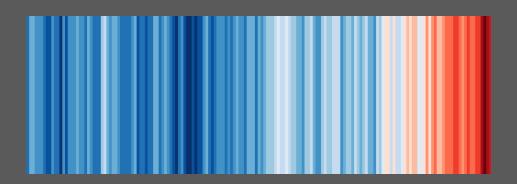
### On taking network power down



Laurent Vanbever

Romain Jacob

nsg.ee.ethz.ch

@ ET

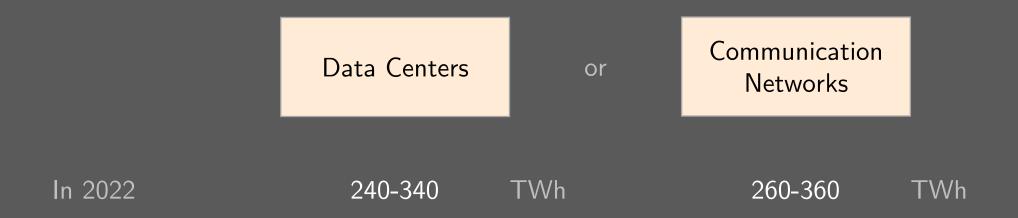
ETH Zürich

EFCL Mini-Conf.

Dec. 11, 2023

Data Centers

Communication Networks



	Data Centers	or	Communication Networks	
In 2022	240-340	TWh	260-360	TWh
111 2022	240-340	IVVII	200-300	1 VVII
In 2015	200	TWh	220	TWh
Change of	+20-70%	in energy	+18-64%	in energy

	Data Centers	or	Communication Networks	
In 2022	240-340	TWh	260-360	TWh
In 2015	200	TWh	220	TWh
Change of	+20-70%	in energy	+18-64%	in energy
	+340%	in workload	+600%	in traffic

https://www.iea.org/energy-system/buildings/data-centres-and-data-transmission-networks

#### Energy efficiency improved a lot

Data Centers

Communication Networks

Change in energy is much smaller than in work done.

+20-70%

in energy

+18-64%

in energy

+340%

in workload

+600%

in traffic

# Energy efficiency improved a lot but not enough!

Data Centers

Communication Networks

Change in energy is positive!

+20-70%

in energy

+18-64%

in energy

# "With great power comes great responsibility"

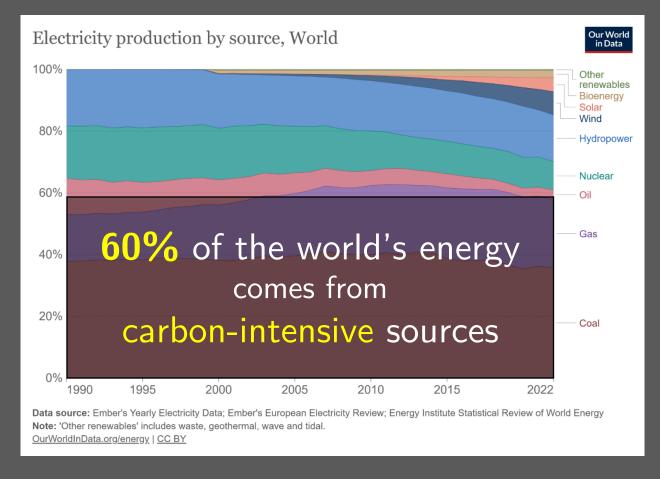
- It is easy to keep increasing network capacity
- It is much harder to keep increasing energy efficiency

# "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.

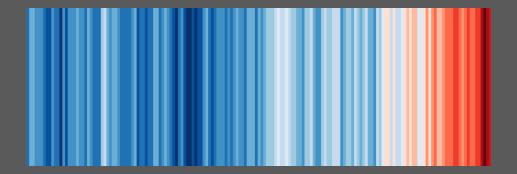
- It is easy to keep increasing network capacity
- It is much harder to keep increasing energy efficiency
- Total energy usage is likely to keep increasing.
- Producing energy emits carbon.



https://ourworldindata.org/grapher/electricity-prod-source-stacked

### On taking network power down

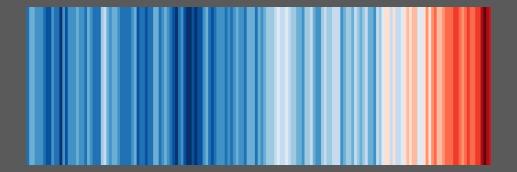
to reduce the Internet footprint.



- Reduce network power with better proportionality
- 2 Avoid rebound effects by avocating for sobriety

### On taking network power down

to **reduce** the Internet footprint.



Reduce network power with better proportionality

Avoid rebound effects by avocating for sobriety

Operational

Carbon efficiency =

J used

Task

J supplied

X

J used

Carbon

Χ

J supplied

... improves with better...

Networks & compute

Infrastructure & HW design

Carbon intensity

Operational

Carbon efficiency =

... improves with better...

J used

Task

Networks & compute

J supplied

J used

Infrastructure & HW design

Not *really* a network matter

Carbon

J supplied

Carbon intensity

Operational

Carbon efficiency

١.

,

,

J supplied

J used

Carbon

J supplied

... improves with better...

Networks & compute

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Infrastructure & HW design

Carbon intensity



Improves with better networks

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x J supplied

J used

Carbon

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Networks & compute

Infrastructure & HW design

Carbon intensity



Main focus of networking

Operational Carbon efficiency =

... improves with better...

J used
Task

X

Networks & compute

J supplied
J used

X

J supplied

Carbon

Infrastructure & HW design

Carbon intensity

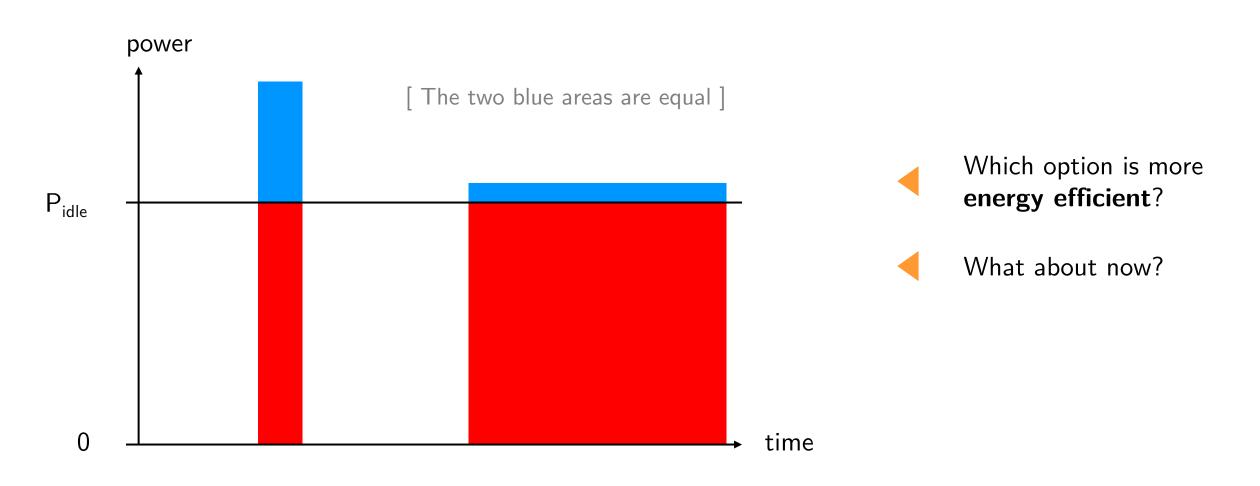


**Main focus** of networking

### Let's consider two energy usage profiles for the same task.



### Let's consider two energy usage profiles for the same task.



# Turning components off whenever possible is the fundamental way of saving energy.

aka "sleeping"

Sleeping is implemented in all consumer IT

Screens Laptops, phones

Radio duty-cyclingloT devices

DVFSCPUs

\_

### Sleeping is implemented in all consumer IT

Screens

Radio duty-cycling

DVFS

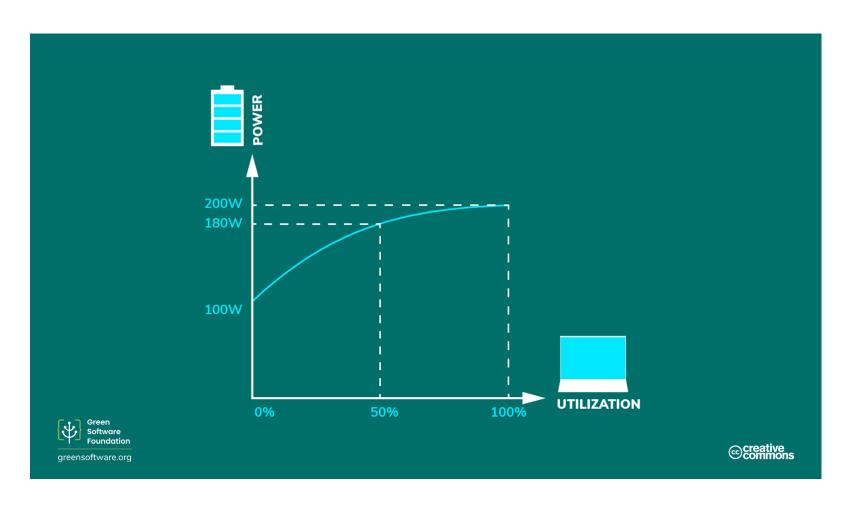
\_\_\_\_

Laptops, phones

IoT devices

CPUs

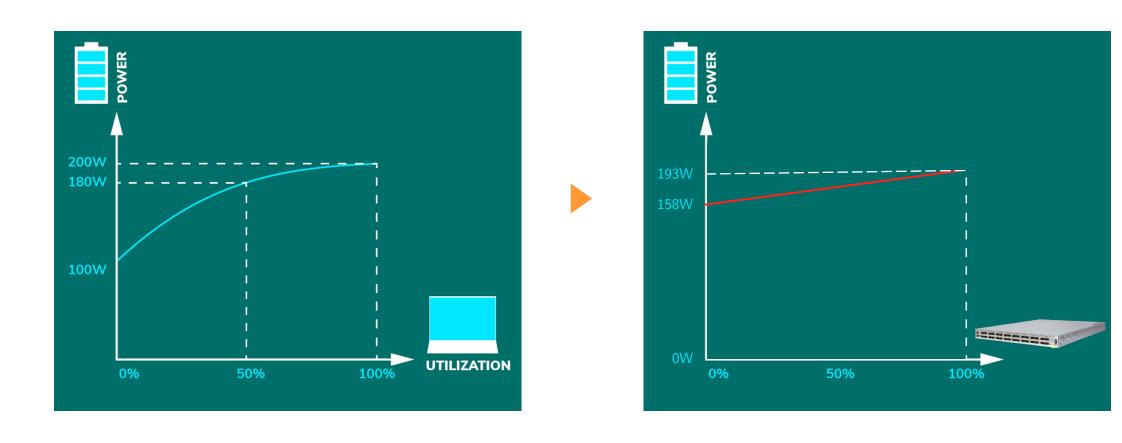
### What about network devices?



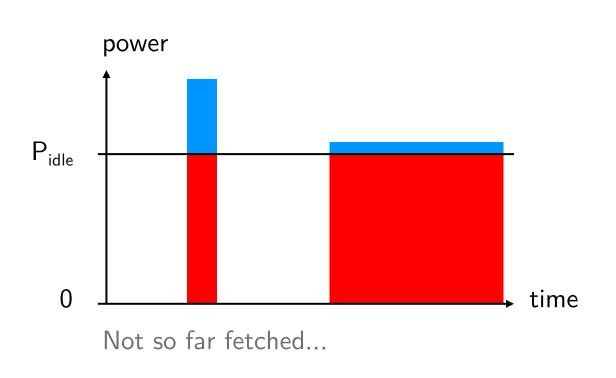
How does such a plot look like for a switch?

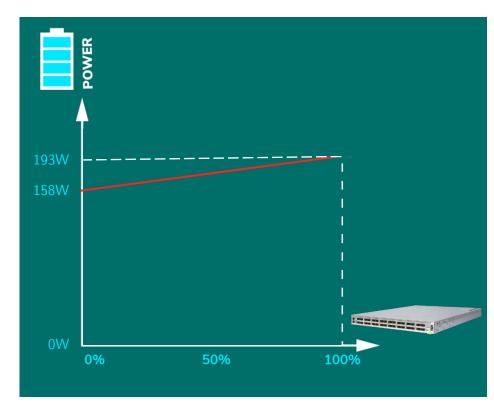
https://learn.greensoftware.foundation/

# The idle power dominates i.e., network power is inelastic.



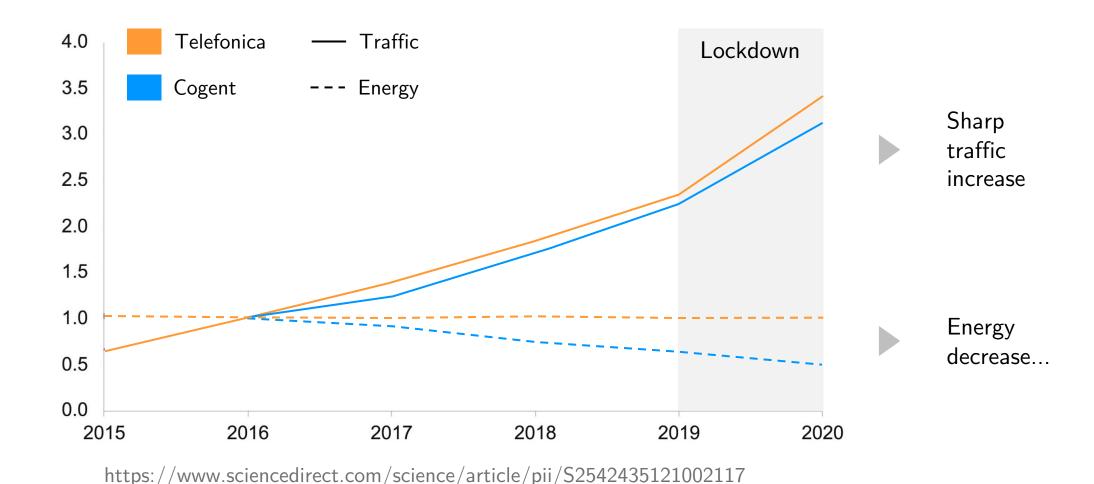
## The idle power dominates i.e., network power is inelastic.





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

#### Greening of the Internet

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#### ABSTRACT

In this paper we examine the somewhat controversial subject of energy consumption of networking devices in the Internet, motivated by data collected by the U.S. Department of Commerce. We discuss the impact on network protocols of saving energy by putting network interfaces and other router & switch components to sleep. Using sample packet traces, we first show that it is indeed reasonable to do this and then we discuss the changes that may need to be made to current Internet protocols to support a more aggressive strategy for sleeping. Since this is a position paper, we do not present results but rather suggest interesting directions for core networking research. The impact of saving energy is huge, particularly in the developing world where energy is a precious resource whose scarcity hinders widespread Internet deelowment.

#### Categories and Subject Descriptors

C.2.1 [Network Architecture & Measurement]: [Network Topology]; C.2.2 [Network Protocols]: [Routing Protocols]; C.2.6 [Internetworking]: [Routers, Standards]

#### **General Terms**

Algorithms, Measurement, Economics

#### Keywords

Energy, Internet, Protocols

#### 1. INTRODUCTION

Recently, an opinion has been expressed in various quarters (see [5, 12]) that the energy consumption of the Internet is "too high" and that since this energy consumption can only grow as the Internet expands, this is a cause for concern. One may disagree, as we do, with the qualitative statement that the energy consumption of the Internet is too high, because it is a small fraction of the overall energy

Device	Approximate	Total
	Number Deployed	AEC TW-h
Hubs	93.5 Million	1.6 TW-h
LAN Switch	95,000	3.2 TW-h
WAN Switch	50,000	0.15 TW-h
Router	3,257	1.1 TW-h

Table 1: Breakdown of energy draw of various networking devices (TW-h refers to Tera-Watt hours and AEC to Annual Electricity Consumption).

consumption. However, the absolute numbers do indicate a need to be more energy efficient. We use the analysis presented by these observers as a starting point to discuss an exciting new direction for future core networking research. We believe that if energy can be conserved by careful engineering then there is no reason why we should not do so as this has implications not only for reducing energy needs in the U.S. but also on speeding up Internet deployment and access in the developing world where energy is very scarce.

access in the developing world where energy is very scarce.

Table 1 [14] summarizes the energy consumption by Internet devices in the U.S. as of the year 2000. These values are copied from Tables 5-59 (Hub), 5-61 (LAN switch), 5-62 (WAN switch), and 5-64 (Router) of [14]. The data is broken up based on network device type, which is useful in analyzing where and how energy savings can be garnered. In order to arrive at the various energy numbers in the table, the authors took into account the percentage of different types of devices deployed (e.g., number of CISCO 2500 type routers, number of 7505s, etc) and then used the average energy consumption values of these devices to arrive at the final numbers shown in the table. Two energy values missing from the table are the energy cost of cooliny the equipment and that of UPS (Uninterruptable Power Supplies) equipment?

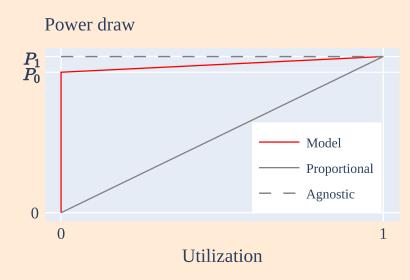
networking devices will increase by 1 TW-h by 2005 [14]. Expressed as a percentage of total U.S. energy expenditure in the year 2000, the energy drawn by the devices in Table 1 accounts for approximately 0.07% of the total. Given

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

2x and 24x more...

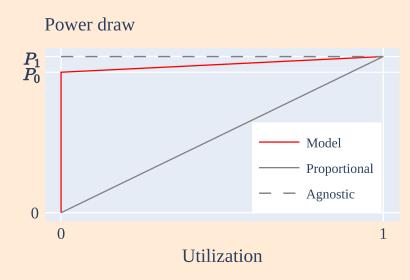
depending on your hypotheses

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



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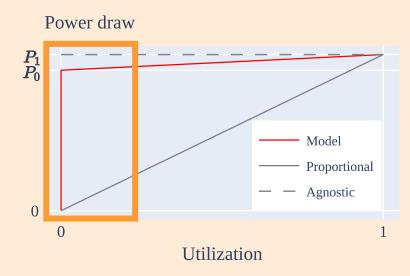
3 Network devices are under-utilized.



- Peak traffic
- Fault tolerance

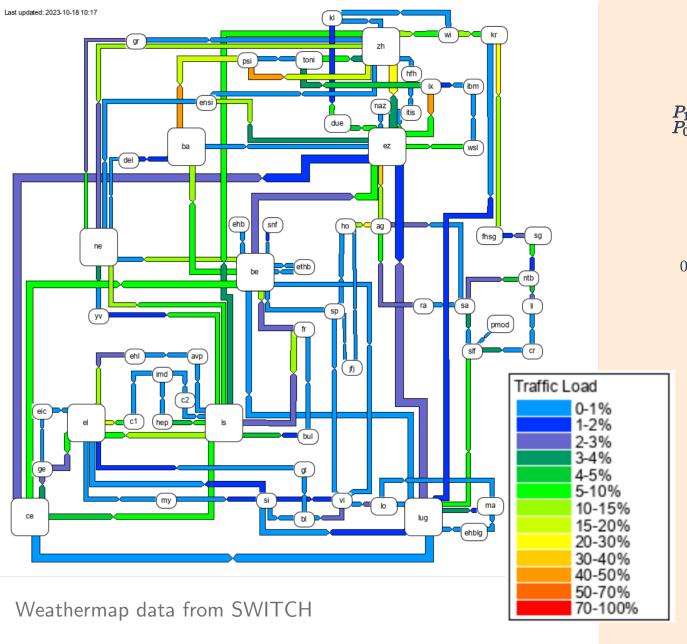
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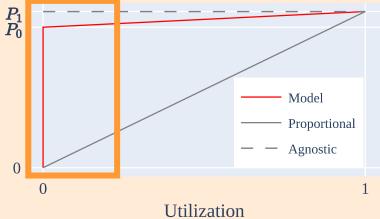




- Peak traffic
- Fault tolerance



#### Power draw





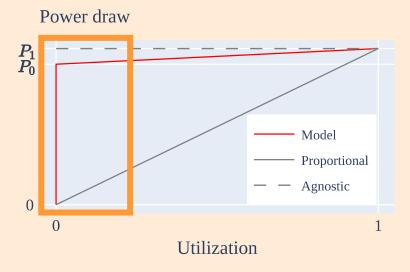
- Peak traffic
- Fault tolerance

#### Network utilization (%)



Date

#### OVH Weathermap dataset

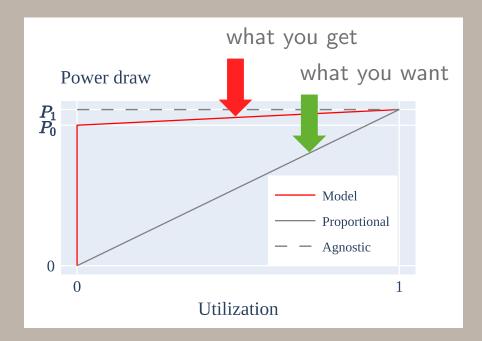




- Peak traffic
- Fault tolerance

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

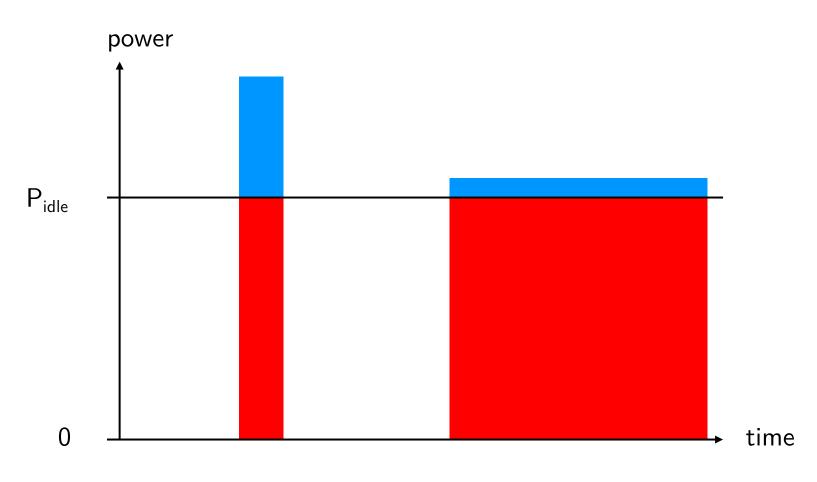
3 Network devices are under-utilized.





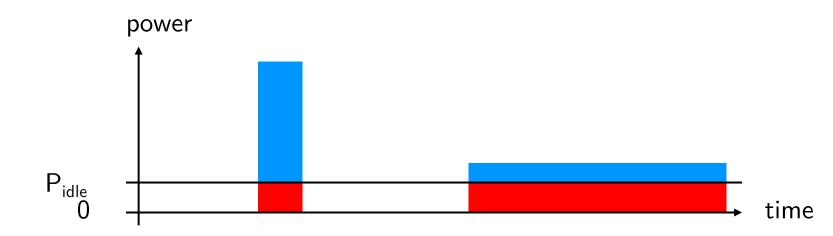
- Peak traffic
- Fault tolerance

## What does proportionality mean for our toy example?



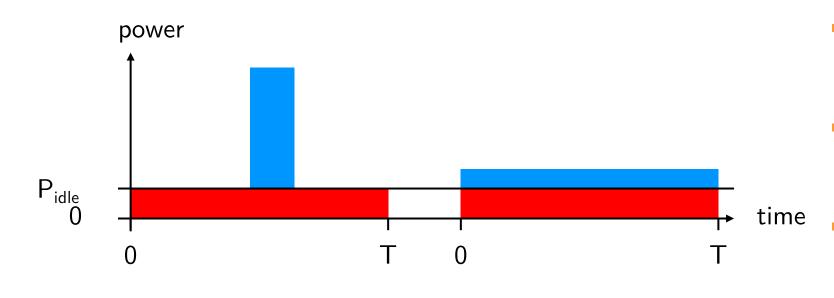
 As idle power dominates, low utilization wastes a lot.

## What does proportionality mean for our toy example?



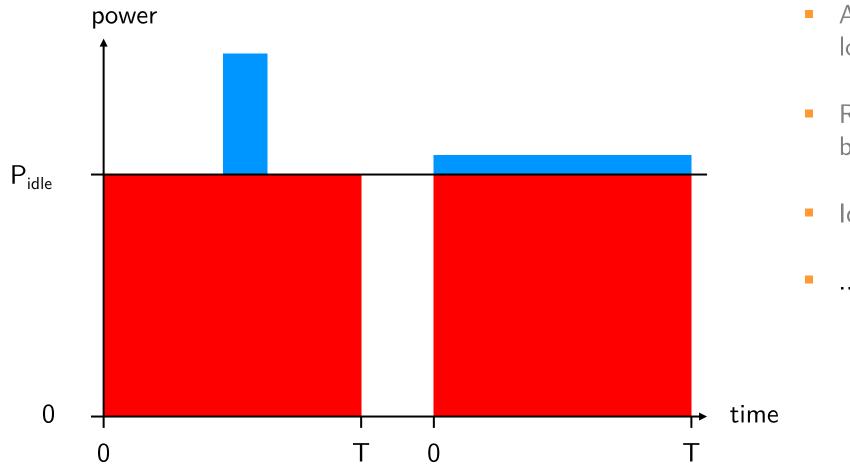
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- Reducing idle power yields better proportionality.

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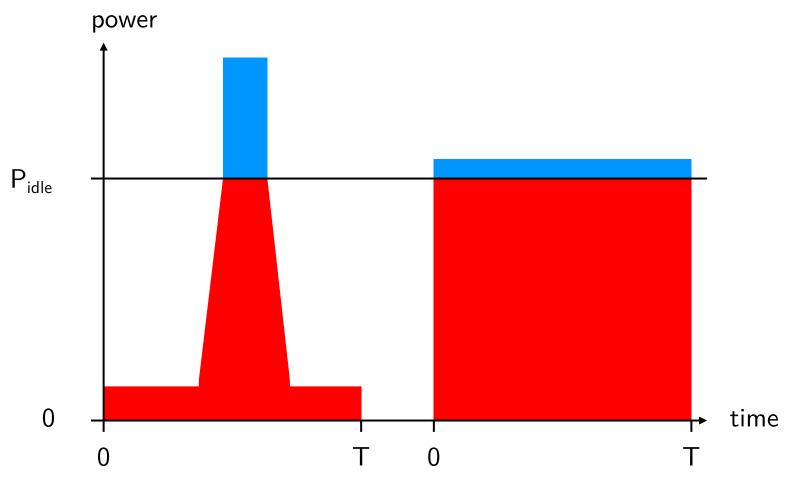
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# What does proportionality mean for our toy example?



- As idle power dominates, low utilization wastes a lot.
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- ... and it dominates.

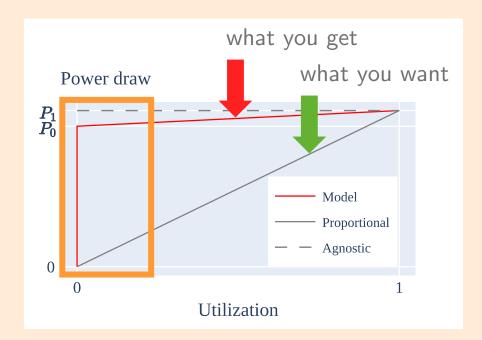
# What does proportionality mean for our toy example?

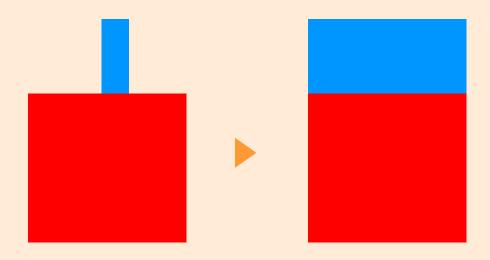


- As idle power dominates, low utilization wastes a lot.
- Reducing idle power yields better proportionality.
- Idle power is always there!
- ... and it dominates.
- Improving proportionality is essentially about taking the "average idle power" down.

# There two ways to improve energy efficiency.

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

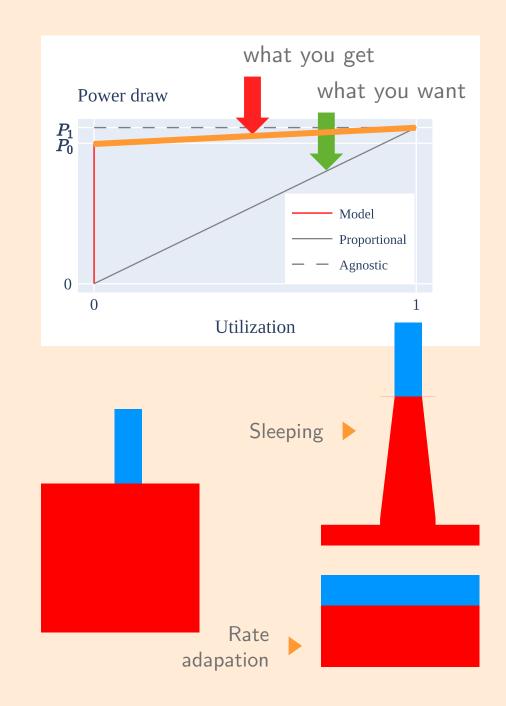




# There two ways to improve energy efficiency.

- 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...

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

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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.

Academia

NSDI 2008

Network operators

RIPE 2023

### **Reducing Network Energy Consumption** via Sleeping and Rate-Adaptation

Sergiu Nedevschi\*† Lucian Popa\*† Gianluca Iannaccone † David Wetherall<sup>‡§</sup> Sylvia Ratnasamy †

### 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 to sleep during idle times, reducing energy consumed in the absence of packets. The second is based on adapting the rate of network operation to the offered workload, reducing the energy consumed when due to two factors. First, networks are provisioned for actively processing packets.

For real-world traffic workloads and topologies and using power constants drawn from existing network equipment, we show that even simple schemes for sleeping or rate-adaptation can offer substantial savings. For instance, our practical algorithms stand to halve energy consumption for lightly utilized networks (10-20%). We show that these savings approach the maximum achievable by any algorithms using the same power management primitives. Moreover this energy can be saved without noticeably increasing loss and with a small and controlled increase in latency (<10ms). Finally, we show that both sleeping and rate adaptation are valuable depending (primarily) on the power profile of network equipment and 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 power-hungry 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[23]. Various studies now estimate the power usage of the US network infrastructure at between 5 and 24 TWh/year[25, 26], or \$0.5-2.4B/year at a rate of \$0.10/KWh, depending on what is included. Public

via standards such as EnergyStar. In fact, EnergyStar standard proposals for 2009 discuss slower operation of network links to conserve energy when idle. A new IEEE 802.3az Task Force was launched in early 2007 to focus on this issue for Ethernet [15].

Fortunately, there is an opportunity for substantial reductions in the energy consumption of existing networks worst-case or busy-hour load, and this load typically exceeds their long-term utilization by a wide margin. For example, measurements reveal backbone utilizations under 30% [16] and up to hour-long idle times at 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 will require two steps. First, network equipment ranging from routers to switches and NICs will need 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) reduce idle consumption by powering off sub-components to different extents, while the latter (e.g., SpeedStep, P-states in Intel processors) tradeoff performance for power via operating frequency. Second, network protocols will need to make use of the hardware primitives to best effect. Again, by analogy with computers, power management preferences control how the system switches between the available states to save energy with minimal impact on users.

Of these two steps, our focus is on the network protocols. Admittedly, these protocols build on hardware support for power management that is in its infancy for networking equipment. Yet the necessary support

### Techniques to reduce network power consumption

Peter Ehiwe, May 2023 @RIPE86

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

### Academia

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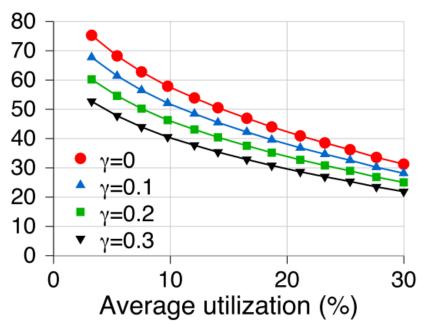
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### Energy Savings (%)



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

### Academia

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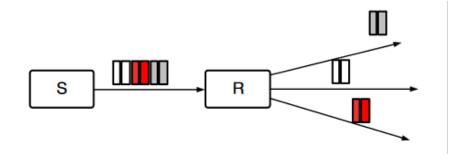
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Buffer-and-Burst



### Assuming

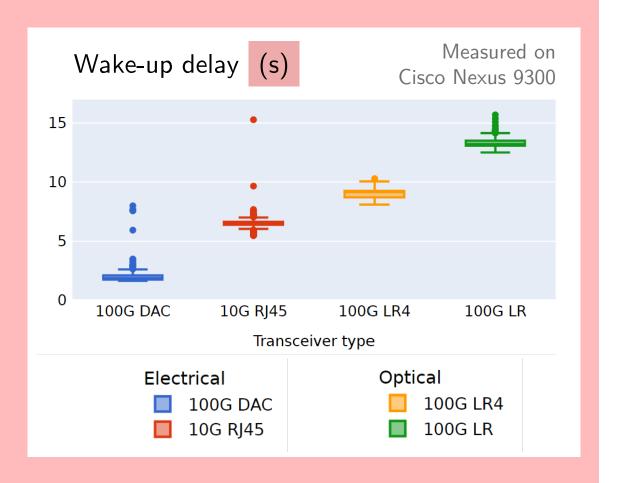
Wake-up delay

Buffering time

10*ms* 

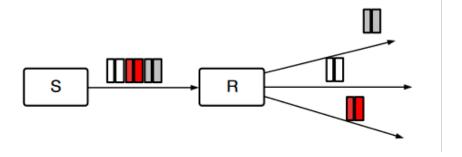
1ms

### Practice



### Theory

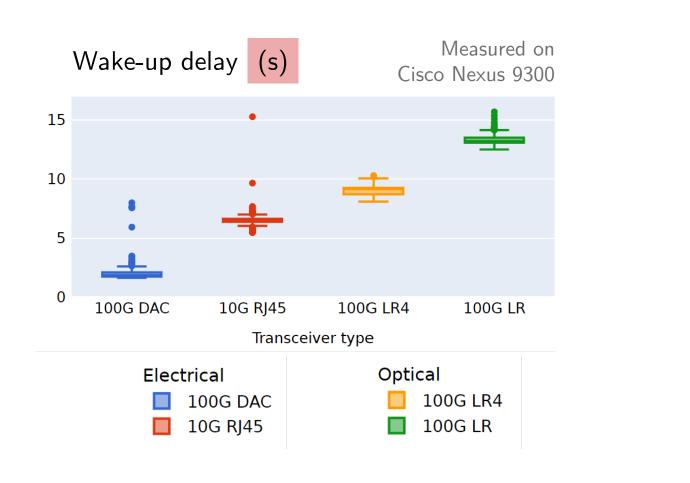
How? Buffer-and-Burst

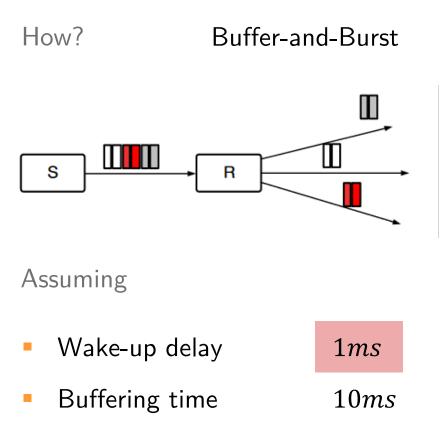


### Assuming

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

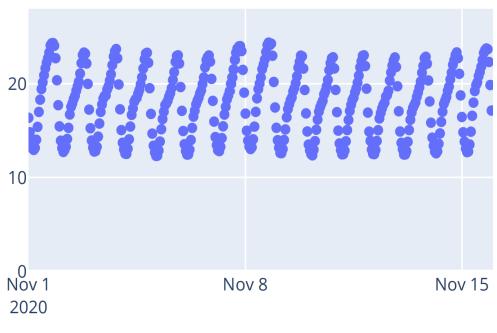
# In practice, transcievers are 1000x slower to start than required for savings via buffering.





# We can still "sleep" at longer timescales.

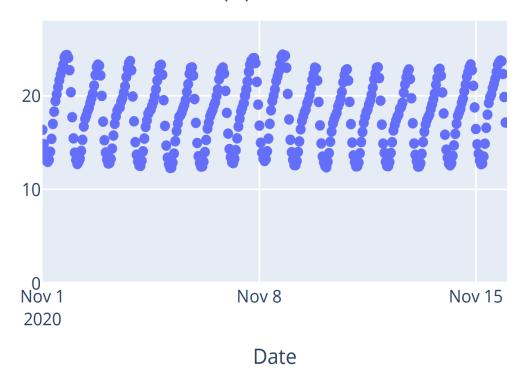
### Network utilization (%)



Date

## We can still "sleep" at longer timescales.

Network utilization (%)



It can be formulated as a usual network optimization problem

with unusual constraints.

# We can still "sleep" at longer timescales.

### Network utilization (%)



Date

### What keeps your network up at night?



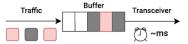
Lukas Röllin, Romain Jacob, Laurent Vanbever



### Theory

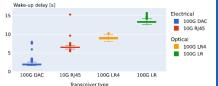
Save energy with sleeping and buffering

Assumption: Transceiver ready within milliseconds



[NSDI '08]: Buffer traffic while transceivers wake up

### Practice Transceiver wake-up takes seconds! Wake-up delay [s]

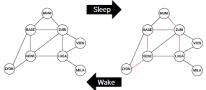


### Contribution

Turning links off still works when considering longer timeframes



The controller turns off non-essential links



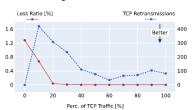
Nodes wake up the network if the load is too high



No disruption to the network

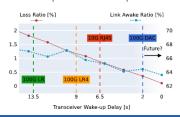
### Result

TCP limits the impact of congestion if traffic changes too fast



### Future

Faster wake-up boosts energy savings and reduces performance impact



# How much energy can we really save?

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

Academia

### via Sleeping and Rate-Adaptation

Sergiu Nedevschi\* Lucian Popu\* Gianluca Iannacco

### Abstract

Abstract
We present the design and evaluation of two forms of
power management schemes that noduce the energy consumption of networks. The first is based on patting, network components to sleep during left eitnes, roducing netweet commend in the abstract of parkets. The second is based on adapting the rate of network operation to the offered workshot, reducing the energy consumed when

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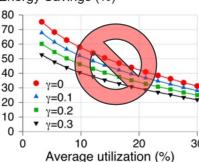
### 1 Introduc

In this paper, we consider power management is networks from a preparative that has recordly long expensing and environmental reasons. Fronzy consumpsion in network exchanges is using a higher capacition in network exchanges is using a higher capacitories of expenses becomes now prove-bunger ansing energy care, this has made here out of powerin entire greater amounts of cooling. Continuous with entire properties of the contraction of the consistence of the contraction of the concinence (21). Visions under now contain the powsuage of the US network information at heteroesuage of the US network information at heteroesned 24 Philyslephil. No. of the 35-45-45per at a rat via standards such as EnergyStar. In fact, EnergyStar standard proposals for 2009 discuss slower operation of network links to conserve energy when idle. A new IEEE 802-3as Task Force was launched in early 2000 to focus on this issue for Elbernet [15].

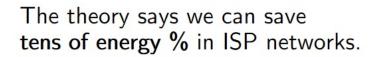
Fortunately, there is an opportunity for substantial obstitutes in the energy communities of uniting network dute to two factors. First, networks are provisioned to describe the state of the factor of the state of

neverte energy consumption ingite be related with absolutely alletting energy between Ern Ser. In the Control of the Control of the Control of the Control flow of the Control of the Control of the Control of the Born source is written and NNC will and power ran there are no studied and the Control of the superior of the Control of the superior of the Control of the Control of the Con

### Energy Savings (%)



# How much energy can we really save?



Academia

### Reducing Network Energy Consumptio

Sergiu Nedevschi\*! Lucian Popa\*! Gianluca Iannace

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### 1 Introduct

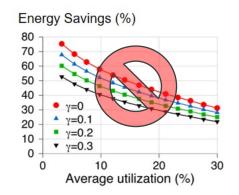
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Formanuly, there is an exponentiary for substantial a duction is the courge consumption of exasting network ductions in the courge consumption of exasting network control of the course of the course

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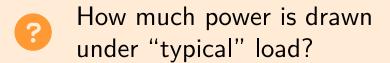
### Hard to say because we lack

- 1 Measurements
- 2 Test cases

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



- Datasheets only talk about the max power
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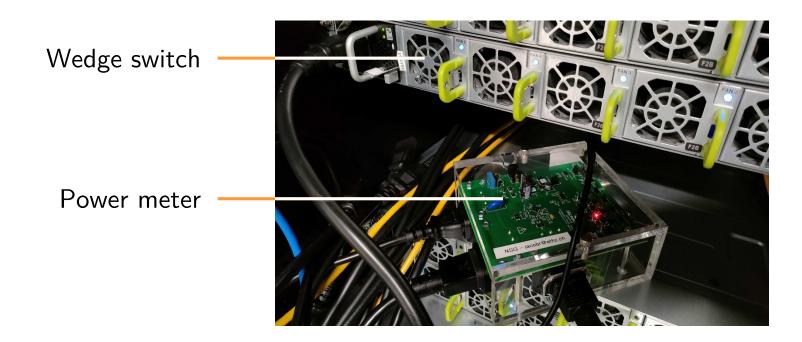




... so we are building our own ...

Profiling a Tofino switch

WEDGE 100BF-32X



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

```
Device power = Static power f(device config)

+ Energy per bit * bit rate

+ Energy per packet * packet rate

+ Fan power ~ f(temperature)

+ Power conversion losses f(power demand)
```

## We work with standardization bodies to define a benchmark for network power.

Benchmarking Methodology Working Group

Internet-Draft

Intended status: Informational
Expires: September 13, 2013

V. Manral

P. Sharma

S. Banerjee

H

Y. Ping

H3C

March 12, 2013

### Benchmarking Power usage of networking devices draft-manral-bmwg-power-usage-04

### 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 begining 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.

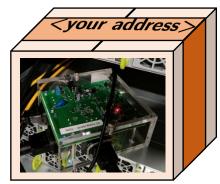
Academics have limited access to devices used in the field.

Can we measure yours?

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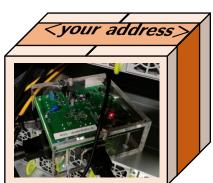
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- ? Can we measure yours?
- We sent you hardware
- You plug it in
- Everyone gets data!



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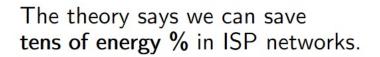


### Vision

### RIPE Atlas for Power Data



# How much energy can we really save?



Academia

### Reducing Network Energy Consumption

Sergiu Nedevschi\* Lucian Popa\* Gianluca Iannace

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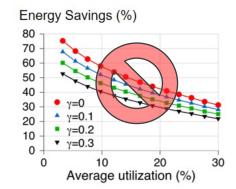
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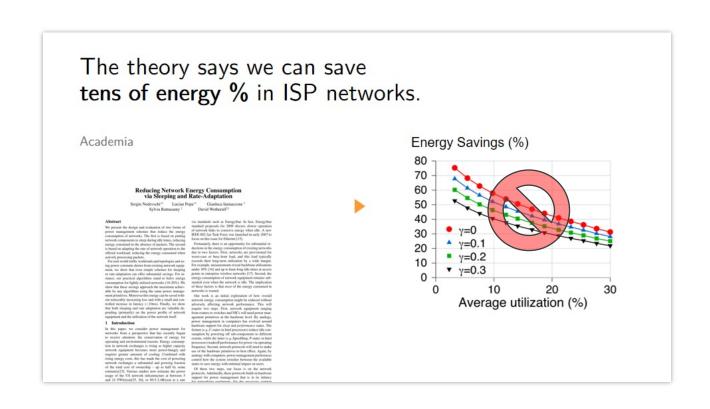
Our work is an initial exploration of how contiment, any consequent may be related with a neutral energy consequent may be related with a special reason of super-lated and the super-lated and positive reason of the super-lated and the superpositive may be related as the super-lated and positive and the super-lated and performance state. In a superilate super-lated and performance state. In a surgical by powring of sub-compounts in differentions, which the latest performance is all the surgical by powring of sub-compounts in differentions, which the latest performance is different to the surgical by powring of sub-compounts in differentions, because the surgical super-latest surgical to surgical by powring of sub-compounts in different surgical by powring of sub-compounts and formation. It surgically the surgical surgic



### Hard to say because we lack

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## Energy savings are hard to estimate because they **depend on the network**.

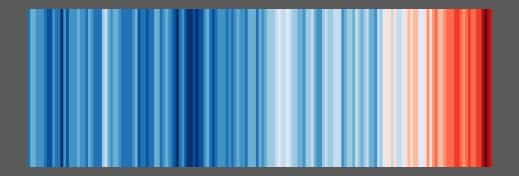


- Anything can happen in simulation.
- We need real traffic dynamics to accuratly assess the impact of sleeping.

? Can we get yours?

### On taking network power down

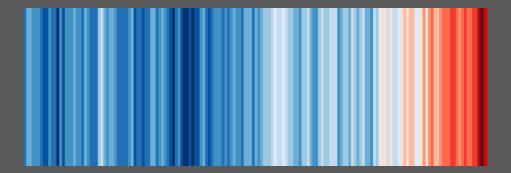
to **reduce** the Internet footprint.



- 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

Avoid rebound effects by avocating for sobriety



Engraving by <u>Edward Goodall</u> (1795-1870), original title *Manchester, from Kersal Moor* after a painting of W. Wylde

Coal-burning factories in 19th-century Manchester, England.

Improved technology allowed coal to fuel the Industrial Revolution.

This greatly increased the consumption of coal.

# Improving efficiency of a resource usage may result in increased consumption of that resource.



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Coal-burning factories in 19th-century Manchester, England.

Improved technology allowed coal to fuel the Industrial Revolution.

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Known as the Jevons paradox or rebound effects

https://en.wikipedia.org/wiki/Jevons\_paradox

### The Jevons paradox is observed the ICT sector.

From 2007 Progress in both to 2020 hardware and software

From 2015 GHG emissions of ICT

to 2020 increased by 5%

### The Jevons paradox is observed the ICT sector.

From 2007 Progress in both to 2020 hardware and software

- Energy efficiency increased
- Energy usage per subscriber increased
  - Jevons paradox on energy

From 2015 GHG emissions of ICT

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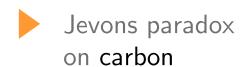
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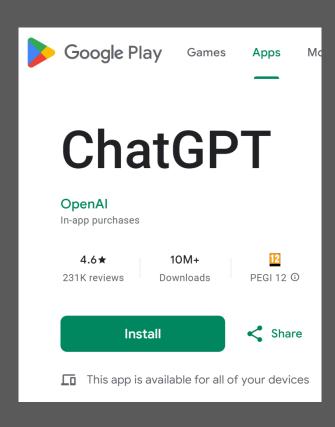
- More devices are being sold
- Most consumers power devices using carbon-intense energy.



https://ssrn.com/abstract=4424264

# As "we" keep asking for more, the energy use will keep rising.



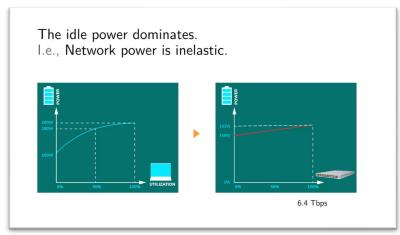




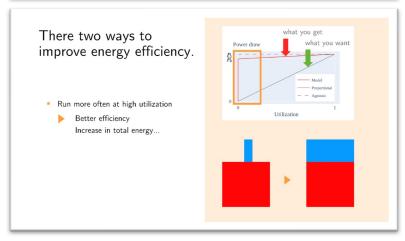
But wait, what about networks?

Didn't we say network power was inelastic anyway?

(I'm glad you asked)



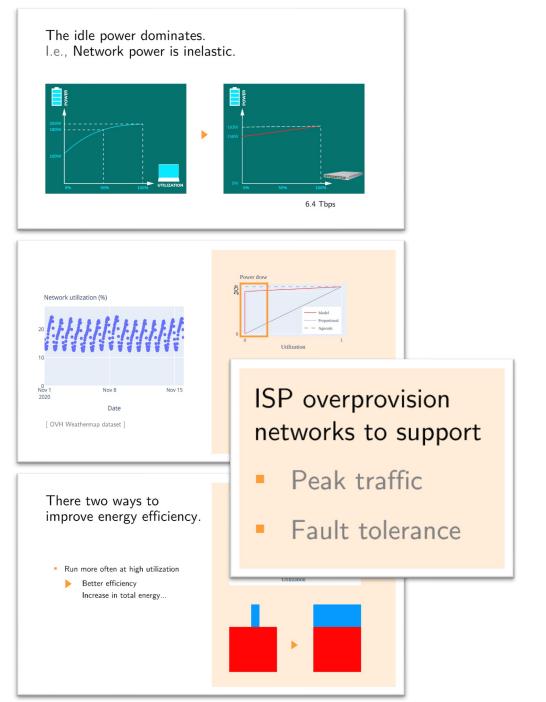




1. Power increases marginally with utilization.

2. Average utilization is low in ISP networks.

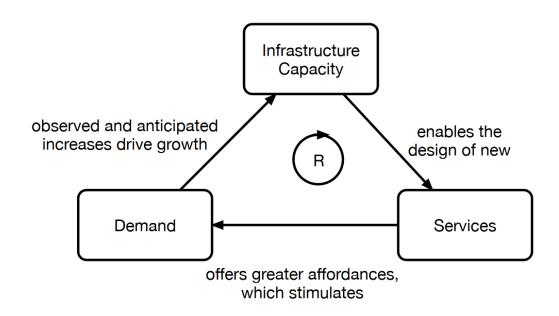
Increasing utilization improves efficiency.



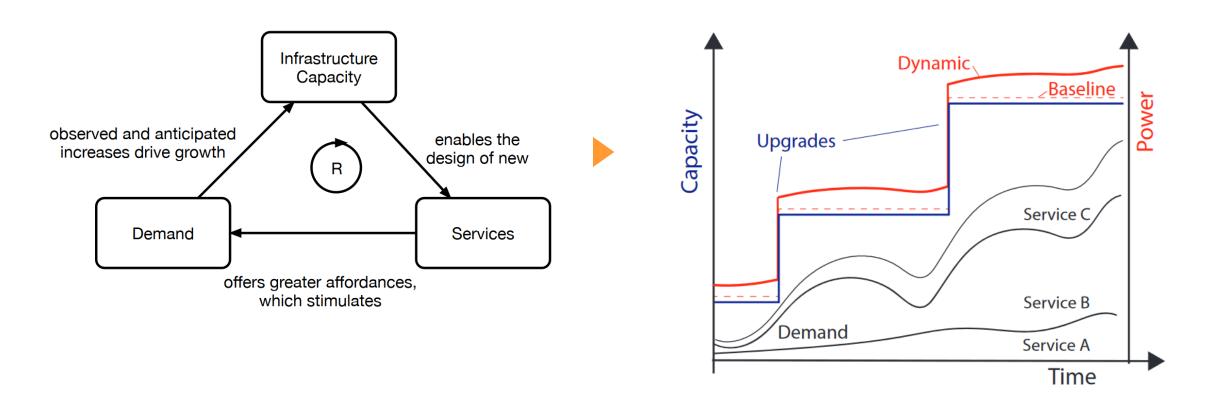
1. Power increases marginally with utilization.

- 2. Average utilization is low in ISP networks.
- 4. Networks are intentionally kept overprovisioned!
- 3. Increasing utilization improves efficiency.

# There is a feedback loop that stimulates network capacity increase



# There is a feedback loop that stimulates network capacity increase and energy usage.



# 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.

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# "We" also includes the private sector...

1.3 million PB

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.

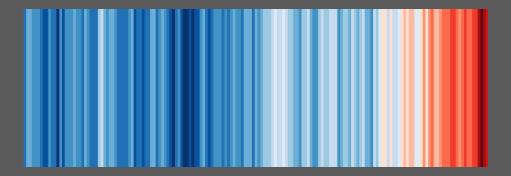
 $28 \times 10^9$ 

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

https://www.datacenterdynamics.com/en/opinions/the-elephant-in-the-data-center-shedding-light-on-dark-data/

### On taking network power down

to **reduce** the Internet footprint.



- Avoid rebound effects by avocating for sobriety
  - Resist the drive to upgrade until you really need it
  - Question your digital "needs"

### On taking network power down

1850

Climate stripes.

Ed Hawkins, 2018

portrays the increase of average global temperature

to **reduce** the Internet footprint.

Laurent Vanbever

Romain Jacob

lvanbever@ethz.ch

jacobr@ethz.ch

EFCL Mini-Conf.

Dec. 11, 2023