

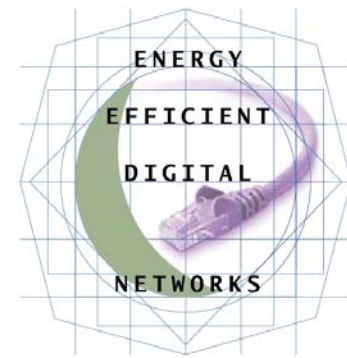
Networks, Energy, and Energy Efficiency

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October 10, 2007

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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



Dig more coal -- the PCs are coming

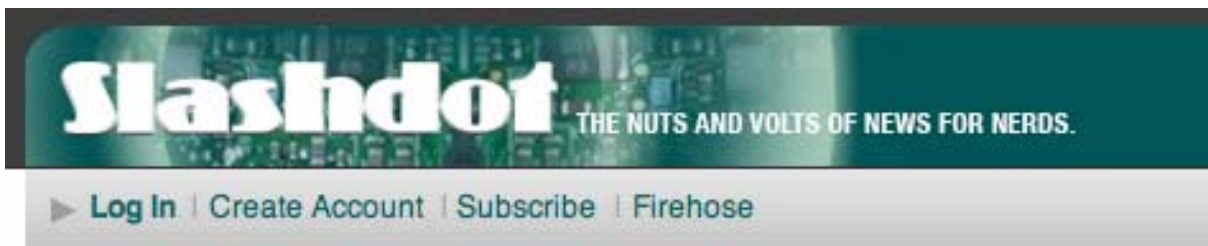
Peter W. Huber and Mark P. Mills, 05.31.99

Southern California Edison, meet Amazon.com. Somewhere in America, a lump of coal is burned every time a book is ordered on-line.

The current fuel-economy rating: about a pound of coal to create, package, store and move 2 megabytes of data. The digital age, it turns out, is very energy-intensive. The Internet may someday save us bricks, mortar and catalog paper, but it is burning up an awful lot of fossil fuel in the process.

“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



Internet Uses 9.4% of Electricity In the US

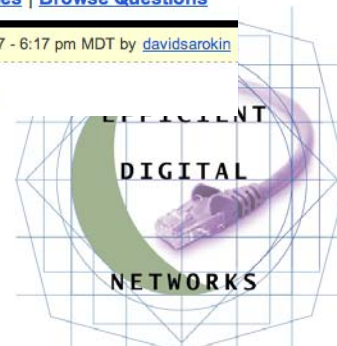
Uclue
got questions? (beta)

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★★★★★ ANSWERED on Fri 17 Aug 2007 - 6:17 pm MDT by [daividsarokin](#)

Question: Energy Use of Internet

2007



How much energy does network equipment consume?



	<i>\$billion</i>	<i>TWh/year</i>
Telecom	\$0.80	8.0
Data center	\$0.20	2.0
Residential	\$0.73	7.3
<u>Commercial (office)</u>	<u>\$0.88</u>	<u>8.8</u>
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 CO₂ per year
 - Roughly equivalent to 30 million cars!

Numbers represent U.S. only

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

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



Networks and Energy



Network equipment

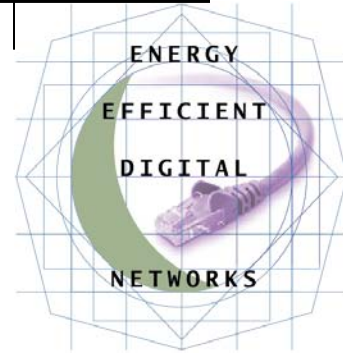
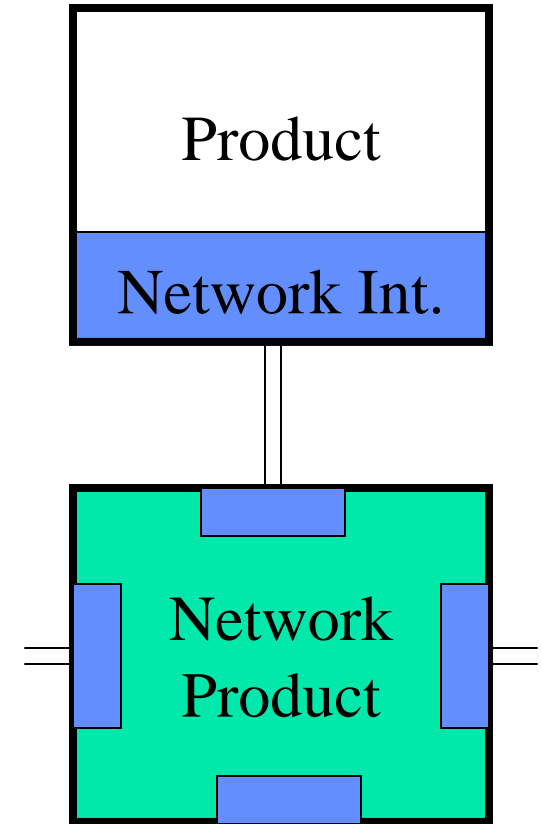
Modems, routers, switches, wireless APs, ...

... vs network^{ed} equipment

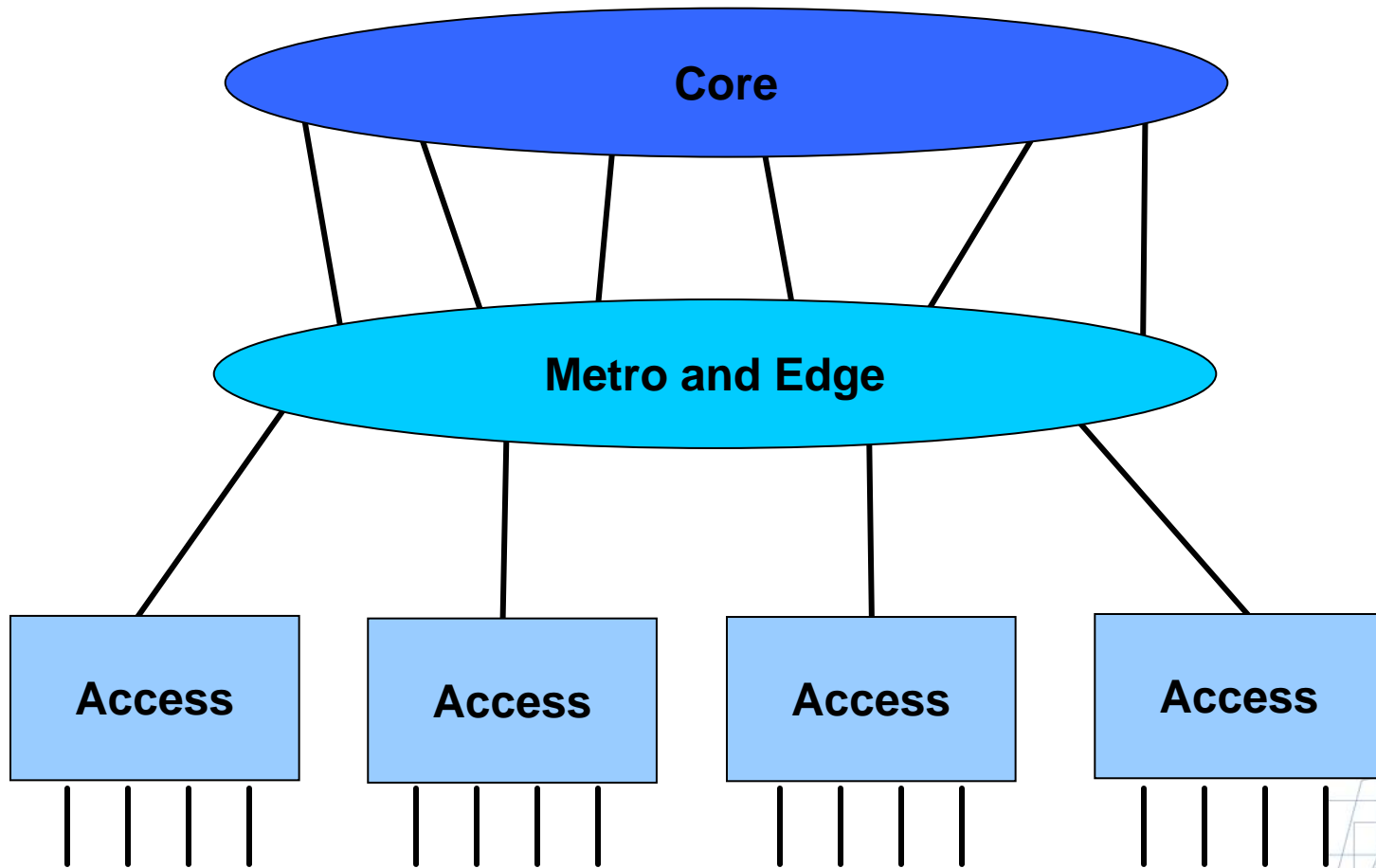
PCs, printers, set-top boxes, ...

How networks drive energy use

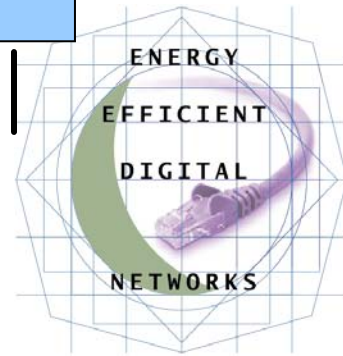
- Direct
 - Network interfaces (NICs)
 - Network products
- Induced in Networked products
 - Increased power levels
 - Increased time in higher power modes



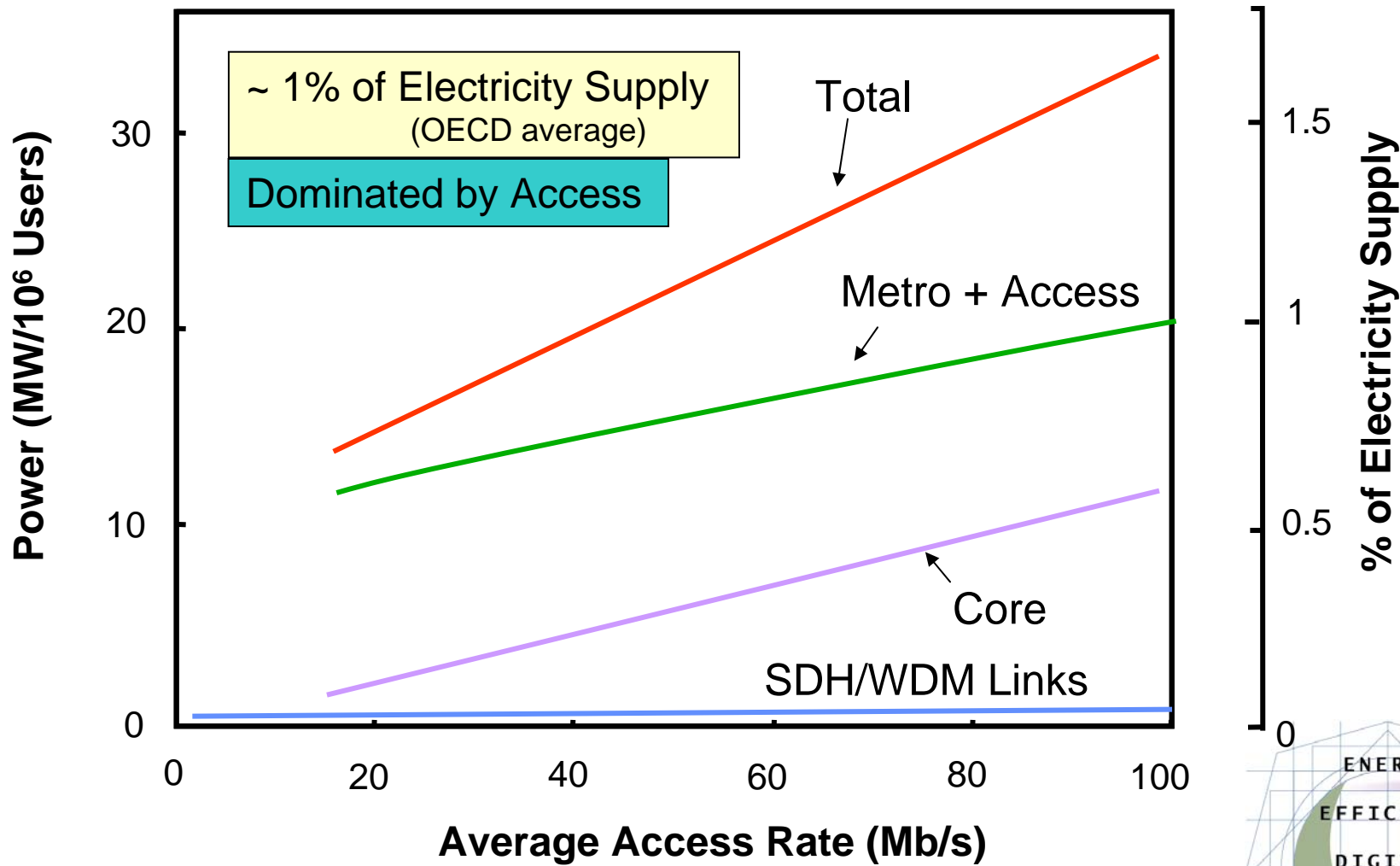
Network Structure



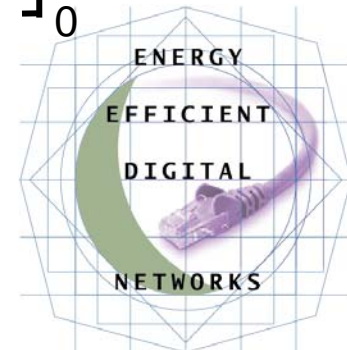
Source: Tucker et al., 2007



Power Consumption of IP Network (Residential portion only)



Source: Tucker et al., 2007



How should we think about networks and energy?

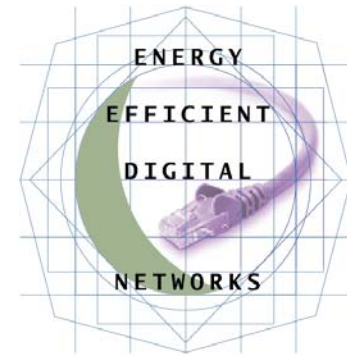


Approaches / Focus

- **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



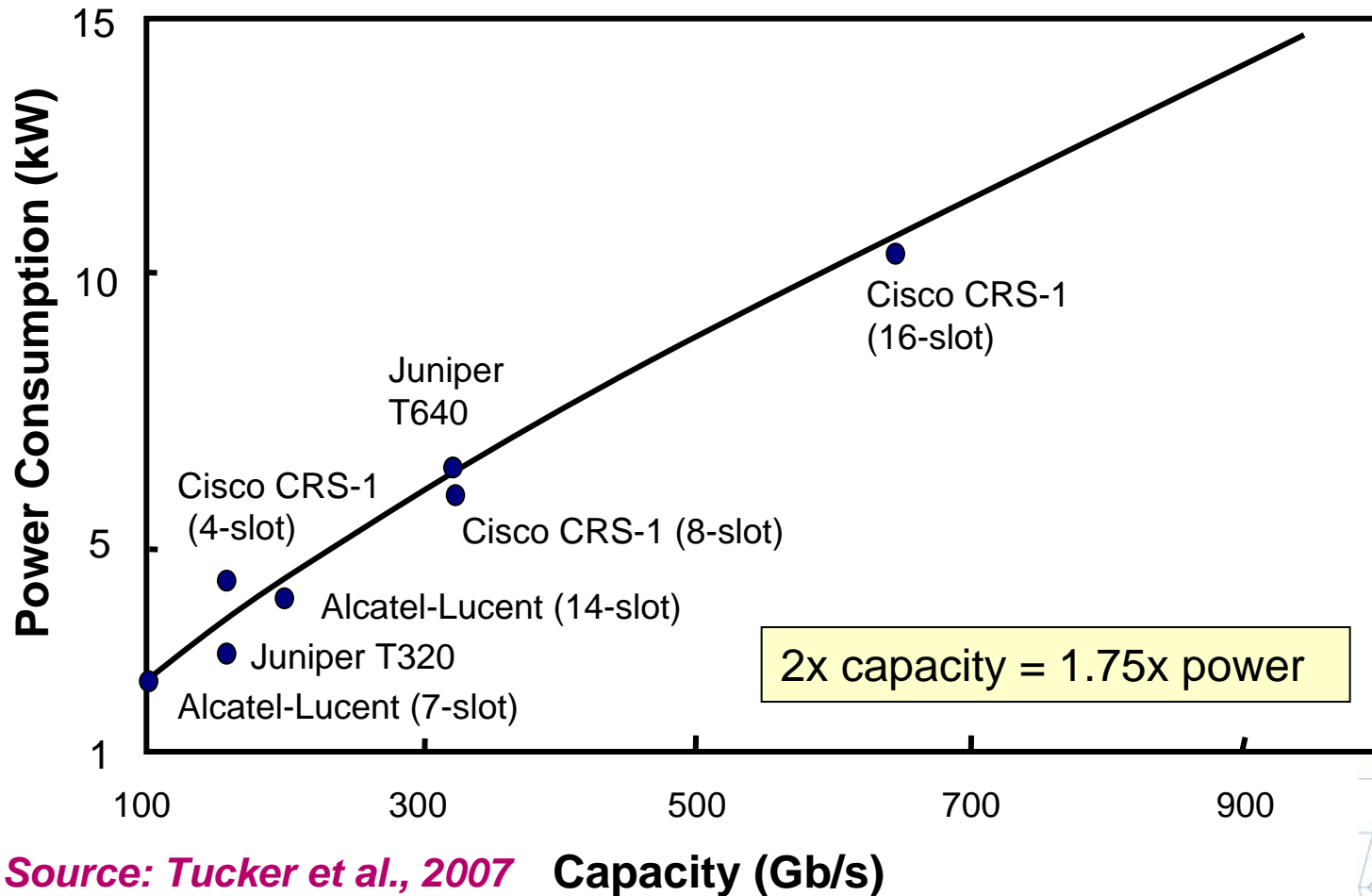
Data



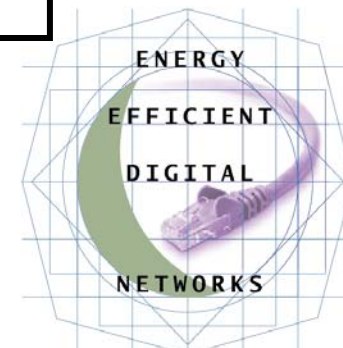
- **Need to ground energy / network research in real data**
 - Clarifies drivers of energy use
 - Often reveals savings opportunities
- **Following slides show examples of such data**
 - Much more needed



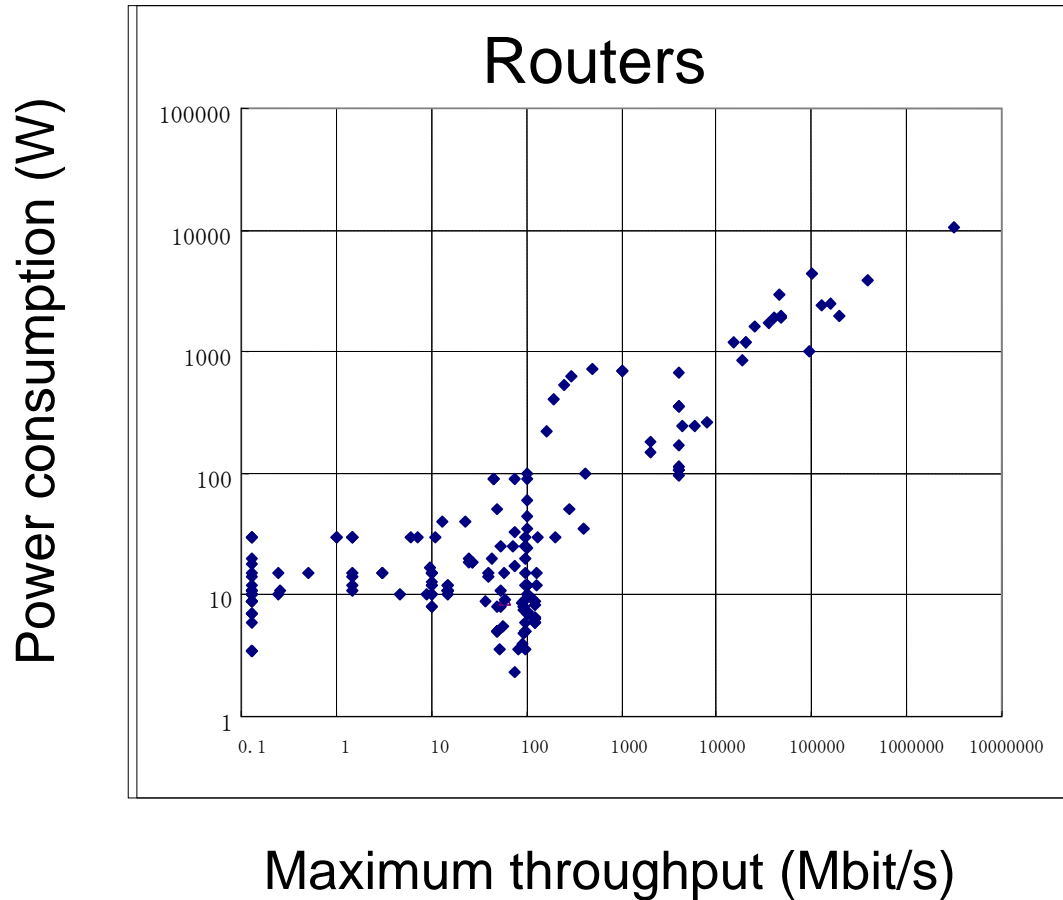
Power Consumption Trends



Source: Tucker et al., 2007 Capacity (Gb/s)



Power Consumption Trends

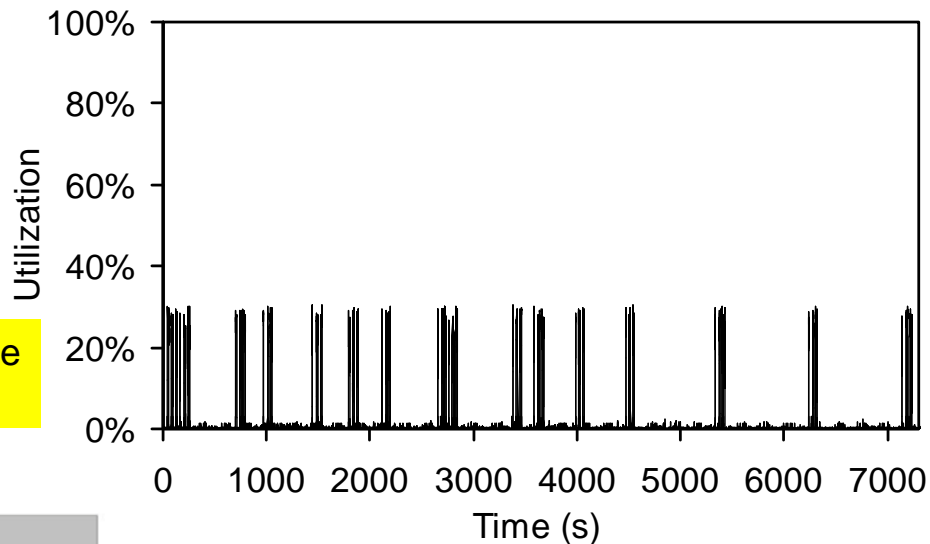


Sample utilization graphs

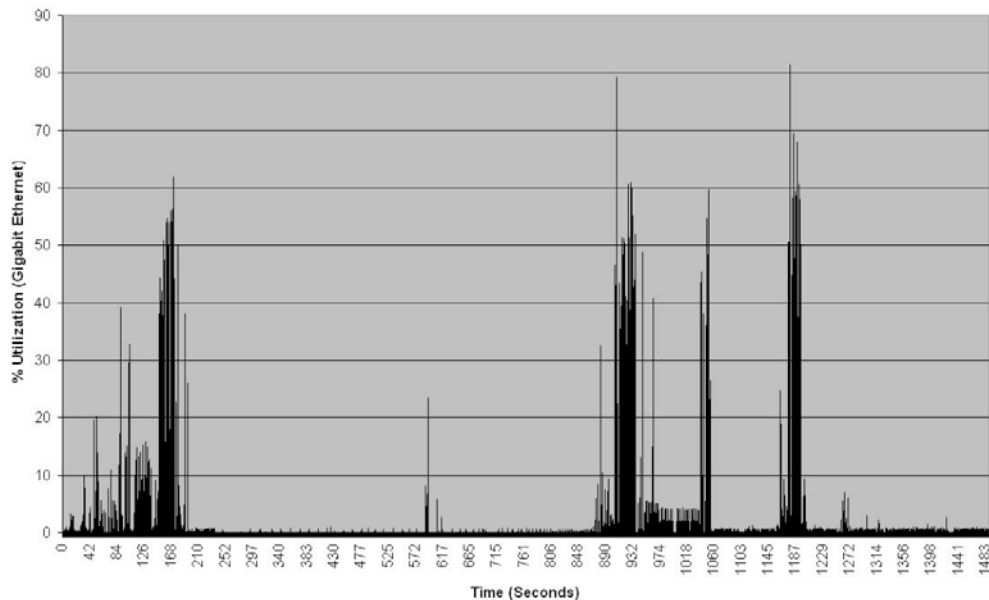


- **Snapshot of a typical 100 Mb Ethernet link**
 - Shows time versus utilization (trace from Portland State Univ.) (Singh)

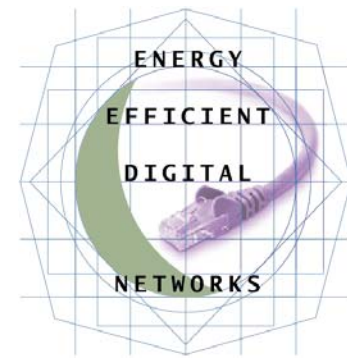
Typical bursty usage
(utilization = 1.0 %)



File Server Bandwidth Utilization Profile



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



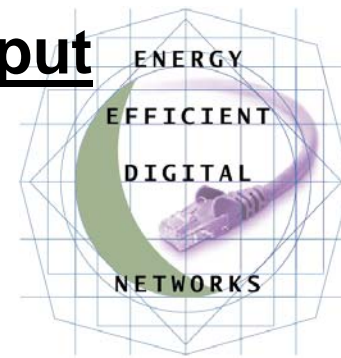
Utilization



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

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

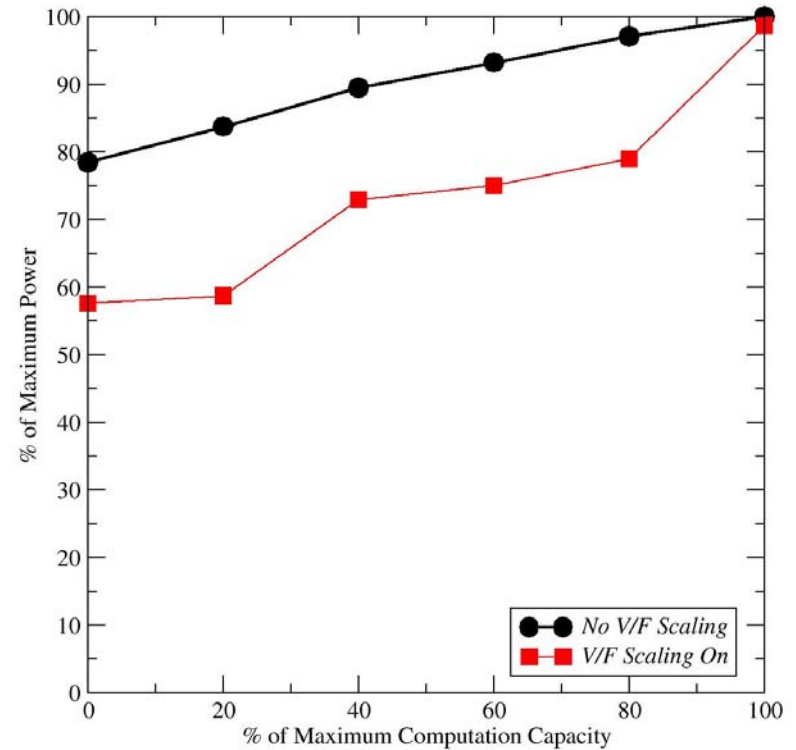
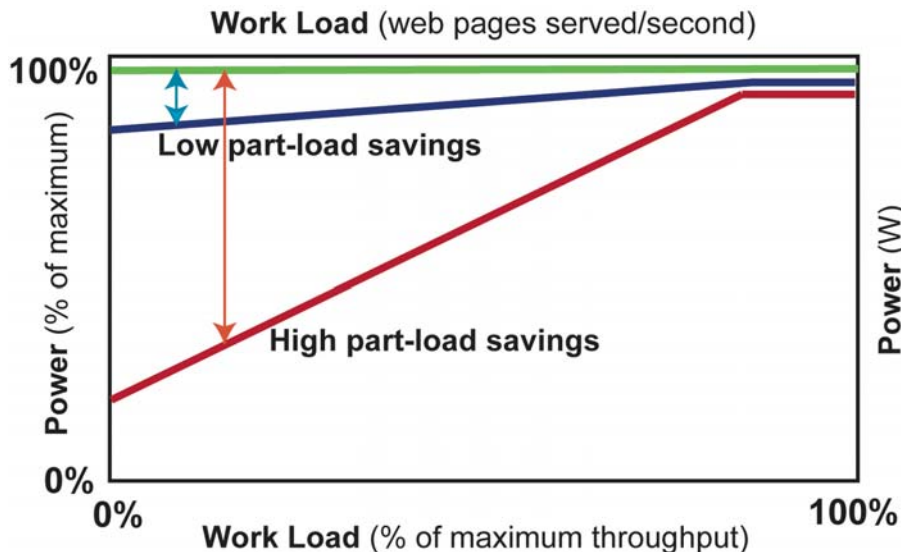
Energy cost is a function capacity, not throughput



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

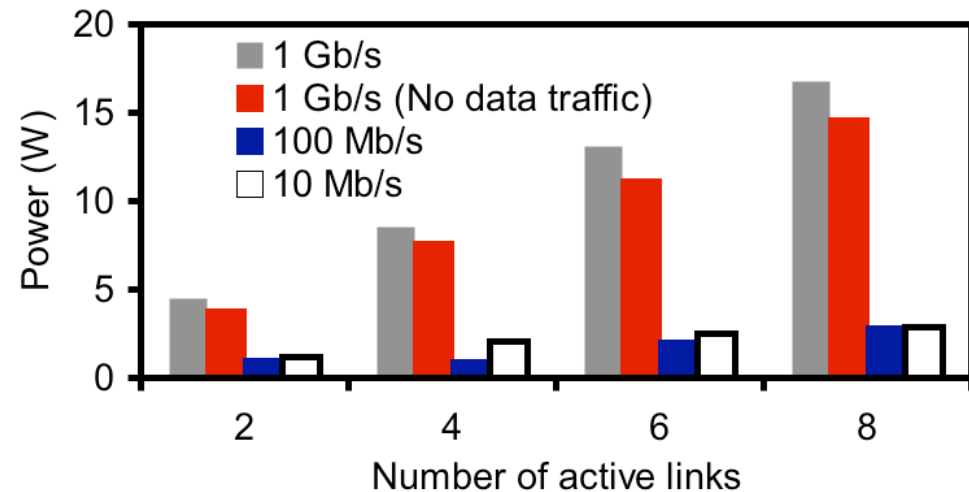


NIC / Link Power

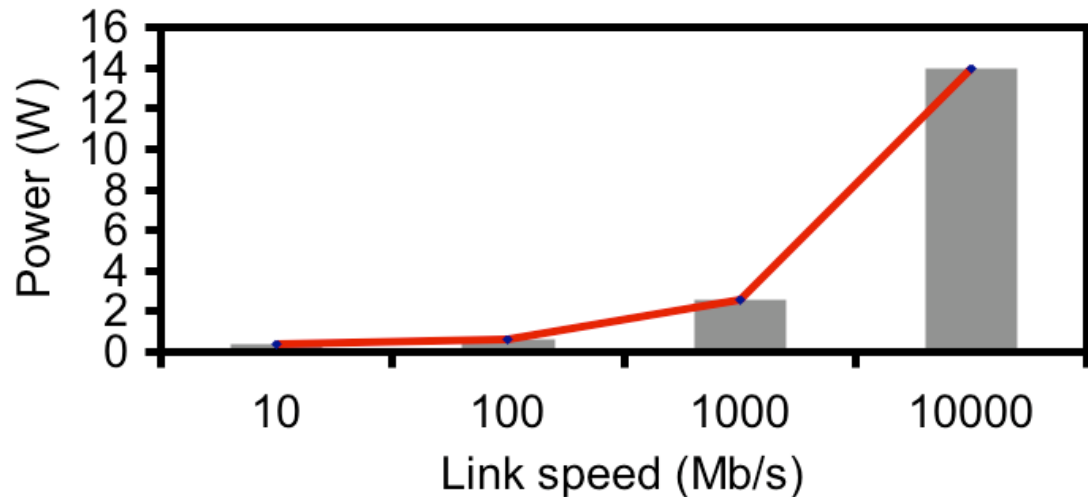


Measurements — all incremental AC power

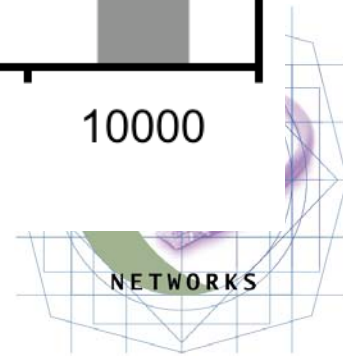
- Typical switch with 24 ports
10 / 100 / 1000 Mb/s



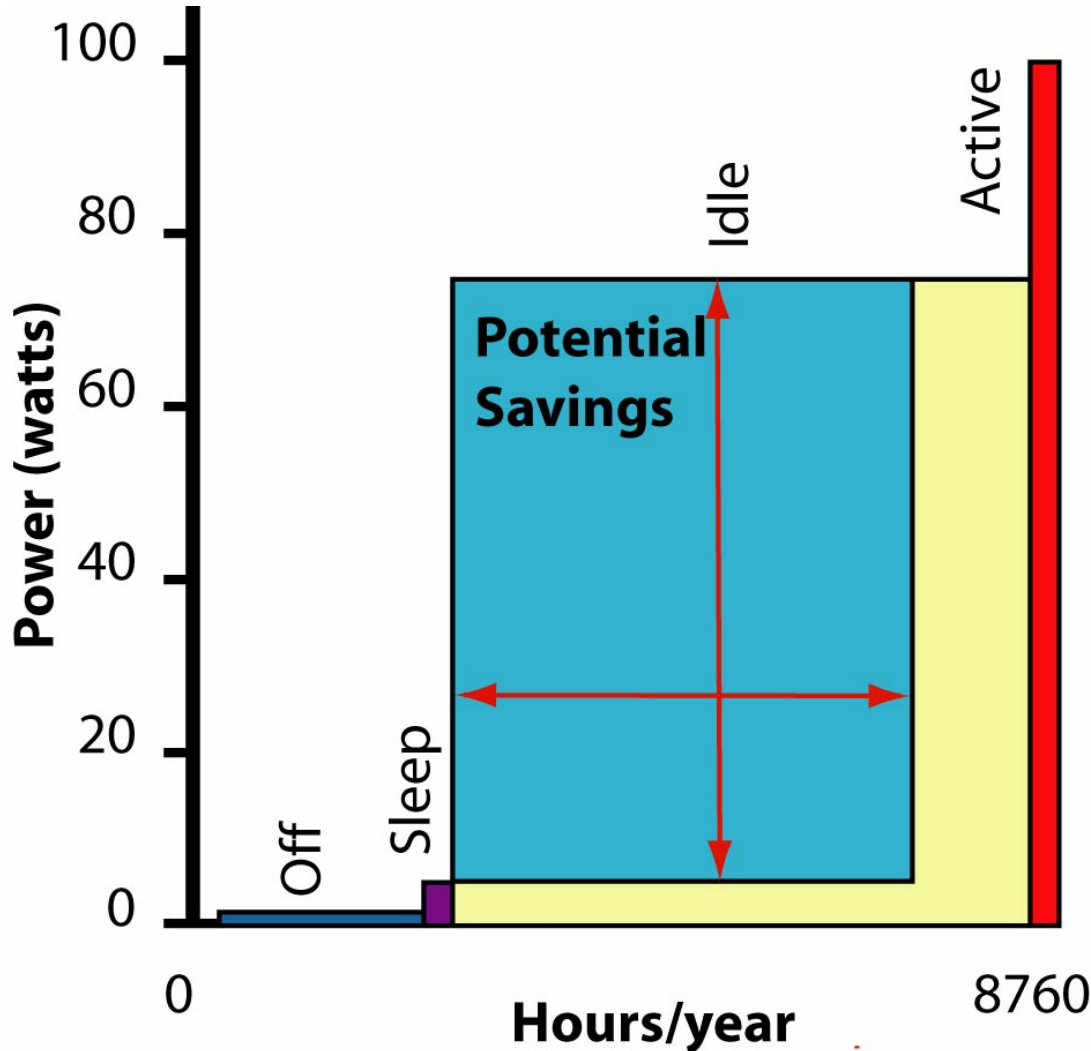
- Various computer NICs averaged



Source: Christensen, 2005



PC Energy Use

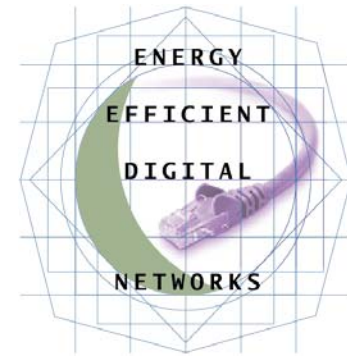


All time for year sorted by power level

Most of time when idle, could be asleep

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

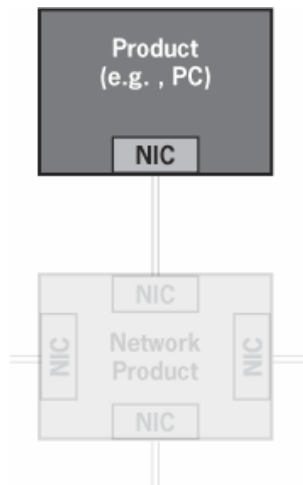
Similar patterns apply to set-top boxes for TVs



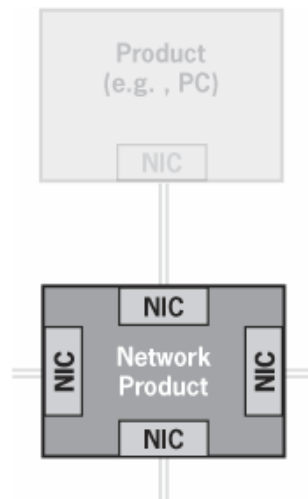
Efficiency Approaches



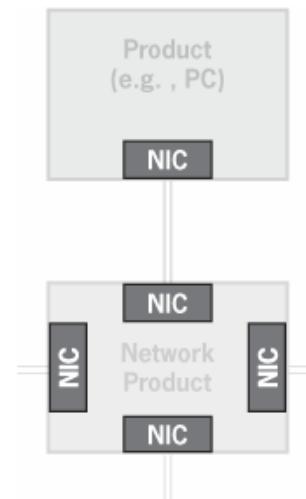
Product Focus



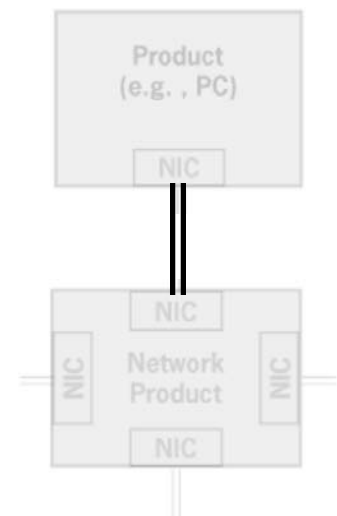
Network Product Focus



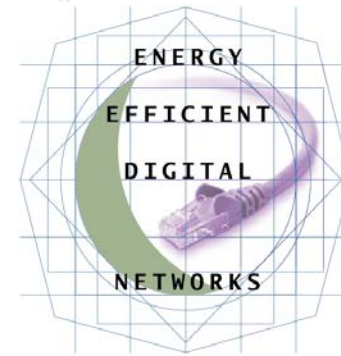
Interface Focus



Protocol Focus



Need all approaches



Research Needs



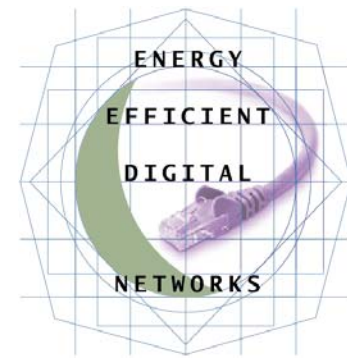
- Modulating **capacity** to need
- Using **latency** requirements to discriminate
- **Selectively-connected** network architecture (NSF-FIND — Paxson et al.)
- **Wireless**
- How to integrate **small devices** into Internet
- **Non-electronic device** energy use networking
 - Lighting, Climate Control,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



What does this mean for GENI?



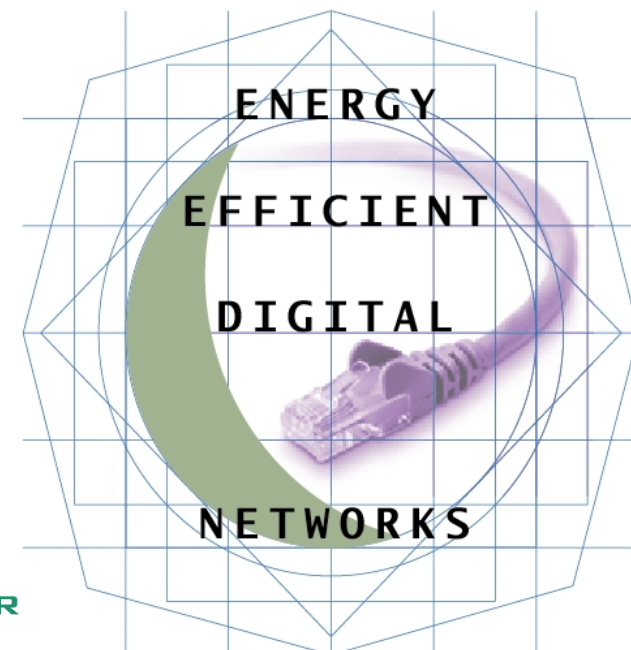
- **May be ways to assess energy consequences of GENI design decisions**
- **Some suitable research questions exist, e.g. shutting down excess non-edge links**
- **For networks / energy in general, action is at the edge**
 - **Does GENI address this at all? Should it?**
 - **Does NSF cover the edge (and 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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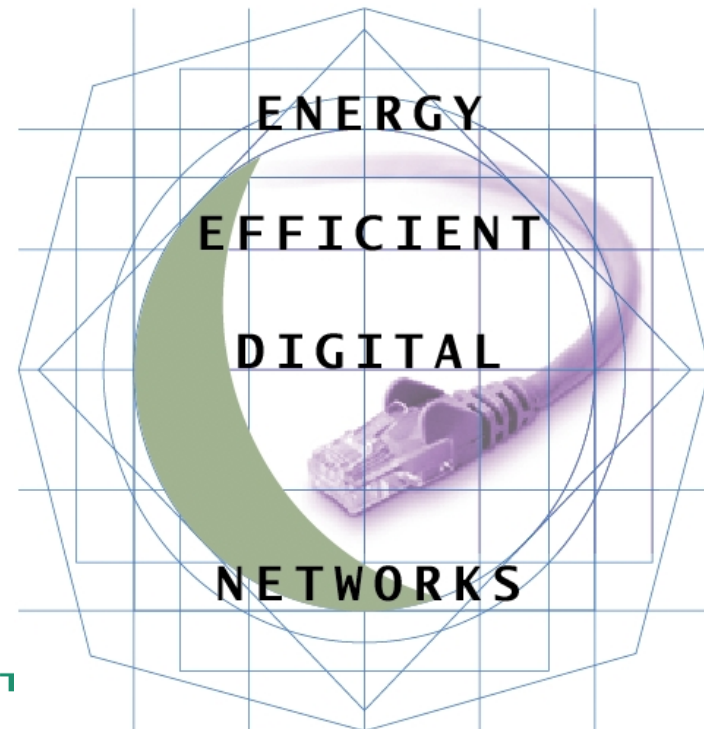
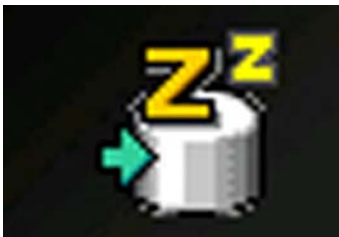
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(m: 510-717-2916)





- **Backup slides**



Adaptive Link Rate — Energy Efficient Ethernet



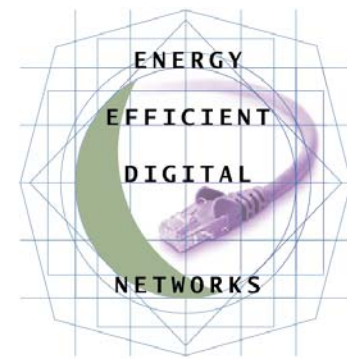
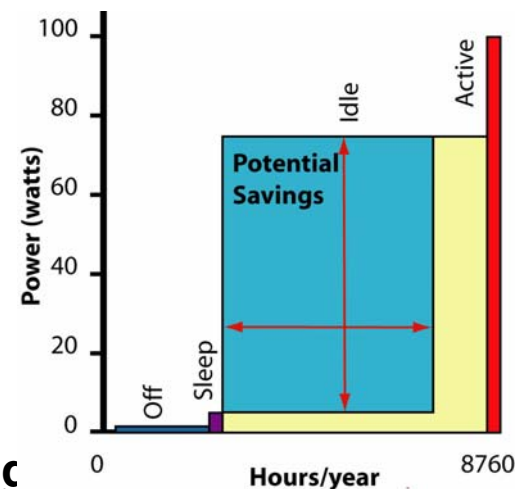
- **Concept**
 - Add power management to Ethernet
- **Method**
 - Reduce link rate at times of low traffic levels
 - Most time on most links is low traffic levels
 - Quick transitions and seamless operation essential
- **Energy Savings**
 - In network interface hardware and rest of system
 - In homes, 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

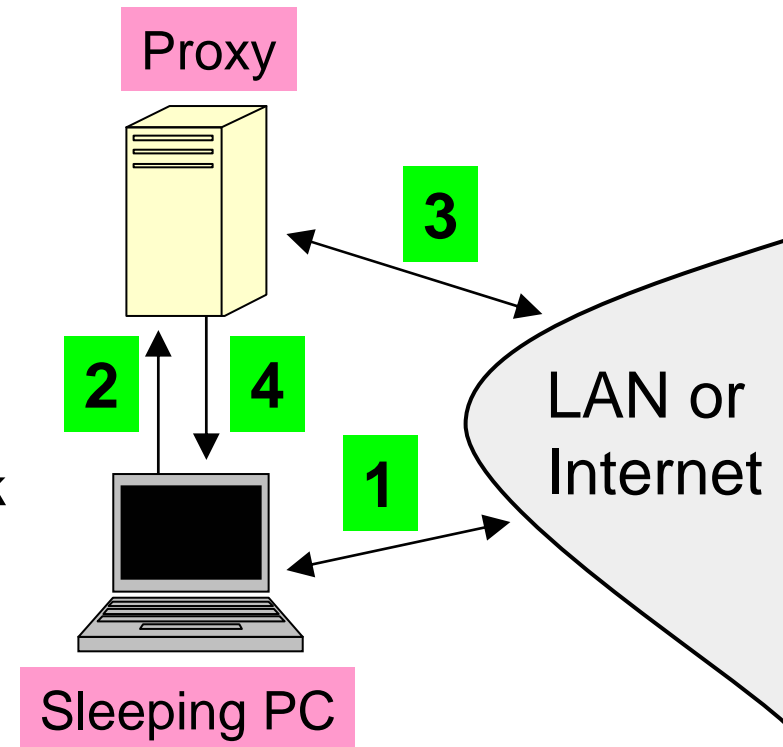


How Proxying Works



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)

