Managing the Growing Energy Cost of the Internet

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Energy and the Internet

Why is Energy Important?

- Operational Expenditure
- Greenhouse Impact
- Energy-limited capacity bottlenecks ("hot spots")
- Enabling energy efficiencies in other sectors
Estimated power consumption of Internet

Power Consumption (W)

Global electricity supply 3% p.a. growth

Power Consumption of Internet

0% p.a. Improvement in technology

15% p.a. Improvement in technology

40% p.a. Data growth

10% p.a. Growth in user numbers

2010 2015 2020

1.5 billion users

Year

Tucker et al., OFC 2013
Internet and home appliances

Electricity consumption (TWh/a)

Baseline 2011

ICT products - home: 124
ICT products - offices: 17
Data Centres: 52
Landline networks: 10
Mobile networks: 10

Forecast 2020

ICT products - home: 123
ICT products - offices: 16
Data Centres: 70
Landline networks: 19
Mobile networks: 31

Power/Energy Consumption Metrics

- Total power
- Power consumption per “throughput”
  - Energy per bit (power per bit rate)
- Power consumption per “good put”
  - Energy per customer bit
- etc

Some trends....
Inside the Internet

Core Network
- Core Routers
- Fibre

Hot spots

Optical Transport Network

Metro/Edge Network
- Edge Routers
- Broadband Network Gateways
- Ethernet Switch

Data Center
- Server
- Storage

Access Network
- DSLAM
- OLT
- PON
- Splitter
- Cabinet
- DSLAM Cu
- FTTP
- DSL
- Fibre
- FTTN
- Cu
Trends in Transport Energy Consumption

![Graph showing trends in transport energy consumption over time. The graph includes data points for various trans-Atlantic and terrestrial systems, with a trend line indicating a ~15% improvement per annum. Key West - Havana, Newhaven - Azores, NY - Paris, TAT-1, TAT-3, TAT-5, TAT-8, TAT-9, TAT-10, TAT-11, TAT-12/13.]
Trends in Router Energy Consumption

Sources: Nielsen, Cisco
Power Consumption of Single-Rack Routers

Sources:
METI, 2006, Nordman, 2007
Cisco CRS-X and Juniper T4000 Data Sheets, 2014
G. Epps, Cisco, 2014
"Burden factor" = 1.1 to 2.0 associated with cooling, conversion/distribution and lighting

Sources: EYP Mission Critical Facilities, Cisco IT, Network World, Customer Interviews, APC
Data Centers

- Processing
- Networking
- Storage

Load-Balancing Switches

Aggregation Switches

Racktop Switches

Racks of Servers

Border Routers

75% of traffic stays in data center

8% of traffic to other data centers

17% of traffic to users

Source: Cisco Global Cloud Index: Forecast & Methodology. 2013 - 2018
## Power Consumption of Storage

<table>
<thead>
<tr>
<th>Tier</th>
<th>2013</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average Energy Efficiency (W/TB)</td>
<td>Average Energy Efficiency (W/TB)</td>
</tr>
<tr>
<td>Solid State Disk</td>
<td>3.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Hi-performance Hard Disk Drive</td>
<td>15.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Capacity HDD</td>
<td>12.8</td>
<td>2.7</td>
</tr>
<tr>
<td>Massive Array of Idle Disks HDD</td>
<td>3.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Removable (tape/optical disk)</td>
<td>0.1</td>
<td>0.01</td>
</tr>
</tbody>
</table>

*Source: Horman & Campbell 2014*
Cost of HDD Storage

Hard drive cost per Gigabyte (USD)

Source: http://www.mkomo.com/cost-per-gigabyte-update
(Matt Komorowski 9-Mar-2014)
Access Network Energy Consumption

Power Per User (W)

Peak Access Rate (Mb/s)

- Wireless
- FTTN
- HFC
- FTTP (PON)

PON is “greenest”

Source: Baliga et al., OFC 2009
Putting it All Together
Network Energy per User Bit

Tucker et al., OFC 2013

Energy per User bit (µJ)

2010 2015 2020

Year

FTTP Access

Core and Metro Switches/Routers

Optical Transport

Total
Gap Between Theory and Practice

Tucker, JSTQE 2011

Network Energy per Bit (J)

Current Trends

Access

Routers and Switches

Transport

Switches

Lower Bounds

Global Network

Year

2010 2015 2020 2025

x 10^4
Gap Between Theory and Practice

Protocols, DSP, device efficiency, interconnects, system margins and penalties, etc.

\[ P_{\text{Total}} \]

\[ P_{\text{overhead}} \]

\[ P_{\text{function}} \]

Inefficiency

Function

Overhead

Subsystem

Management and power overheads, interconnects, etc.
Gap Between Theory and Practice
Diurnal Traffic Variations

Italy

Network Traffic

North America

Equipment power consumption vs. Traffic (b/s)

Real

Ideal

Diurnal Traffic Variations in Italy and North America

Network Traffic variations are shown for Italy and North America, with different patterns for each region.

North America shows higher traffic variation compared to Italy.

The equipment power consumption is plotted against traffic (b/s) with a comparison between ideal and real consumption patterns.
Photo Sharing on the Cloud

• Stunning growth of Facebook traffic:
  – 240+ billion photos
  – 350+ million photos added per day
  – 750+ million photos were uploaded over New Year’s Eve
  – 7000+ Tera-Byte memory added per month

• Facebook reports its annual data center energy consumption
Facebook Ecosystem

- “Hot” & “Warm” photos are distributed by a Content Delivery Network
- Cold Photos are distributed directly from data centres
Photo Sharing Energy

- Facebook 2012 total data centre IT energy: 516 GWh (Source: Facebook)
- Total network energy consumption: 304 GWh (Jalali et al., 2014)
- Photo sharing network energy $\sim 60\%$ of FB total data centre IT energy
  - Wireless (4G/LTE) access network is main energy consumer
- Energy per photo: $\sim 10$ Wh per year (1 mW average continuous)

![Annual upload energy](image1)

- Upload energy consumption (GWh)
  - Access 10.5
  - Metro/Core 0.06
  - User devices 2.00

![Annual download energy](image2)

- Download energy consumption (GWh)
  - Access 174.00
  - Metro/Core 1.1
  - Edge servers 14.1
  - User devices 103.00
Improving network energy efficiency

• Plenty of scope for improvement
• Some approaches
  – New technologies and Moore’s law
  – Low-energy circuit design
  – Improved network architectures
  – Improved data protocols
Optimization of Video on Demand

Key Issue:
Trade off between energy for storage and energy for delivery

Each movie is replicated on R servers

Direct optical link to edge router

Core Network

Metro/Edge Network

Access Network

Distant IPTV Server

“Local” IPTV Server

Server

Storage
Delivery of Streaming IPTV

Baliga et al., OFC, 2009
Delivery of Streaming IPTV

Baliga et al., OFC, 2009
Data by Mail vs. Data by the Internet

Data by Mail:
- Melbourne
- 10^6 128-GB micro SD cards
- 2x10^4 Kg CO_2 (24 hours)
- Cargo Jet

Data by Internet:
- 1.3x10^8 GB
- 1000 Gb/s for 10^6 seconds
- The Internet
- 10 µJ/bit
- 2x10^6 Kg CO_2 (1 month)

Sydney
Energy Efficiency and “Rebound”

“Jevon’s paradox” (Rebound effect)

– Improving efficiency will stimulate economic activity & increase power consumption
GeSI: SMARTer 2020 Report

ICT can contribute to global abatement of emissions

Source: GeSI “Smarter 2020”, 2012
Travel Replacement by Video Conferencing

Air Travel

~500 kg/person return

Melbourne

Video Conferencing

2 X 1 Gb/s for 6 hours = 3 TB

~15 kg/person

Business Meeting

Sydney
Rod’s Telecommute Calculator

- Tele-work
- Business Meeting in Canberra
- Bicycle
- Telecommute
- Train
- Car
- Plane

Distance travelled (km)

Bitrate-Time Product

Mb/s-hr

Gb/s-hr
Conclusions

• Energy consumption of the network is growing

• Access network energy dominates
  – Core and metro networking to overtake access in ~2020
  – Optical transport is relatively “green”
  – Beware “the cloud”

• Many opportunities for improving network energy efficiency
  – Technologies and circuits
  – Architectures
  – Protocols
  – And more.......
## Embodied Energy

<table>
<thead>
<tr>
<th>Equipment class</th>
<th>Typical lifetime</th>
<th>Lifetime cycle stage ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Operation</td>
</tr>
<tr>
<td>Router – small chassis/blade (2 slots)</td>
<td></td>
<td>85%</td>
</tr>
<tr>
<td>Router – medium chassis/blade (3 – 6 slots)</td>
<td></td>
<td>85%</td>
</tr>
<tr>
<td>Router – large chassis/blade (9 + slots)</td>
<td>10 years</td>
<td>95%</td>
</tr>
<tr>
<td>Router – core</td>
<td></td>
<td>90%</td>
</tr>
<tr>
<td>Switch – small chassis/blade (2 slots)</td>
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<td>15 years</td>
<td>95%</td>
</tr>
<tr>
<td>Switch – enterprise</td>
<td></td>
<td>90%</td>
</tr>
</tbody>
</table>