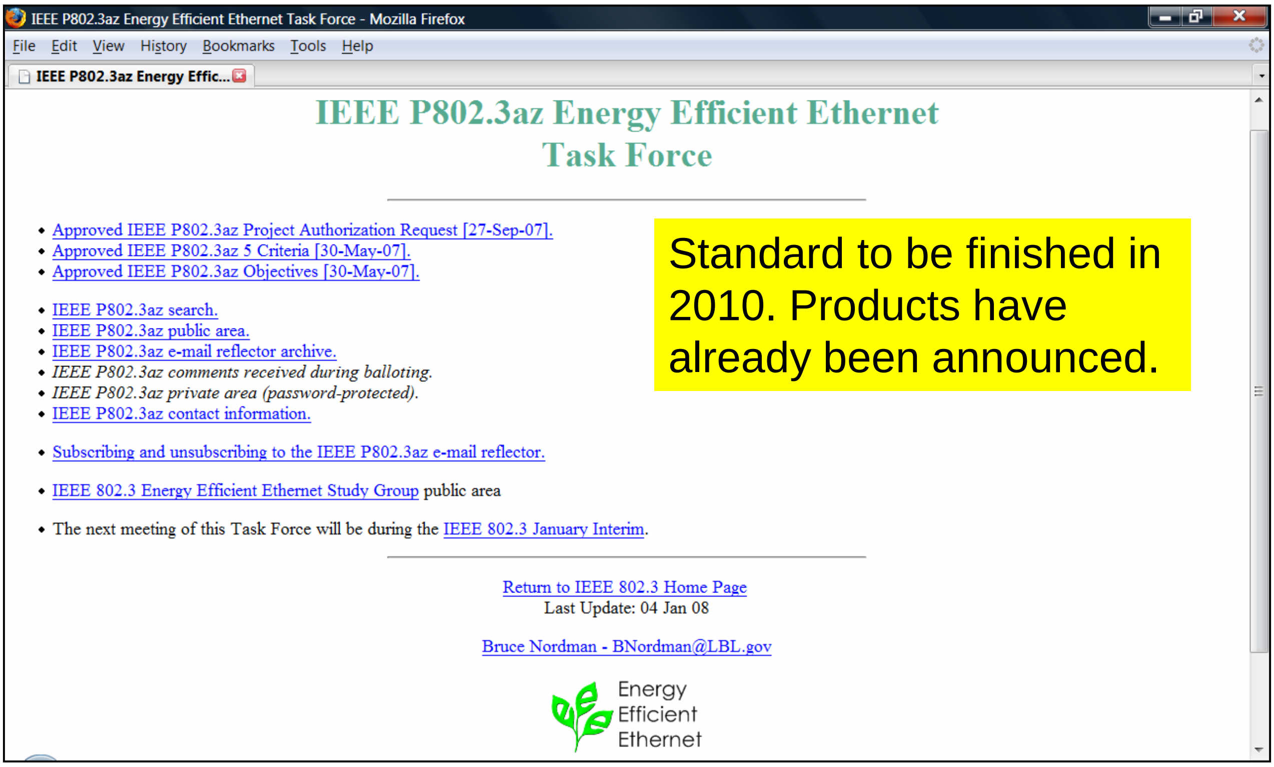
1) Very low switching time (few microseconds)

2) Greater energy savings that ALR/RPS

IEEE 802.3az is standardizing low power idle

Now an IEEE 802.3az task force

http://www.ieee802.org/3/az/index.html


IEEE P802.3az Energy Efficient Ethernet Task Force - Mozilla Firefox

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IEEE P802.3az Energy Efficient Ethernet Task Force

- Approved IEEE P802.3az Project Authorization Request [27-Sep-07].
- Approved IEEE P802.3az 5 Criteria [30-May-07].
- Approved IEEE P802.3az Objectives [30-May-07].

- IEEE P802.3az search.
- IEEE P802.3az public area.
- IEEE P802.3az e-mail reflector archive.
- *IEEE P802.3az comments received during balloting.*
- *IEEE P802.3az private area (password-protected).*
- IEEE P802.3az contact information.

- Subscribing and unsubscribing to the IEEE P802.3az e-mail reflector.

- IEEE 802.3 Energy Efficient Ethernet Study Group public area

- The next meeting of this Task Force will be during the IEEE 802.3 January Interim.

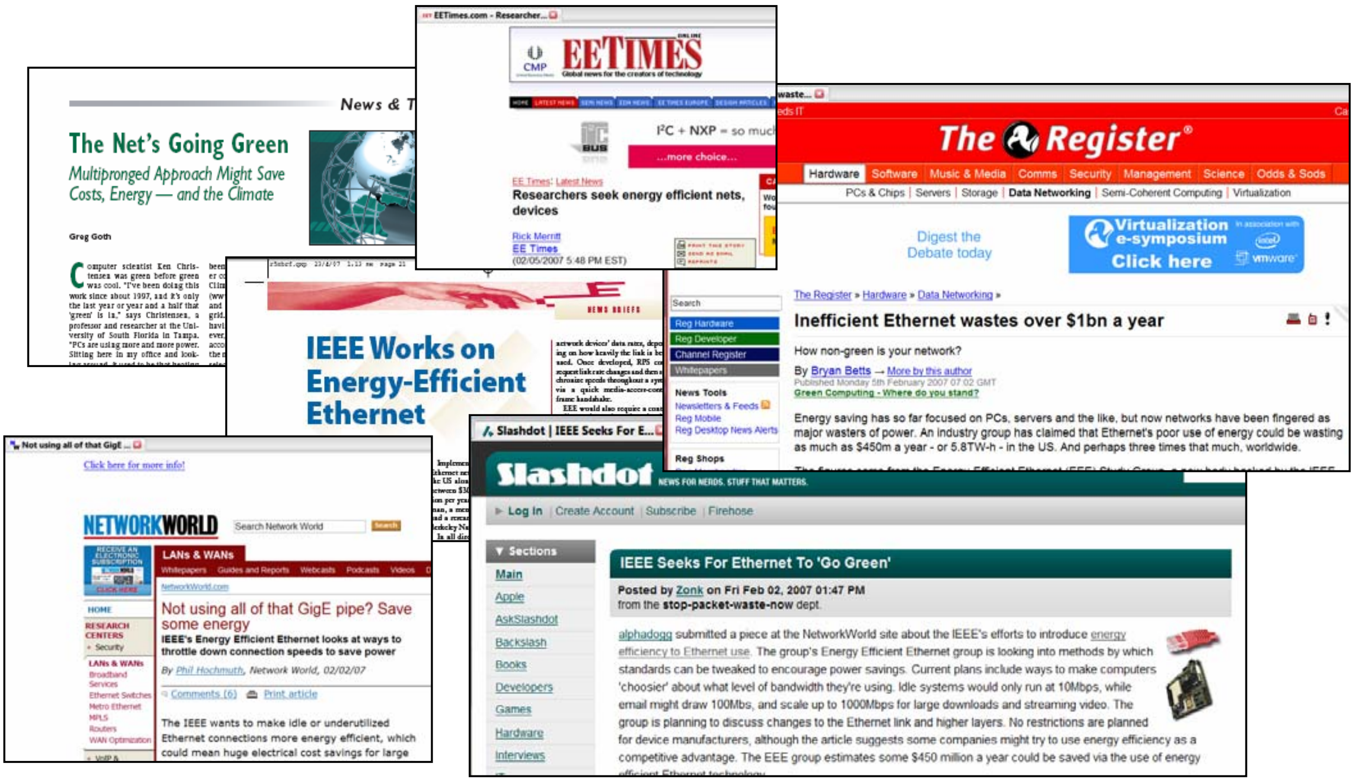
Return to IEEE 802.3 Home Page
Last Update: 04 Jan 08

Bruce Nordman - BNordman@LBL.gov

Energy Efficient Ethernet

Standard to be finished in 2010. Products have already been announced.

Some press on EEE



How much savings may we get?

Estimate is from Bruce Nordman (LBNL)

"… estimate that with networking devices in homes, offices, and data centers running at 1 Gb/s, switching to 100 Mb/s whenever possible could save more than US $300 million in energy costs."
- IEEE Spectrum (May 2008)

Greater savings from 10 Gb/s down the road

EEE in EPA Energy Star

EPA Energy Star for Computer Servers, Tier 2

- "Energy Efficient Ethernet: All physical layer Ethernet in servers covered by the Computer Server specification must meet the Energy Efficient Ethernet (IEEE 802.3az) standard upon its approval by the IEEE."*

To be in computer (PC) spec later

* From ENERGY STAR® Version 1.0 Program Requirements for Computer Servers, Tier 2: PRELIMINARY

EEE in new products

Realtek Ethernet NIC

* From http://www.realtek.com.tw/press/newsViewOne.aspx.

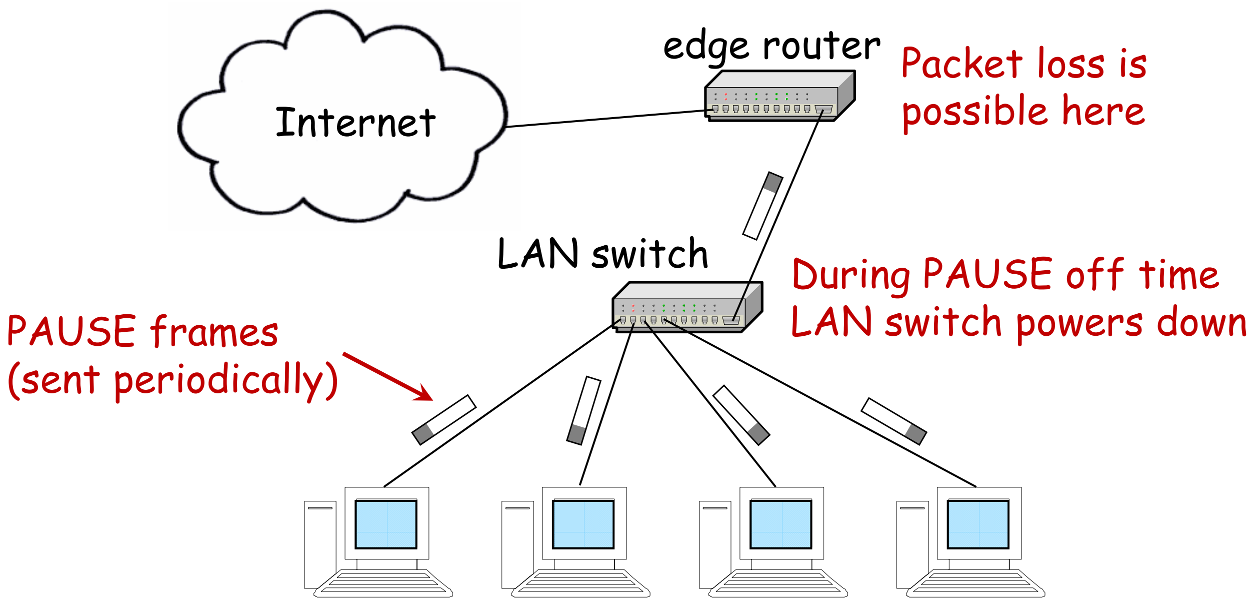
More thinking on reducing energy use

Can we shape the traffic during periods of low utilization to get predictable idle periods?

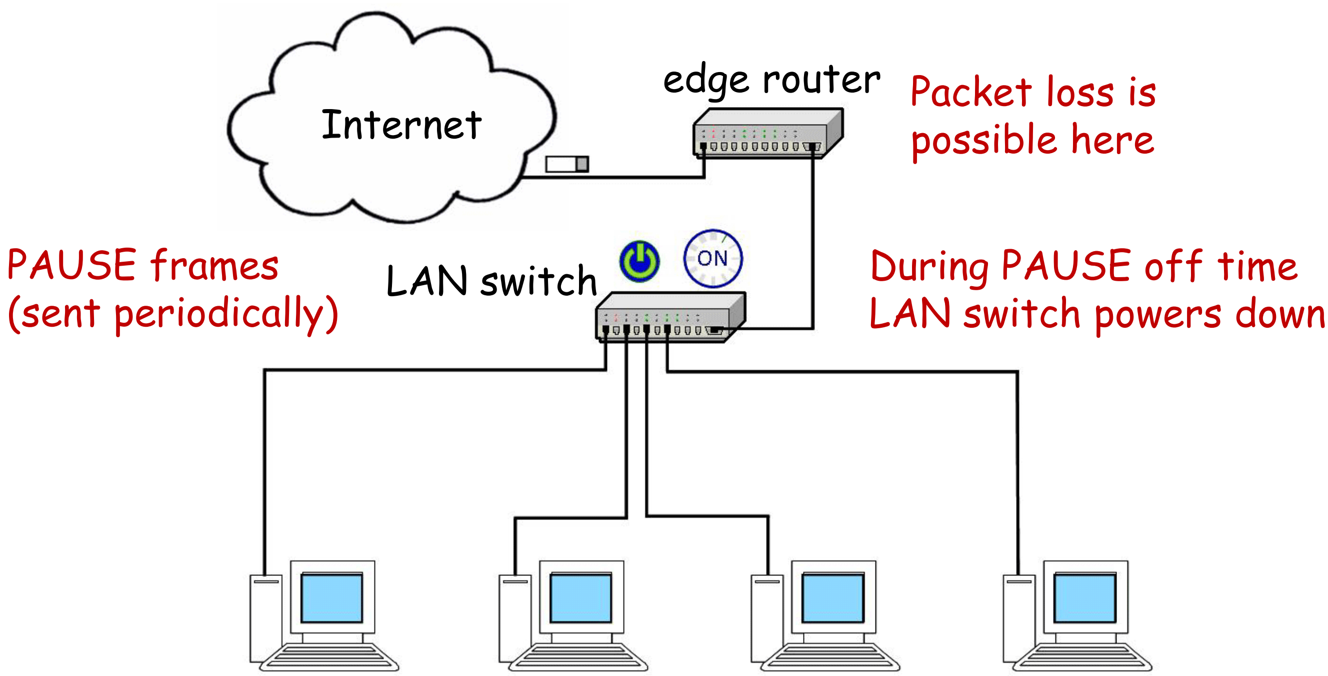
To allow controlled power-down of switches

Periodically Paused Switched Ethernet

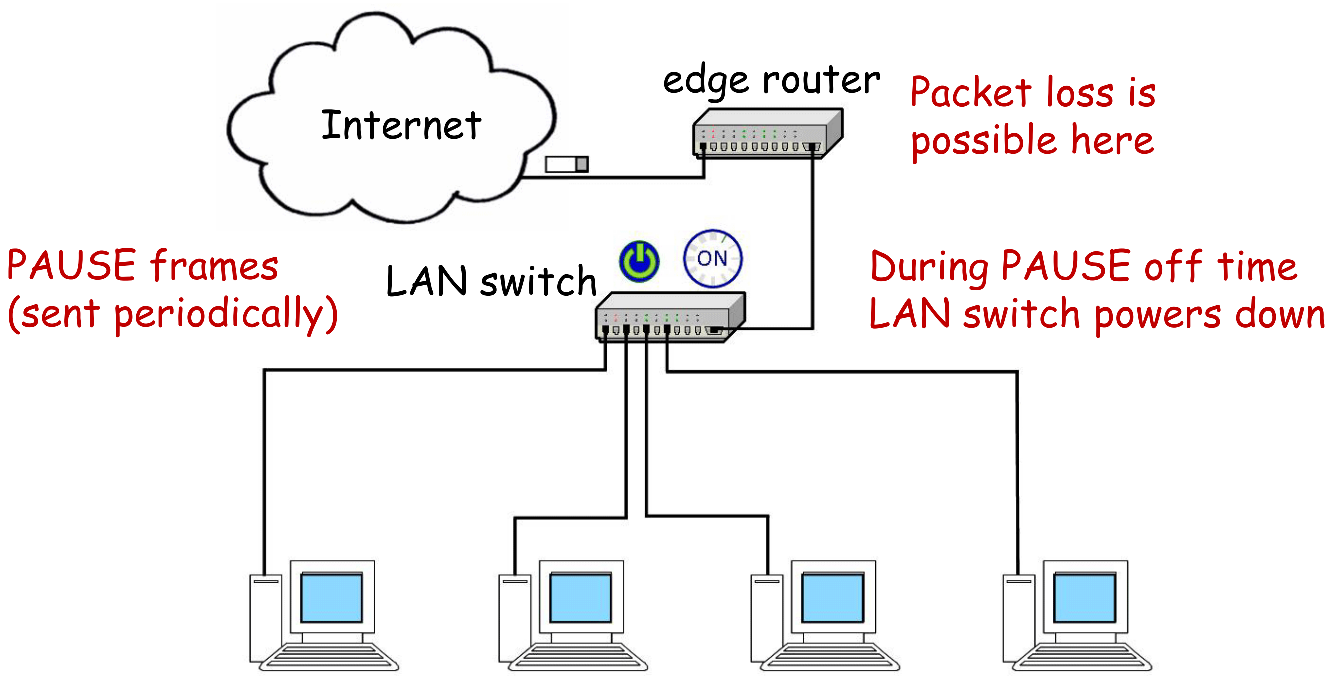
Basic idea is to periodically send PAUSE frames
- Power down during PAUSE (link is off) interval



PPSE animation



PPSE animation



PPSE parameters

- **Key parameters**
  - t_{off} = time off (the PAUSE quanta time)
  - t_{on} = time on
  - D = duty cycle

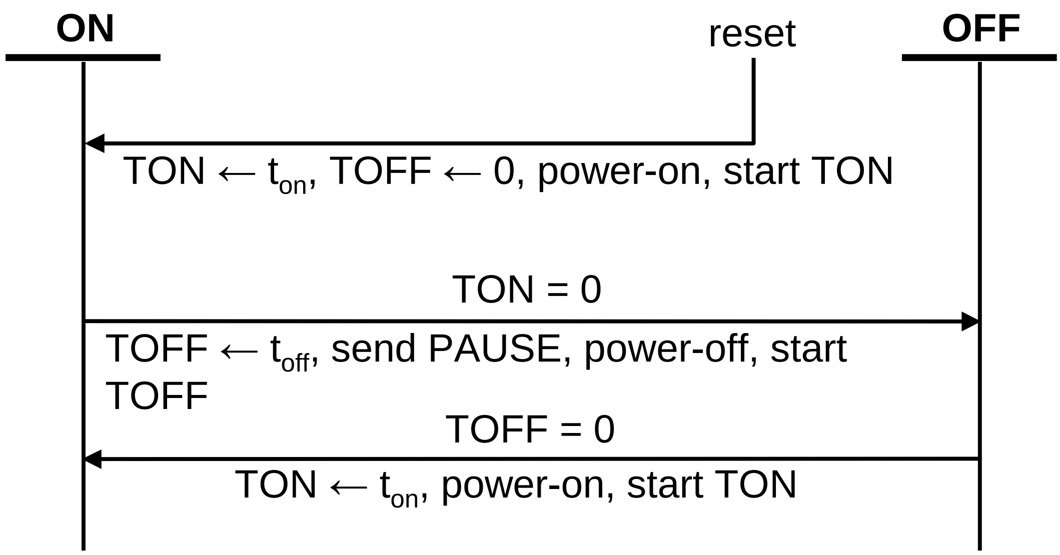
$$\boxed{D = \frac{t_{on}}{t_{on} + t_{off}}}$$

$$\boxed{t_{on} = \frac{D \cdot t_{off}}{1 - D}}$$

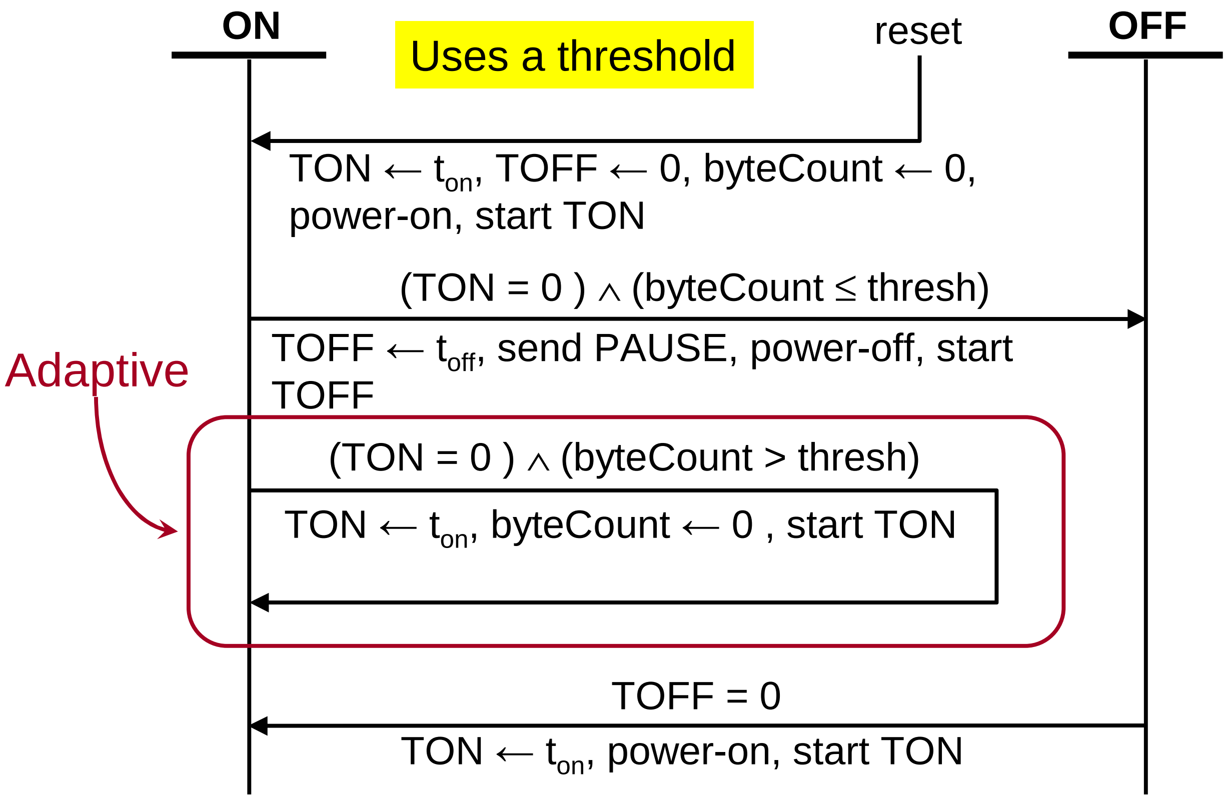
➡ Energy saved is roughly (1 – D)

FSM for simple PPSE

TON and TOFF are timers



FSM for adaptive PPSE



Does PPSE work?

- **We have emulated PPC in a test bed**
  - Test bed looks sort of like the previous figure
  - Use a PC to send PAUSE packets through a repeater
  - All links were 100 Mb/s
- **We have developed a simulation model**
  - For studying PPSE policies and queueing behavior
- **We are currently building analytical models**
  - Of the PPSE controlled queues

(Emulated) PPSE evaluation

Experimented with streaming video

- Used a 50% duty cycle on 100 Mb/s link
  - t_{off} = 50, 100, and 300 milliseconds
  - $t_{on} = t_{off}$

Artifact (at t_{off} = 300 ms)

Future challenges

Where can we go from here?

... energy savings *of* and *by* ICT.

Challenges in green networks

Challenges in five areas

1) General (or overall)
2) Network equipment
3) Network hosts
4) Data centers
5) Distributed applications

Goal is low power use at low utilization

Challenges in green networks 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
- Architectures for selective connectivity
  - Need mechanisms/protocols for selective connectivity
    - Includes notions of proxying

Challenges in green networks continued

Network equipment

- Green routers and switches
  - Re-design routers and switches for energy efficiency
- Data caching for energy efficiency
  - Caching to reduce load network and servers
- Traffic shaping for energy efficiency
  - Shaping traffic for short-term shutdown
- Traffic engineering for energy efficiency
  - Routing to consolidate routes for long-term shutdown

Challenges in green networks continued

Network hosts

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

Data center specific

- High bandwidth / low latency for dynamic virtualization
  - Useful for server shutdown
- Move computing work to where power is cheapest
  - "Follow the moon" for data center activity

Challenges in green networks continued

Distributed applications

- P2P, multiplayer games, and virtual worlds
  - Need to address these large and growing energy consumers
- Webcams and sensors everywhere
  - Need to address these large and growing energy consumers

Using ICT to reduce CO_2 footprint

Ideas from SMART 2020

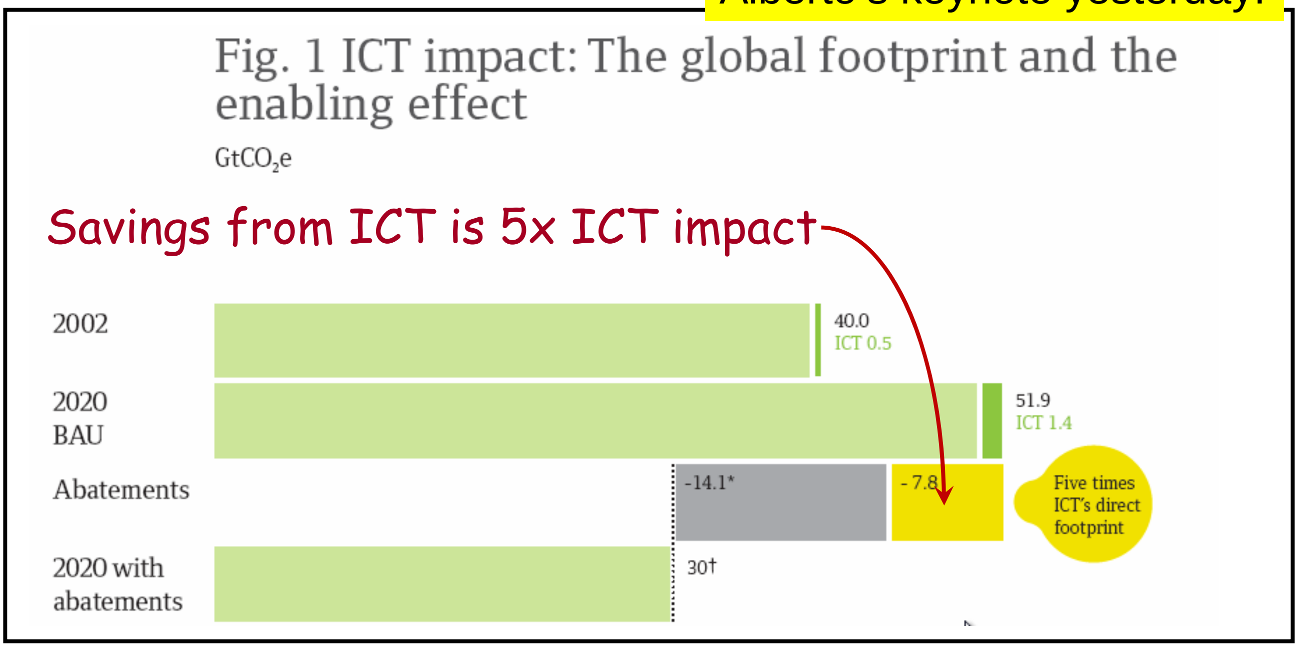
- Smart motor systems
  - Optimized industrial systems
- Smart logistics
  - More efficient transport
- Smart buildings
  - Better management and automation
- Smart grids
  - Reduce distribution losses

SMART 2020

ICT as an enabler of CO_2 reduction

ICT can enable savings

Alberto's keynote yesterday!



From SMART 2020 report

ICT is dematerializing the economy

Our economy is increasingly about…

Moving bits and not atoms

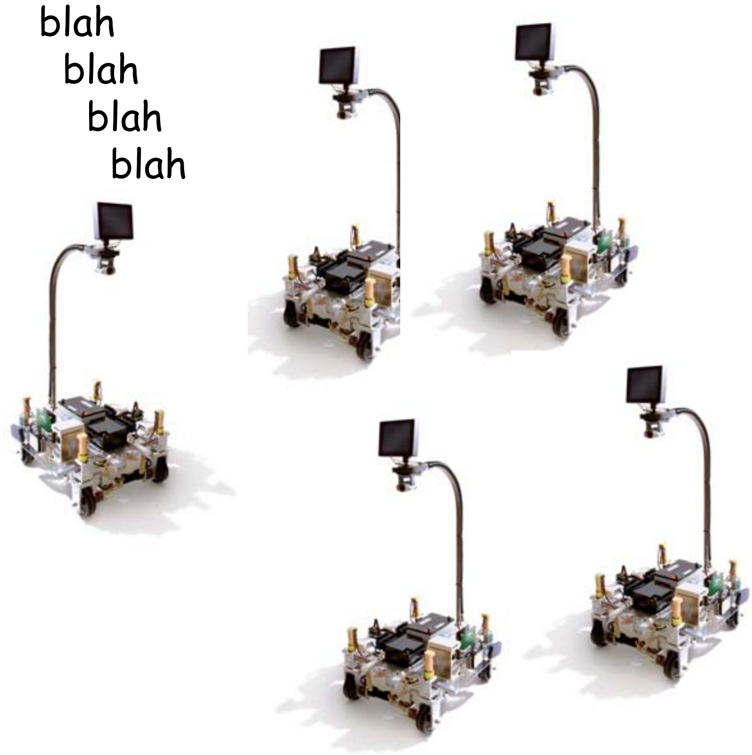
- This is how most of us now earn a living
- Made possible by networks
- Continuing trend may help us be ***comfortably green***

Conclusions

- **ICT has large and growing energy use**
- **Majority of energy use is and will be in hosts**
- **Growing energy use in broadband networks**
- **Least growth in energy use of data centers**
- **Proxying is one way to reduce host energy use**
- **EEE to reduce networks energy use**
- **Moving bits and not atoms = less CO_2**

Welcome to keynote for LCN 2029…

blah
blah
blah
blah



Will this be the conference of the future?

No people, just robots and video sent back home.

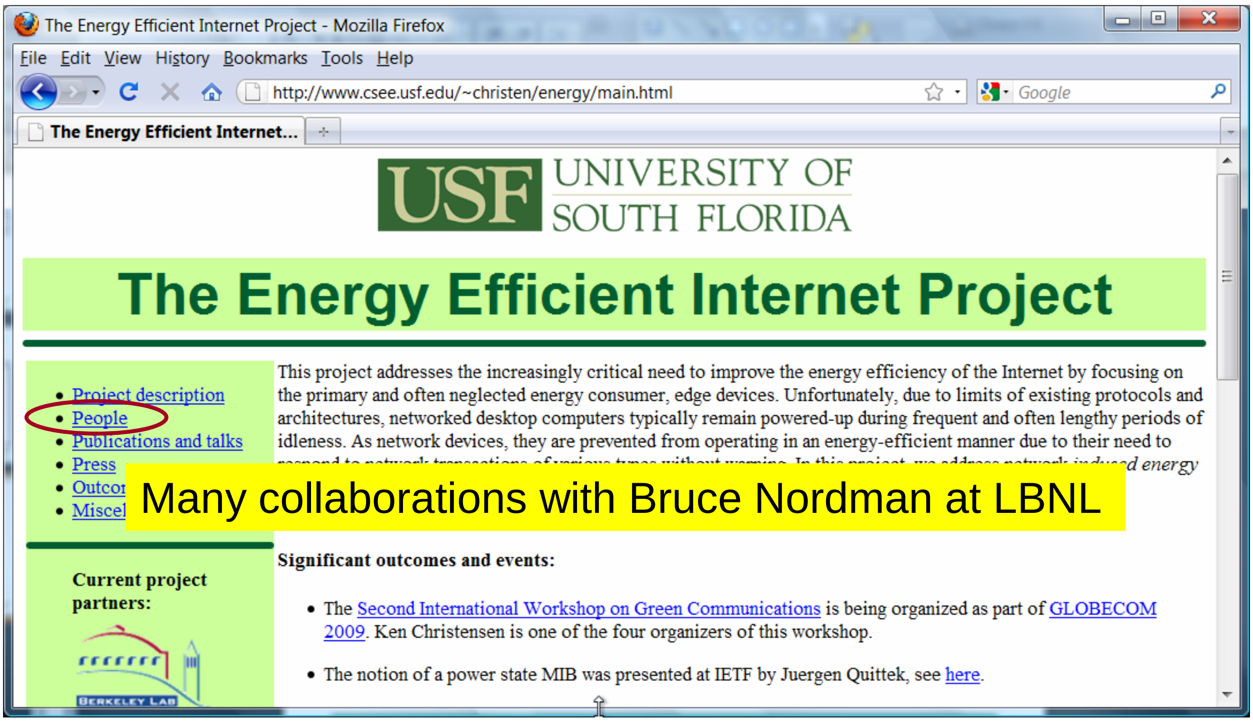
I hope not!

See y'all next year in Colorado, USA! ☺

Any questions?

Ken Christensen

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



Many collaborations with Bruce Nordman at LBNL