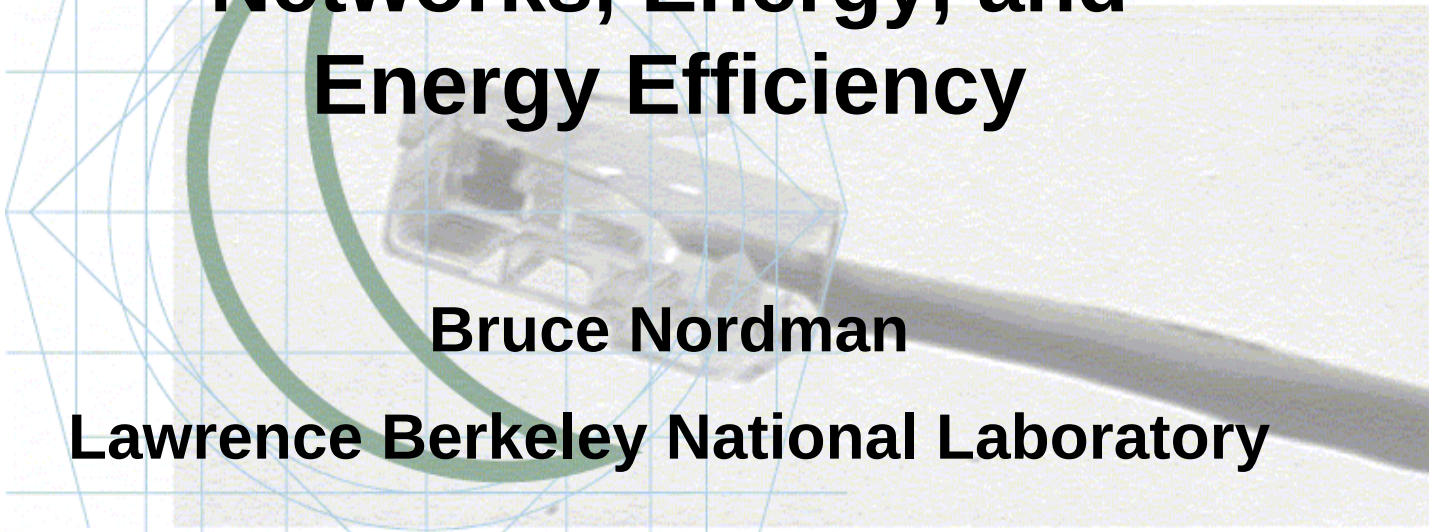
Networks, Energy, and Energy Efficiency



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Overview

- How much energy does “The Internet” use
- How should we think about networks and energy?
- Data
- Key issues for energy efficiency
- Research Needs

Key Collaborator: Ken Christensen, USF

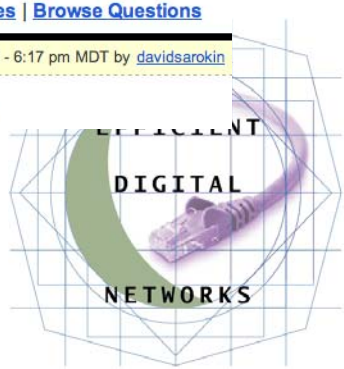
How much energy does the Internet use?

1999

"At least 100 million nodes on the Internet, … add up to … **8% of total U.S. demand**. … It's now reasonable to project that **half of the electric grid** will be powering the digital- Internet economy within the next decade."

emphasis added

2007



How much energy does network equipment consume?

	$billion	*TWh/year*
Telecom	$0.80	8.0
Data center	**$0.20**	**2.0**
Residential	**$0.73**	**7.3**
Commercial (office)	**$0.88**	**8.8**
Subtotal	$1.80	18
IP Service providers (access, metro, core)	< ?	< ?

- **All of these figures rough estimates for 2006**
- *None of this includes cooling or UPS*
- *$0.10/kWh used for convenience*

How about All Electronics?

- PCs/etc., consumer electronics, telephony
  - Residential, commercial, industrial
- 250 TWh/year
- About 7% of U.S. total electricity
- Well over $20 billion/year
- Over 180 million tons of CO_2 per year
  - Roughly equivalent to 30 million cars!

PCs etc. are digitally networked now — *Consumer Electronics* (CE) will be soon

Numbers represent U.S. only

One central baseload power plant (about 7 TWh/yr)

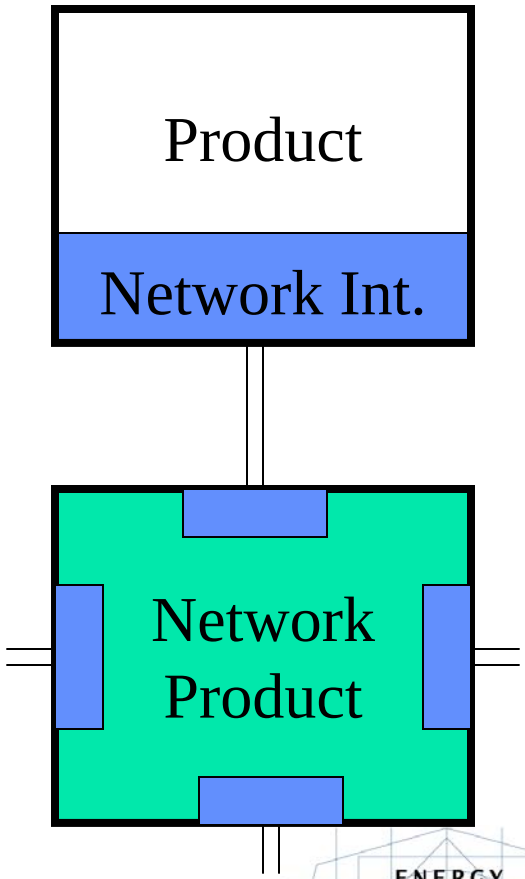
Networks and Energy

Network equipment ….

Modems, routers, switches, wireless APs, …

… vs networked equipment

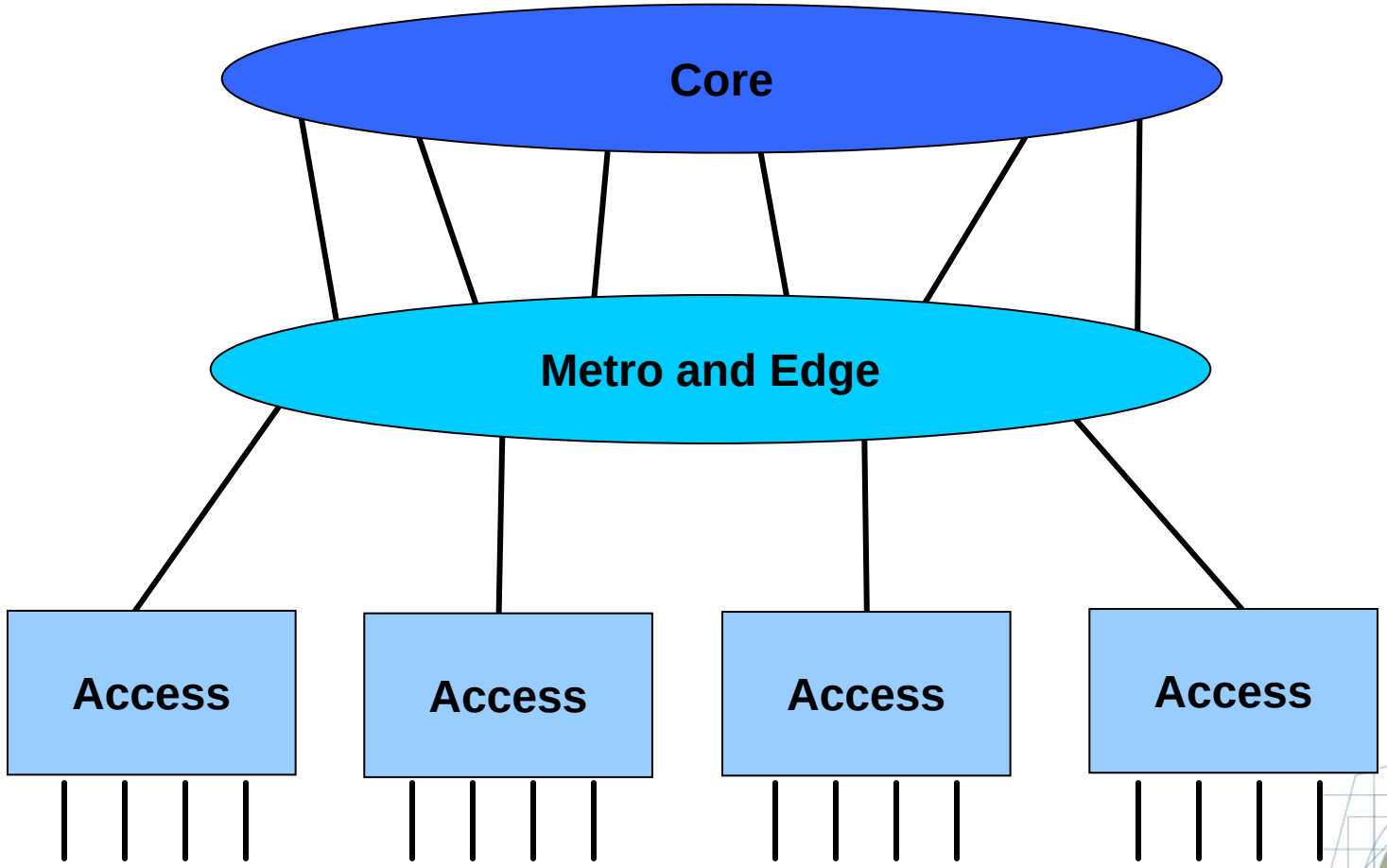
PCs, printers, set-top boxes, …



How networks drive energy use

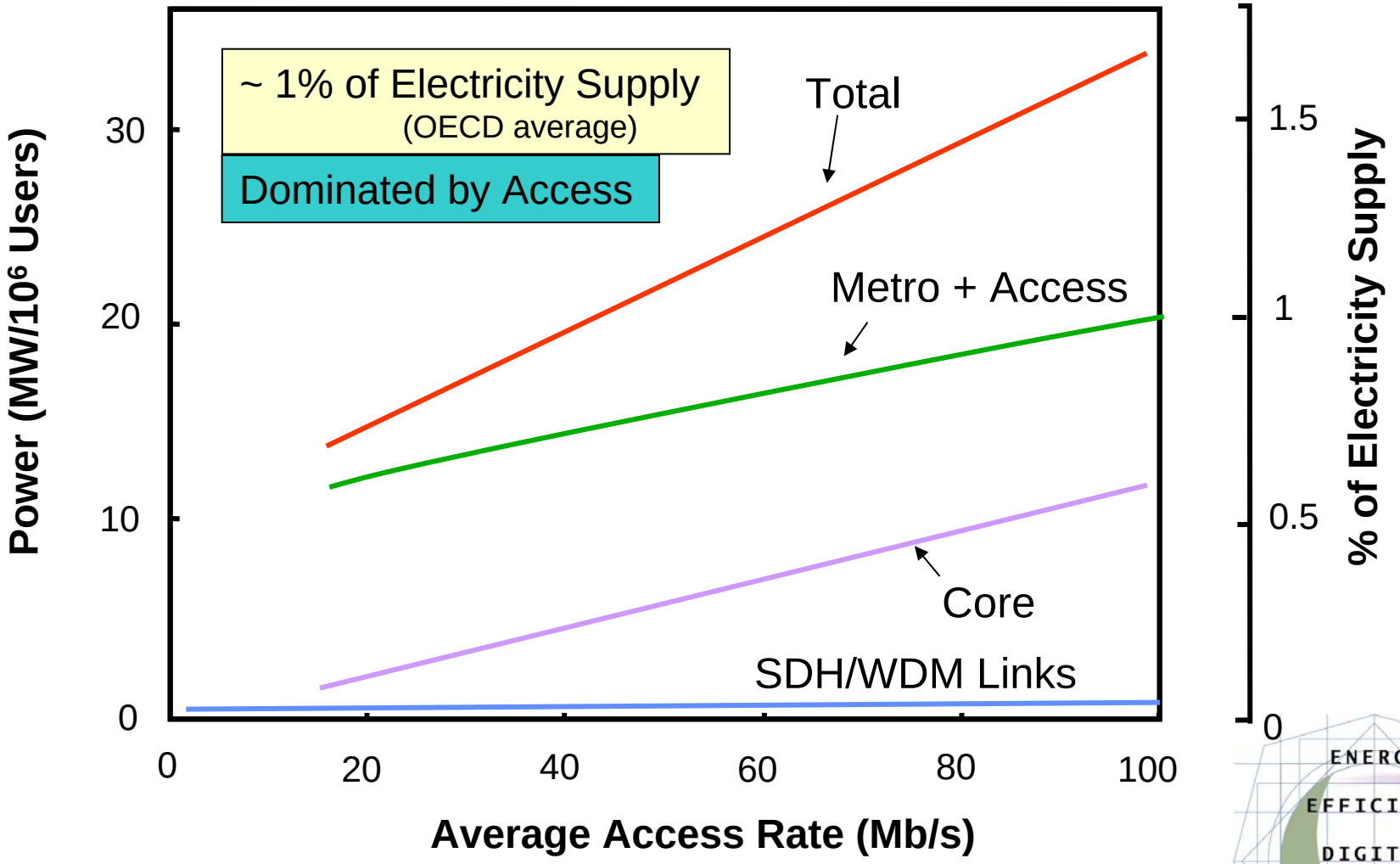
- **Direct**
  - **Network interfaces (NICs)**
  - **Network products**
- **Induced in Networked products**
  - **Increased power levels**
  - **Increased time in higher power modes**

Network Structure



Source: Tucker et al., 2007

Power Consumption of IP Network
(Residential portion only)



Source: Tucker et al., 2007

How should we think about networks and energy?

Approaches / Focus

- **Device**
  - **AC*-powered products**
- **Link**
  - **Capacity, usage, distance, technology**
- **Throughput**
  - **Traffic totals, patterns, distribution**
- **Application / Protocol**
  - **Drivers of infrastructure, nodes**

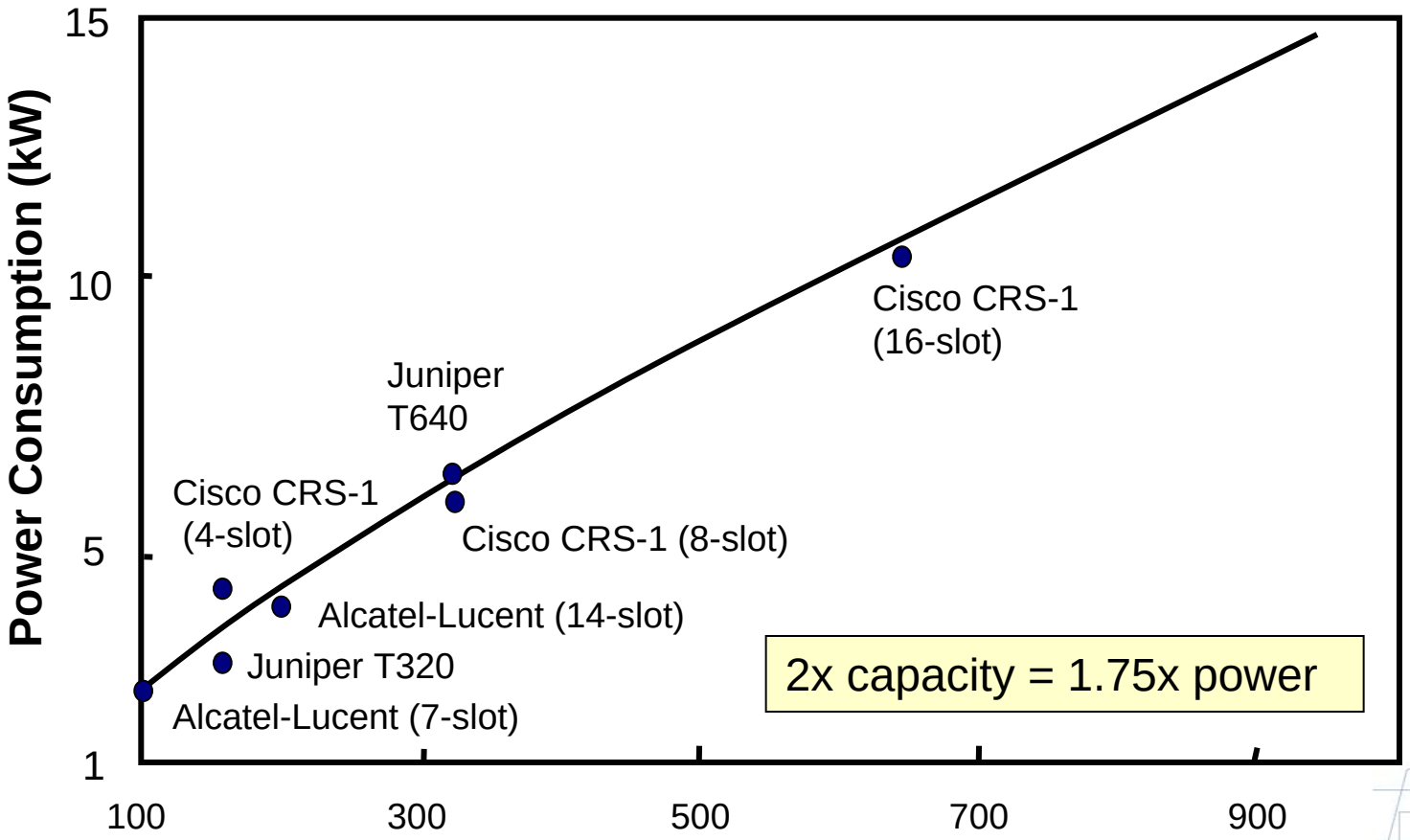
Essential to use all approaches simultaneously

Data

- **Need to ground energy / network research in real data**
  - **–Clarifies drivers of energy use**
  - **–Often reveals savings opportunities**

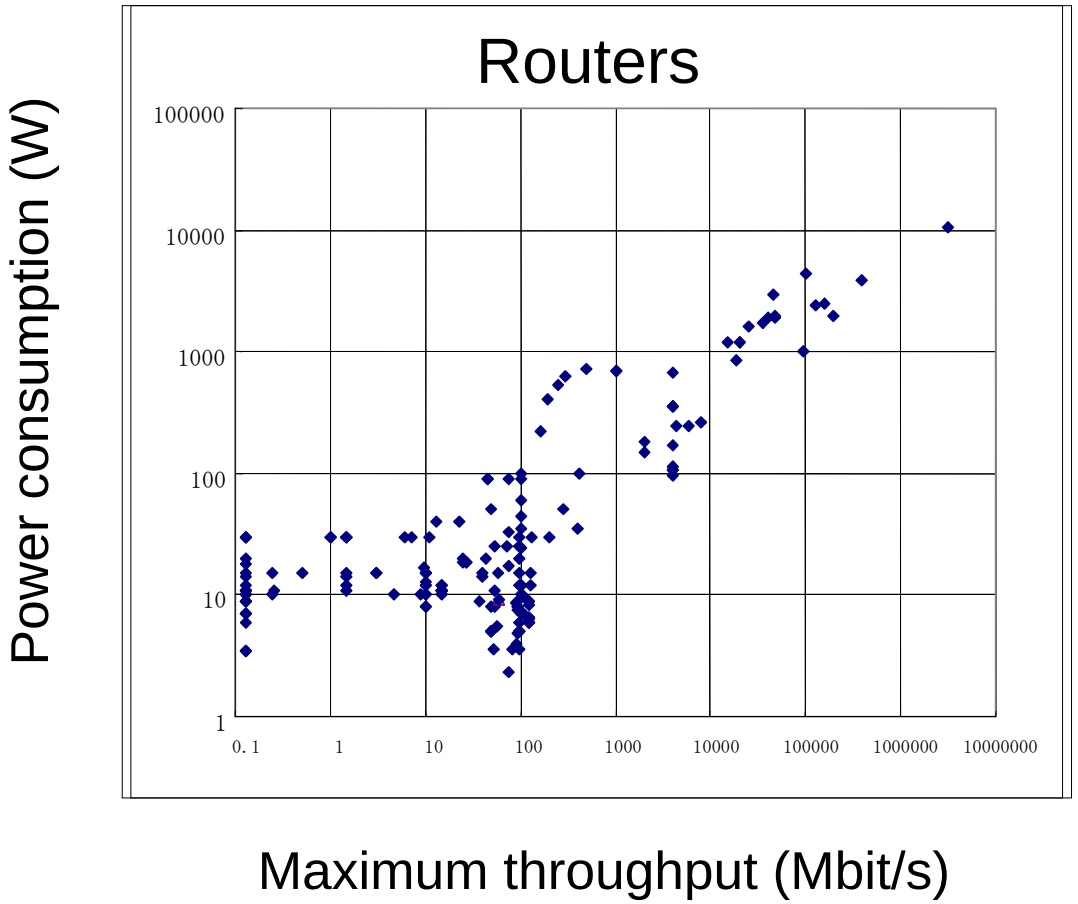
- **Following slides show examples of such data**
  - **–Much more needed**

Power Consumption Trends



Source: Tucker et al., 2007

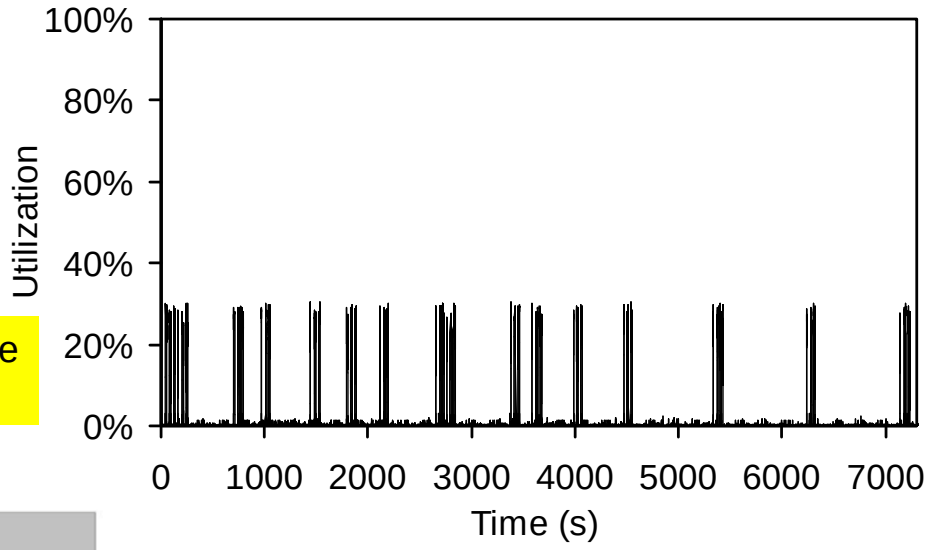
Power Consumption Trends



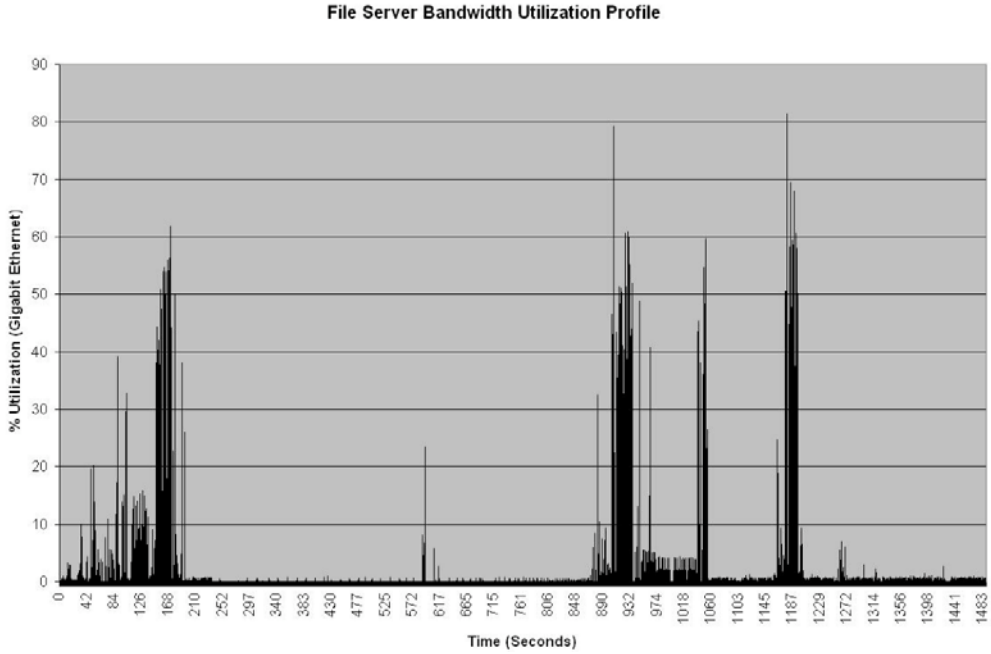
Source: METI, 2006

Sample utilization graphs

- **Snapshot of a typical 100 Mb Ethernet link**
  - **Shows time versus utilization (trace from Portland State Univ.)** *(Singh)*



Typical bursty usage (utilization = 1.0 %)



- **File server link utilization (daytime)** *(Bennett, 2006)*

Utilization

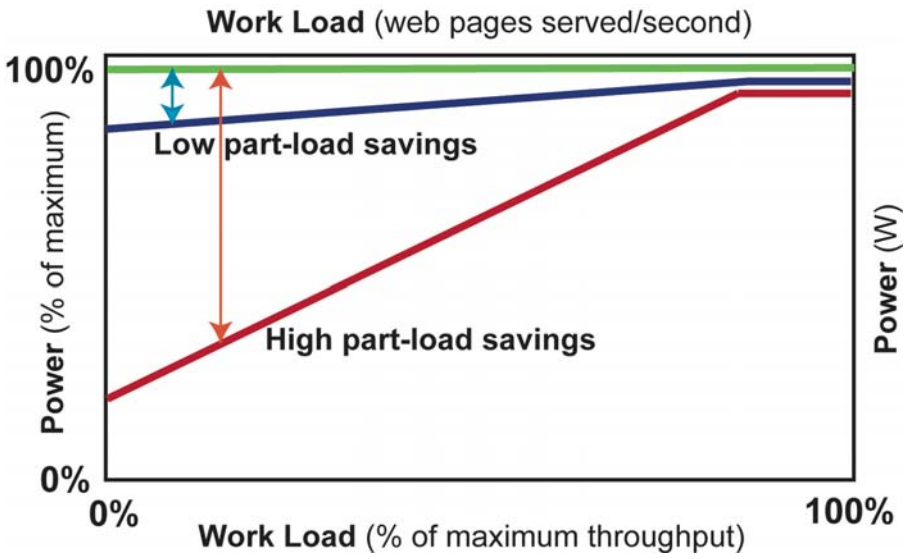
- ***Data networks are lightly utilized, and will stay that way***, **A. M. Odlyzko, *Review of Network Economics*, 2003**

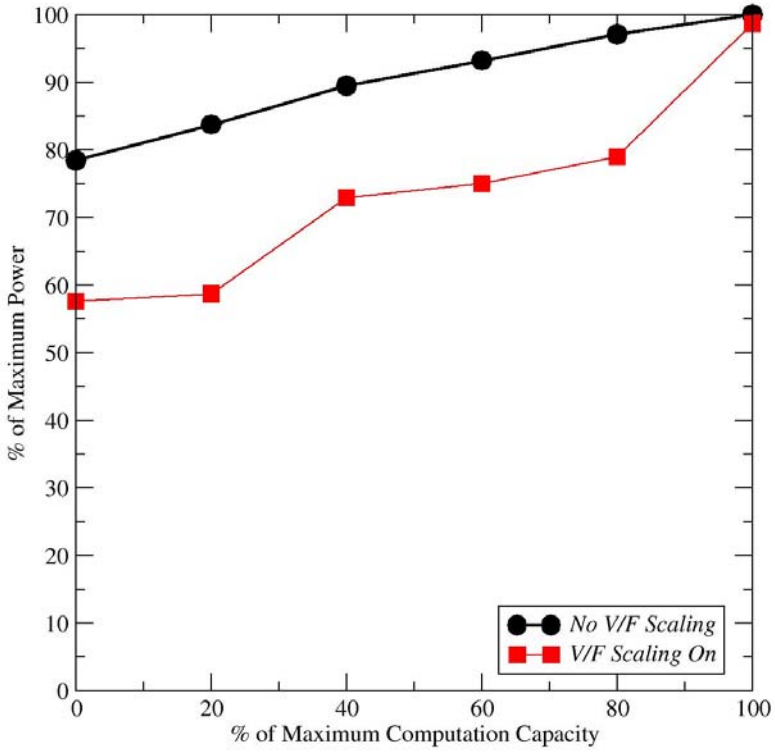
Network	Utilization
AT&T switched voice	33%
Internet backbones	15%
Private line networks	3~5%
LANs	1%

Energy cost is a function capacity, not throughput

Modulating Power to Match Compute Load

- **Concept and real data showing how server power drops with computing load**
- **Test procedures needed to gather such data for network equipment**



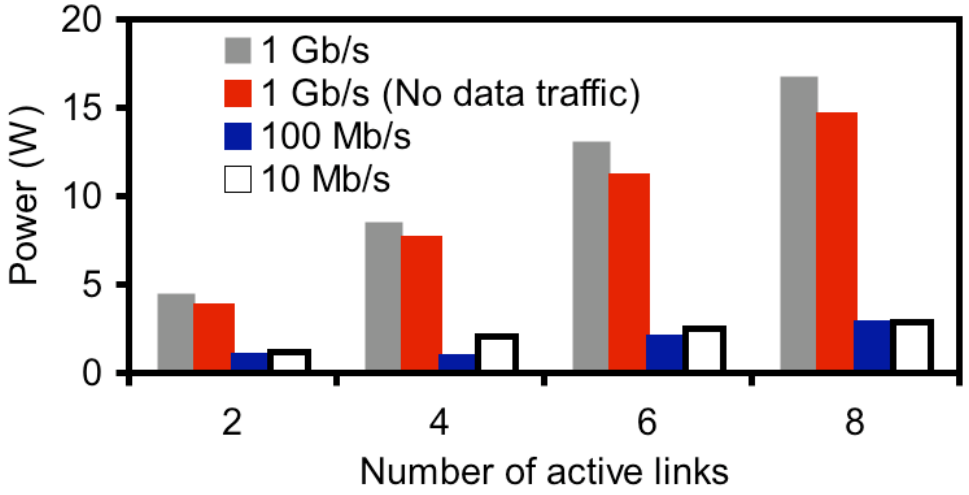


Source: Nordman, 2005

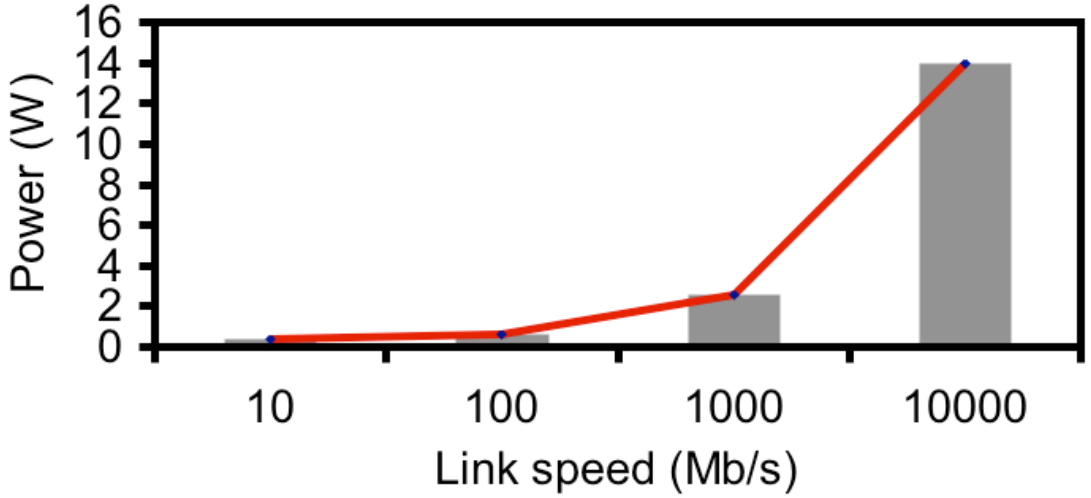
NIC / Link Power

Measurements — all incremental AC power

- **Typical switch with 24 ports**
  10 / 100 / 1000 Mb/s

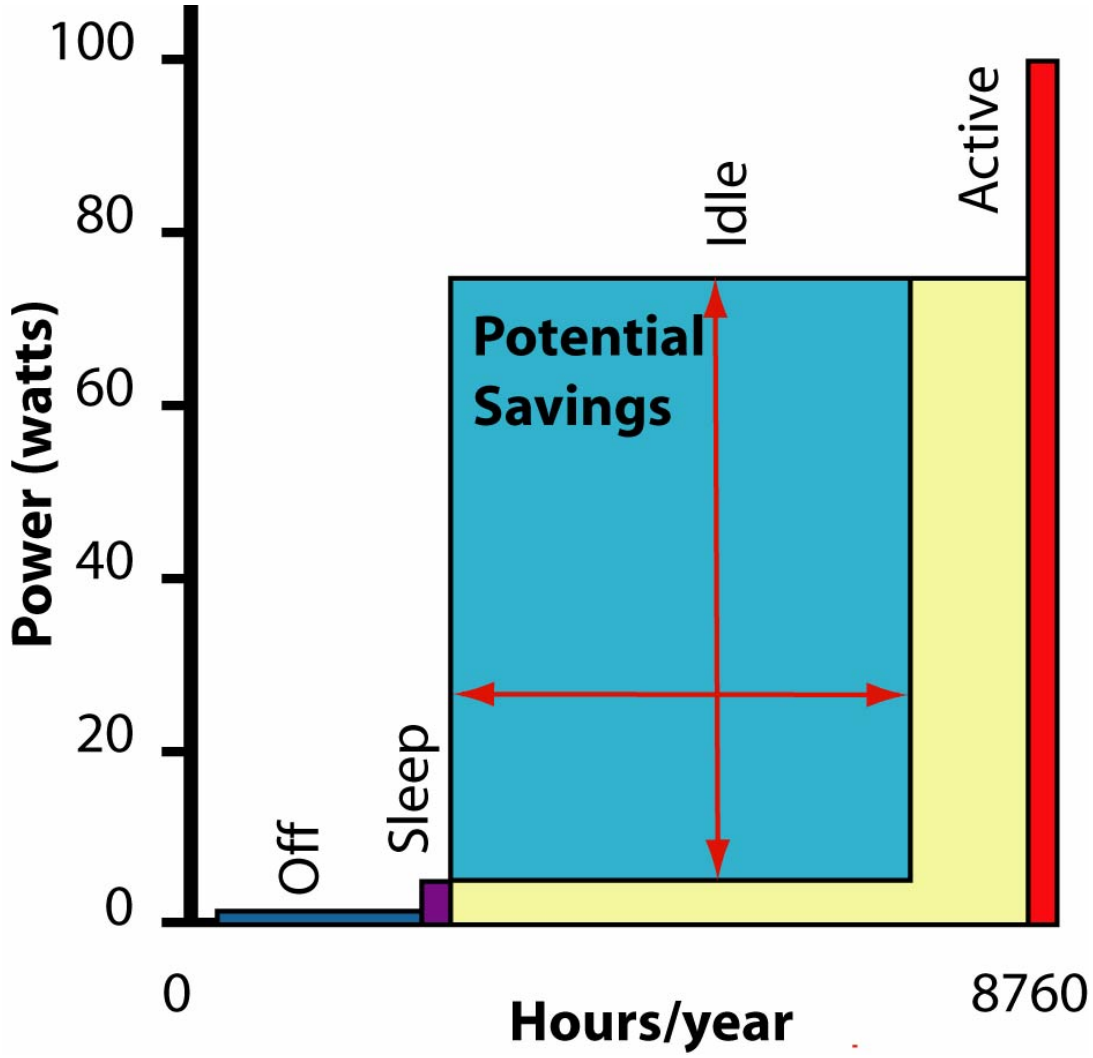


- **Various computer NICs averaged**



Source: Christensen, 2005

PC Energy Use



All time for year sorted by power level

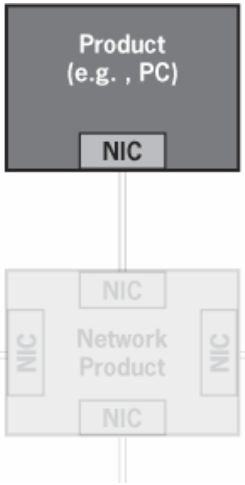
Most of time when idle, could be asleep

PC savings potential is **most** of current consumption

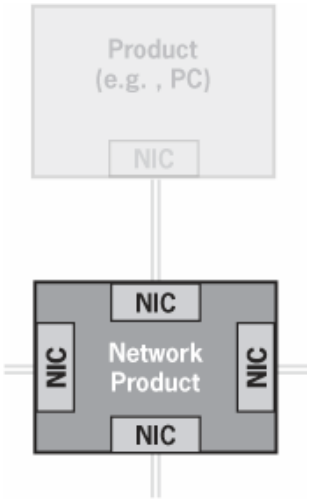
Similar patterns apply to set-top boxes for TVs

Efficiency Approaches

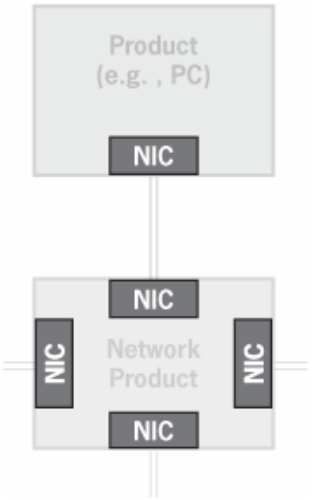
Product Focus



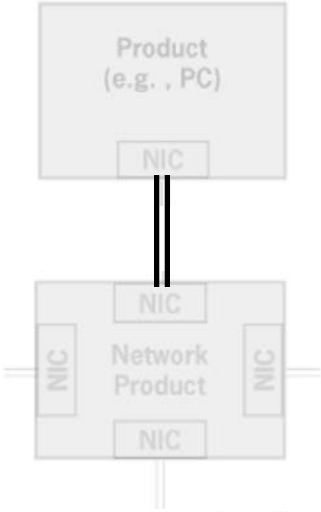
Network Product Focus



Interface Focus



Protocol Focus



Need all approaches

Research Needs

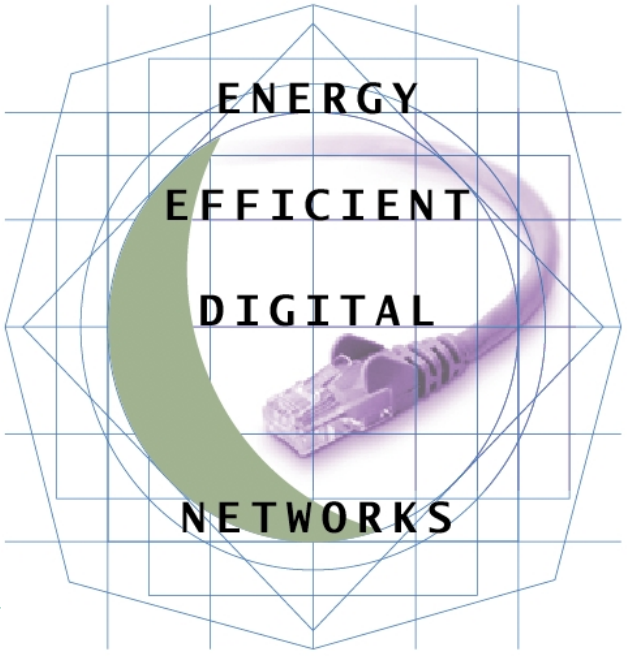
- Modulating capacity to need
- Using latency requirements to discriminate
- Selectively-connected network architecture (NSF-FIND — Paxson et al.)
- Wireless
- How to integrate small devices into Internet
- Non-electronic device energy use networking
  - –Lighting, Climate Control, …

What does this mean for GENI?

- May be ways to assess energy consequences of GENI design decisions
- Some suitable research questions exist, e.g. shutting down excess non-edge links
- For networks / energy in general, action is at the edge
  - Does GENI address this at all? Should it?
  - Does NSF cover the edge (and beyond) sufficiently?

Summary

- Electronics a significant and increasing use of electricity — networks a modest piece of this
- For energy, the action is at the edge
- Many important research topics — short- and-long term
  - Relationship to GENI an open question
- More data needed to reveal current conditions
- Energy may offer best way to connect networks with “real world” on large scale
  - An important tool for addressing climate change



Thank you!

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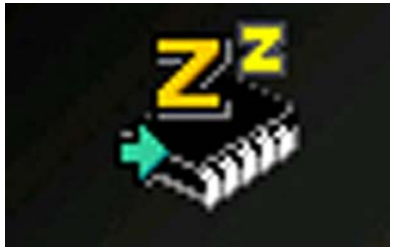
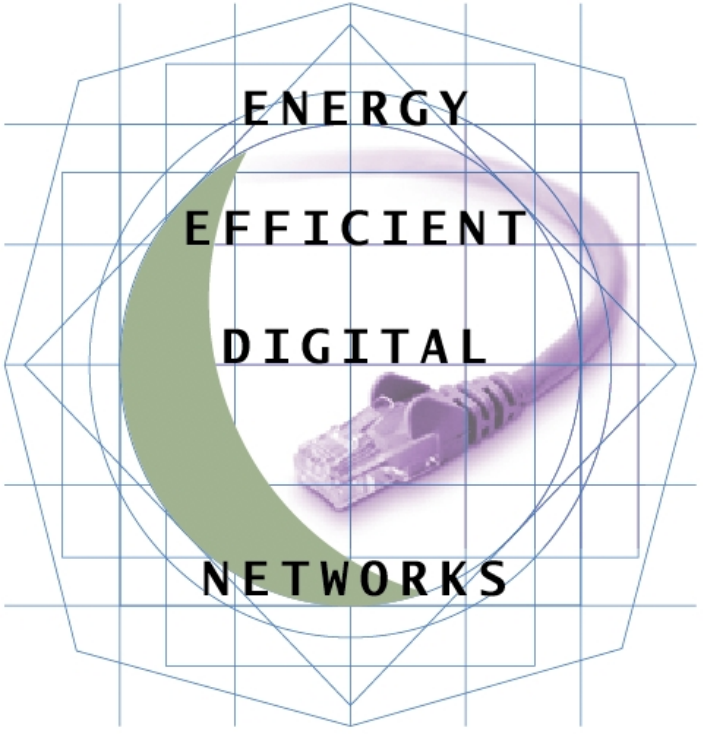




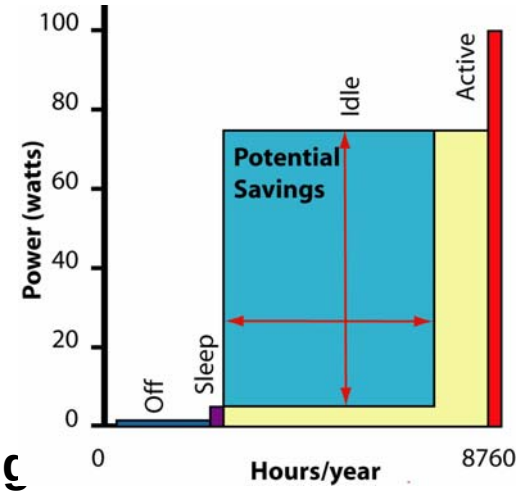
- **Backup slides**

Adaptive Link Rate — Energy Efficient Ethernet

- Concept
  - Add power management to Ethernet
- Method
  - Reduce link rate at times of low traffic levels
    - Most time on most links is low traffic levels
  - Quick transitions and seamless operation essential
- Energy Savings
  - In network interface hardware and rest of system
  - In homes, commercial buildings, and data centers
  - U.S. direct savings — $ several hundred million/year
- Status
  - In midst of IEEE 802.3 standards process
  - Hardware should be available in several years
- LBNL role
  - Initiate project, chair committee, link to energy efficiency community

Proxying

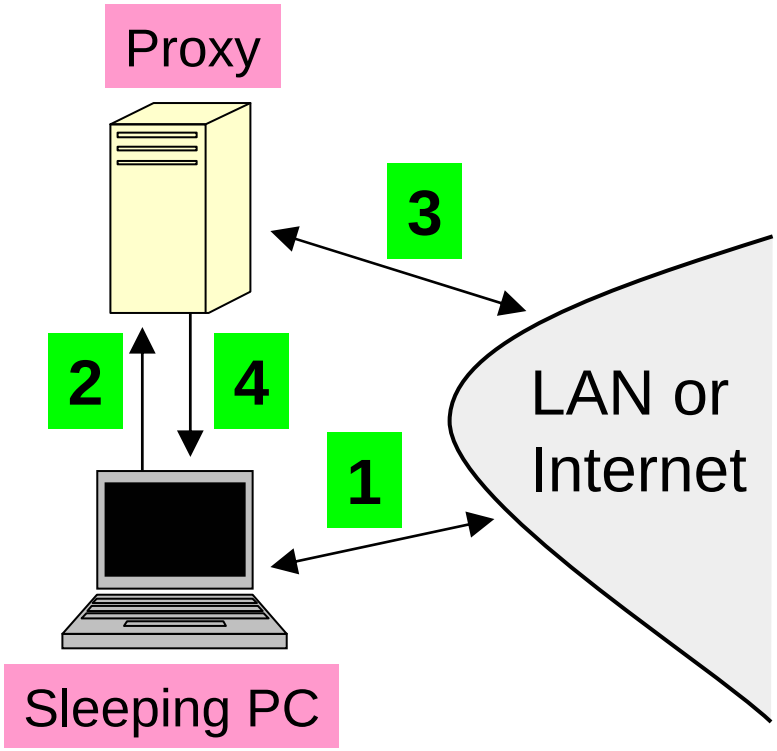
- Concept
  - Allow sleeping PCs to remain fully network connected
- Method
  - Define standard for how network interface can maintain "full network presence"
- Energy Savings
  - Likely < 1 W extra for proxy hardware
  - Avoids > 50 W for PC being on
  - U.S. direct savings — Easily > $1 billion/year
- Status
  - Working with industry to draft content of proxying
- LBNL role
  - Initiate project, coordinate with academia, industry, standards organizations, energy community



How Proxying Works

Proxy operation

1. **PC awake; becomes idle**
2. **PC transfers network presence to proxy on going to sleep**
3. **Proxy responds to routine network traffic for sleeping PC**
4. **Proxy wakes up PC as needed**



Proxy can be internal (NIC) or external (in other PC, switch or router, wireless base station, or dedicated device)