On taking network power down

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What do you think consumes more energy?

Data Centers

Communication Networks
What do you think consumes more energy?

Data Centers or Communication Networks

In 2022

240-340 TWh

260-360 TWh

What do you think consumes more energy?

Data Centers

In 2022: 240-340 TWh
In 2015: 200 TWh
Change of: +20-70% in energy

or

Communication Networks

In 2022: 260-360 TWh
In 2015: 220 TWh
Change of: +18-64% in energy

What do you think consumes more energy?

Data Centers or Communication Networks

<table>
<thead>
<tr>
<th>Year</th>
<th>Energy Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>2022</td>
<td>240-340 TWh</td>
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<td>2015</td>
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<tr>
<td>Change of</td>
<td>+20-70% in energy</td>
</tr>
<tr>
<td></td>
<td>+340% in workload</td>
</tr>
<tr>
<td></td>
<td>+260-360 TWh</td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
<td>+18-64% in energy</td>
</tr>
<tr>
<td></td>
<td>+600% in traffic</td>
</tr>
</tbody>
</table>

Energy efficiency improved a lot

- Data Centers
  - Change in energy is much smaller than in work done.
  - +20-70% in energy
  - +340% in workload

- Communication Networks
  - Change in energy
  - +18-64% in energy
  - +600% in traffic
Energy efficiency improved a lot but **not enough**!

**Data Centers**

Change in energy is **positive**!

+20-70% in energy

**Communication Networks**

+18-64% in energy
“With great power comes great responsibility”

- It is easy to keep increasing network capacity
- It is much harder to keep increasing energy efficiency
“With great power comes great responsibility”

- It is easy to keep increasing network capacity.
- It is much harder to keep increasing energy efficiency.
- Total energy usage is likely to keep increasing.
“With great power comes great responsibility” and carbon footprint.

- It is easy to keep increasing *network capacity*
- It is much harder to keep increasing *energy efficiency*

Total energy usage is likely to keep increasing.

Producing *energy* emits *carbon*.

https://ourworldindata.org/grapher/electricity-prod-source-stacked
On taking network power **down** to reduce the Internet footprint.

1. Reduce network power with better proportionality
2. Avoid rebound effects by advocating for sobriety
On taking network power **down** to reduce the Internet footprint.

1. **Reduce network power** with better proportionality
   
   Avoid rebound effects by avocating for sobriety
Operational Carbon efficiency = \[
\frac{J \text{ used}}{\text{Task}} \times \frac{J \text{ supplied}}{J \text{ used}} \times \frac{\text{Carbon}}{J \text{ supplied}}
\]

... improves with better...

Networks & compute

Infrastructure & HW design

Carbon intensity
Operational Carbon efficiency = \[ \frac{\text{J used}}{\text{Task}} \times \frac{\text{J supplied}}{\text{J used}} \times \frac{\text{Carbon}}{\text{J supplied}} \]

... improves with better...

Not really a network matter
Operational Carbon efficiency = \( \frac{J \text{ used}}{\text{Task}} \times \frac{J \text{ supplied}}{J \text{ used}} \times \text{Carbon } J \text{ supplied} \) 

... improves with better...

Networks & compute 

Infrastructure & HW design 

Improves with better networks
Operational Carbon efficiency = \[ \frac{\text{J used}}{\text{Task}} \times \frac{\text{J supplied}}{\text{J used}} \times \frac{\text{Carbon}}{\text{J supplied}} \]

... improves with better...

Main focus of networking

Networks & compute

Infrastructure & HW design

Carbon intensity
Operational Carbon efficiency = J used Task \times J supplied \times Carbon intensity

Networks & compute

... improves with better...

Main focus of networking

Operational Carbon intensity improves with better...
Let’s consider two energy usage profiles for the same task.

- High power
- Short time

- Low power
- Long time

[ The two blue areas are equal ]

Which option is more energy efficient?
Let’s consider two energy usage profiles for the same task.

[ The two blue areas are equal ]

Which option is more energy efficient?

What about now?
Turning components off whenever possible is the fundamental way of saving energy. aka “sleeping”

Sleeping is implemented in all consumer IT

- Screens
- Radio duty-cycling
- DVFS
- ...
Sleeping is implemented in all consumer IT

- Screens
- Radio duty-cycling
- DVFS
- ...

What about network devices?
How does such a plot look like for a switch?
The idle power dominates i.e., network power is inelastic.
The idle power dominates i.e., network power is **inelastic**.

Not so far fetched...
How “bad” is power inelasticity?
On the bright side, inelasticity means we can carry more traffic with the same power!
On the dark side, it results in
very inefficient wired networks...

SIGCOMM 2003

The Internet core consumes
more Joules per Bytes
than wireless LANs.

2x and 24x more...
depending on your hypotheses
Network devices are always “on.”
1. Network devices are always “on.”

2. Network devices’ energy consumption is mainly independent of traffic load.
1. Network devices are always “on.”

2. Network devices’ energy consumption is mainly independent of traffic load.

3. Network devices are under-utilized.

ISP overprovision networks to support:

- Peak traffic
- Fault tolerance
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ISP overprovision networks to support:
- Peak traffic
- Fault tolerance
What does proportionality mean for our toy example?

- As idle power dominates, low utilization wastes a lot.
What does proportionality mean for our toy example?

- As idle power dominates, low utilization wastes a lot.
- Reducing idle power yields better proportionality.
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- Idle power is always there!
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- ... and it dominates.
What does proportionality mean for our toy example?

- As idle power dominates, low utilization wastes a lot.
- Reducing idle power yields better proportionality.
- Idle power is always there!
- ... and it dominates.

**Improving proportionality** is essentially about taking the “average idle power” down.
There two ways to improve energy efficiency.

- Run more often at high utilization
  - Better efficiency
  - Increase in total energy...
There are two ways to improve energy efficiency.

- Run more often at high utilization
  - Better efficiency
  - Increase in total energy...

- Take low-utilization power down

Our focus
The basic idea is to turn off “stuff” whenever possible.

What can we possibly turn off?

- Ports
- Line cards
- Entire device...
The basic idea is to turn off “stuff” whenever possible.

What can we possibly turn off?

- Ports
- Line cards
- Entire device...
- Memory banks
- Power supplies
- LEDs
  ... etc.
The basic idea is to turn off “stuff” whenever possible.

What can we possibly turn off?

- Ports
- Line cards
- Entire device...
- Memory banks
- Power supplies
- LEDs ... etc.

It can be more subtle than on/off.

- Change a port rate from 100G to 10G
- Down-clock the ASIC
- Cache frequently used FIB entries
The basic idea is to turn off “stuff” whenever possible. That’s nothing new.
The theory says we can save tens of energy % in ISP networks.

Reducing Network Energy Consumption via Sleeping and Rate-Adaptation
Sergio Nedevschi, Lucia Pope, Sylvia Ratnasamy, Giannicola Iannaccone, David Wheeler

Abstract
We present the design and evaluation of two forms of power management schemes that reduce the energy consumption of networks. The first is based on putting network components in deep sleep during idle times, reducing energy consumed in the absence of activity. The second is based on adapting the rate of network operation to the observed workload, reducing the energy consumed when activity is present.

For real-world traffic workloads and topologies and existing power consumption in idle network equipment, we show that even simple schemes for sleeping and rate-salutation can offer substantial savings. For example, one practical algorithm used to balance energy consumption for lightly used networks (10-20%) shows that these savings approach the maximum achievable at any algorithm using the same power management guidelines. Moreover, the energy can be saved without significantly increasing latency and with a small and controllable increase in latency (<10%). Finally, we show that both sleeping and rate adaptations are valuable depending primarily on the power profile of network equipment and on the utilization of the network itself.

1 Introduction
In this paper, we consider power management for networks from a perspective that has recently begun to receive attention: the conservation of energy for operating and environmental reasons. Energy consumption in network exchanges is rising as higher capacity network equipment becomes more powerful and requires greater amounts of cooling. Combined with rising energy costs, this has made the cost of powering network exchanges a substantial and growing fraction of the total cost of ownership — up to half by some estimates.[21] Various studies now estimate the power usage of the US network infrastructure at between 5 and 24 TWh/year[23, 31], or 50-300% of the power that is actually used in the US. One way to reduce energy costs is to simply close down network equipment that is not in use.

via standards such as EnergyEyes. In fact, EnergyEyes standard procedures for 2008 discuss slower operation of network links to consume energy when idle. A new IEEE 802.11 Task Force was launched in early 2000 to focus on this issue for Ethernet.[11]

Fortunately, there is no opportunity for substantial reductions in the energy consumption of existing networks due to two factors. First, networks are provisioned for variable or many-hour load, and this load typically extends their long-term utilization by a wide margin. For example, measurements reveal backbone utilization under 30%[16] and up to near full load at times of access points in enterprise wireless networks.[17] Second, the energy consumption of network equipment remains substantial even when the network is idle. The implication of these factors is that most of the energy consumed in networks is wasted.

Our work is an initial exploration of how overall network energy consumption might be reduced without adversely affecting network performance. This requires two steps: First, network equipment powering from sources to switches and NICs will need to power management primitives at the hardware level. By analogy, power management in computers has evolved around hardware support for sleep and performance states. The former (e.g., C-states in Intel processors) reduces idle consumption by powering off idle components in different ways, while the latter (e.g., Spindown). Power states in Intel processors provide both performance for power (i.e., changing frequency, second, network protocols will need to make use of the hardware primitives to be most effective. Again, by analogy with computers, power management primitives are available in the system stack between the loadable states to save energy with minimal impact on users.

Of these two steps, one focuses on the network protocols. Admittedly, these protocols hold no hardware support for power management that is in the infancy for networking equipment. Yet the necessary support remains.

Energy Savings (%)

Average utilization (%)
The theory says we can save tens of energy % in ISP networks.

Academia

Reducing Network Energy Consumption via Sleeping and Rate-Adaptation
Sergio Nedevschi (1, 2) Lucian Popa (1) Giambra Jannacccone (1) David Wetherall (1)

Abstract
We present the design and evaluation of two forms of power management schemes that reduce the energy consumption of network switches. The first is based on putting network components in sleep during idle times, reducing energy consumed in the absence of packets. The second is based on adapting the rate of network transmission to the offered load, reducing the energy consumed when activity is present.

For real-world traffic workloads and topologies and existing power constraints drawn from existing network equipment, we show that even simple schemes for sleeping or rate-adaptation can offer substantial savings. To test our scheme, we use a practical model used to analyze energy consumption for lightly loaded networks (10-20%). As we show that these savings approach the maximum achievable by any algorithms using the same power management policies. Moreover the energy can be saved with out noticeably increasing latency and with a small and controlled increase in latency (<0ms). Finally, we show that both sleeping and rate-adaptation are valuable depending on the source profile of network traffic and the utilization of the network itself.

1 Introduction
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via standards such as EnergyYield. For instance, EnergyYield standard protocols for 2008 discuss slower operation of network links to conserve energy when idle. A new

Assuming
- Wake-up delay 1ms
- Buffering time 10ms

Fortunately, there is an opportunity for substantial reduction in the energy consumption of existing networks due to two factors. First, networks are provisioned for voice or data-burst load and this load typically occurs for a long period of time. For example, measurements reveal that high bandwidth loads under 30% of the capacity are bursty and up to half the time with bursts of data.

Our work in an initial exploration of how network energy consumption might be reduced without adversely affecting network performance. This takes two steps. First, network equipment capacity is measured and used to power consumption by portions of traffic. The slower operation of network switches reduces power consumption by portions of traffic. The slower operation of network switches reduces power consumption by portions of traffic. The slower operation of network switches reduces power consumption by portions of traffic. The slower operation of network switches reduces power consumption by portions of traffic. The slower operation of network switches reduces power consumption by portions of traffic. The slower operation of network switches reduces power consumption by portions of traffic. The slower operation of network switches reduces power consumption by portions of traffic. The slower operation of network switches reduces power consumption by portions of traffic. 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Wake-up delay (s) measured on Cisco Nexus 9300: 1 ms and 10 ms.

How?

Buffer-and-Burst

Assuming:
- Wake-up delay: 1 ms
- Buffering time: 10 ms
In practice, transcievers are 1000x slower to start than required for savings via buffering.

### Wake-up delay

<table>
<thead>
<tr>
<th>Transceiver type</th>
<th>Wake-up delay (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100G DAC</td>
<td></td>
</tr>
<tr>
<td>10G RJ45</td>
<td></td>
</tr>
<tr>
<td>100G LR4</td>
<td></td>
</tr>
<tr>
<td>100G LR</td>
<td></td>
</tr>
</tbody>
</table>

Measured on Cisco Nexus 9300

### How?

Buffer-and-Burst

Assuming

- Wake-up delay: 1ms
- Buffering time: 10ms
We can still “sleep” at longer timescales.
We can still “sleep” at longer timescales.

It can be formulated as a usual network optimization problem with unusual constraints.
We can still “sleep” at longer timescales.
How much energy can we really save?

The theory says we can save tens of energy % in ISP networks.
How much energy can we really save?

The theory says we can save tens of energy % in ISP networks.

Hard to say because we lack

1. Measurements
2. Test cases
Energy savings are hard to estimate because we lack good power models.

- Datasheets only talk about the max power
- Devices are never under full load
Energy savings are hard to estimate because we lack good power models.

- Datasheets only talk about the max power
- Devices are never under full load

How much power is drawn under “typical” load?
Energy savings are hard to estimate because we lack good power models.

... so we are building our own ...

Profiling a Tofino switch

WEDGE 100BF-32X
Energy savings are hard to estimate because we lack good power models.

... so we are building our own ...

\[
\text{Device power} = \text{Static power} + \text{Energy per bit} \times \text{bit rate} + \text{Energy per packet} \times \text{packet rate} + \text{Fan power} + \text{Power conversion losses}
\]
We work with standardization bodies to define a benchmark for network power.

Benchmarking Methodology Working Group
V. Manral
P. Sharma
S. Banerjee
HP
Y. Ping
H3C
March 12, 2013

Abstract

With the rapid growth of networks around the globe there is an ever increasing need to improve the energy efficiency of network devices. Operators are beginning to seek more information of power consumption in the network, have no standard mechanism to measure, report and compare power usage of different networking equipment under different network configuration and conditions.

This document provides suggestions for measuring power usage of live networks under different traffic loads and various switch router configuration settings. It provides a benchmarking suite which can
We have a modelling approach. We don’t have devices that need modeling.

Academics have limited access to devices used in the field.

Can we measure yours?
We have a modelling approach. We don’t have devices that need modeling.

 Academics have limited access to devices used in the field.

 ? Can we measure yours?

 - We sent you hardware
 - You plug it in
 - Everyone gets data! 🔄
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Can we measure yours?

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Vision
RIPE Atlas for Power Data
How much energy can we really save?

The theory says we can save tens of energy % in ISP networks.

Hard to say because we lack

1. Measurements
2. Test cases
Energy savings are hard to estimate because they depend on the network.

- Anything can happen in simulation.
- We need real traffic dynamics to accurately assess the impact of sleeping.

The theory says we can save tens of energy % in ISP networks.

Can we get yours?
On taking network power **down** to reduce the Internet footprint.

1. Reduce network power with better proportionality
   - We can “sleep” at daily timescales one in many ideas for better proportionality
   - We need some help to know if it is worth it
On taking network power **down** to reduce the Internet footprint.

Reduce network power with better proportionality

2. Avoid rebound effects by advocating for sobriety

**Improved technology** allowed coal to fuel the Industrial Revolution.

This **greatly increased** the consumption of coal.

Engraving by Edward Goodall (1795-1870), original title Manchester, from Kersal Moor after a painting of W. Wylde
Improving efficiency of a resource usage may result in increased consumption of that resource.


Improved technology allowed coal to fuel the Industrial Revolution.

This greatly increased the consumption of coal.

Known as the Jevons paradox or rebound effects.

The Jevons paradox is observed the ICT sector.

From 2007 to 2020, progress in both hardware and software increased by 5%.

From 2015 to 2020, GHG emissions of ICT increased by 5%.

https://ssrn.com/abstract=4424264
The Jevons paradox is observed in the ICT sector.

From 2007 to 2020:
- Progress in both hardware and software
- Energy efficiency increased
- Energy usage per subscriber increased

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https://ssrn.com/abstract=4424264
The Jevons paradox is observed in the ICT sector.

**From 2007 to 2020**
- Progress in both hardware and software
- Energy efficiency increased
- Energy usage per subscriber increased
- Jevons paradox on energy

**From 2015 to 2020**
- GHG emissions of ICT increased by 5%
- More devices are being sold
- Most consumers power devices using carbon-intense energy
- Jevons paradox on carbon

https://ssrn.com/abstract=4424264
As “we” keep asking for more, the energy use will keep rising.
But wait, what about networks?

Didn’t we say network power was inelastic anyway?

(I’m glad you asked)
1. Power increases marginally with utilization.

2. Average utilization is low in ISP networks.

3. Increasing utilization improves efficiency.
1. Power increases marginally with utilization.

2. Average utilization is low in ISP networks.

3. Increasing utilization improves efficiency.

4. Networks are intentionally kept over provisioned!
There is a feedback loop that stimulates network capacity increase

https://doi.org/10.1145/2858036.2858378
There is a feedback loop that stimulates network capacity increase and energy usage.

https://doi.org/10.1145/2858036.2858378

https://research-information.bris.ac.uk/en/publications/rethinking-allocation-in-high-baseload-systems-a-demand-proportio
We must embrace some digital sobriety.

Everything has a cost.

- Every picture we upload
- Every app we download
- Every movie we stream
- Every conversation we archive

It is not to say we must not do it but we must be mindful when doing it and do it only when actually useful.
We must embrace some digital sobriety.

Everything has a cost.

- Every picture we upload
- Every app we download
- Every movie we stream
- Every conversation we archive

It is not to say we must not do it but we must be mindful when doing it, and do it only when actually useful.

“We” also includes the private sector...

According to the World Economic Forum, companies generate 1.3 trillion gigabytes of dark data every day. Storing that data for a year using non-renewables generates as much CO2 as three million flights from London to New York.

28x10^9

In 2020, Google said it stored four trillion photos, with 28 billion new photos and videos uploaded each week.

On taking network power **down** to reduce the Internet footprint.

2. Avoid rebound effects by advocating for sobriety
   - Resist the drive to upgrade until you really need it
   - Question your digital “needs”
On taking network power down to reduce the Internet footprint.

Climate stripes. Ed Hawkins, 2018 portrays the increase of average global temperature.

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