Energy Efficiency in Cloud Computing and Optical Networking

Rod Tucker, Kerry Hinton, Rob Ayre

Centre for Energy-Efficient Telecommunications
University of Melbourne
Outline

• Introduction and overview of energy consumption and efficiency in communications networks

• Estimating energy consumption in ICT equipment
  – Telecommunications
  – The “cloud”

• Improving network energy efficiency
  – Technologies
  – Architectures
  – Protocols
  – The cloud
World’s technology capacity

Source: M. Hilbert, P. Lopez, Science, 2011
Internet traffic growth trends

Source: Kilper et al., JSTQE 2011
Projections of data centre traffic

Source: Cisco Cloud Index 2011
Power consumption of the global Internet

- 2010: 1.5 billion users, Power Consumption of Internet (Including servers) ~ $10^{10}$ W
- 2015: 20% p.a. Growth in user numbers, Power Consumption of Internet (Including servers) ~ $10^{11}$ W
- 2020: 40% p.a. Data growth, Power Consumption of Internet (Including servers) ~ $10^{12}$ W

- Global electricity supply, 3% p.a. growth
- 0% p.a. efficiency gains
- 15% p.a. efficiency gains
- 40% p.a. Data growth
- 10% p.a. Growth in user numbers
Why does energy matter?

• If nothing is done to address the growing “efficiency gap”:
  – ICT will consume ever larger proportion of global energy
  – Energy consumption could become a barrier to network growth

• Economic and engineering imperatives:
  – Energy is a growing component of OPEX
  – Increased energy consumption → increased footprint
Estimating ICT power consumption

• Inventory based estimates
  – Look at what is out there
    • Use sales and deployment data from vendors and surveys
    • Accessing accurate data is problematic

• Network design and dimensioning based estimates
  – Design a network that will satisfy current and projected demands
    • Use typical network design rules
    • Difficult to include network inefficiencies, overlays & legacies

• Transaction based estimates
  – Look at services required and design a network to provide them
    • Similar to network design approach
## Summary of estimates

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>% national electricity use</th>
<th>Country</th>
<th>PC’s, office equip. &amp; servers</th>
<th>Wireless access</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Huber</td>
<td>1999</td>
<td>13%</td>
<td>USA</td>
<td>Yes</td>
<td>No</td>
<td>Severe over estimate</td>
</tr>
<tr>
<td>Koomey</td>
<td>1999</td>
<td>2%</td>
<td>USA</td>
<td>Yes</td>
<td>No</td>
<td>Users &amp; equipment estimate</td>
</tr>
<tr>
<td>Kawatomo</td>
<td>2001</td>
<td>3%</td>
<td>USA</td>
<td>Yes</td>
<td>No</td>
<td>Users &amp; equipment estimate</td>
</tr>
<tr>
<td>Turk</td>
<td>2001</td>
<td>0.5 - 1.7%</td>
<td>Germany</td>
<td>Yes</td>
<td>No</td>
<td>Users &amp; equipment estimate</td>
</tr>
<tr>
<td>Barthel</td>
<td>2001</td>
<td>0.9 – 1.5%</td>
<td>Germany</td>
<td>Yes</td>
<td>Yes</td>
<td>Users &amp; equipment estimate</td>
</tr>
<tr>
<td>Roth</td>
<td>2002</td>
<td>&lt; 2.3%</td>
<td>USA</td>
<td>Yes</td>
<td>Yes</td>
<td>Users &amp; equipment estimate</td>
</tr>
<tr>
<td>Cremer</td>
<td>2003</td>
<td>7.1%</td>
<td>Germany</td>
<td>Yes</td>
<td>Yes</td>
<td>Users &amp; equipment estimate</td>
</tr>
<tr>
<td>Baliga</td>
<td>2007</td>
<td>0.5%</td>
<td>OECD</td>
<td>No</td>
<td>No</td>
<td>Network design &amp; dimensioning</td>
</tr>
<tr>
<td>Vereecken</td>
<td>2010</td>
<td>Not given</td>
<td>Not given</td>
<td>No</td>
<td>No</td>
<td>Network design &amp; dimensioning</td>
</tr>
<tr>
<td>Lange</td>
<td>2010</td>
<td>Not given</td>
<td>Not given</td>
<td>No</td>
<td>Yes</td>
<td>Network design &amp; dimensioning</td>
</tr>
<tr>
<td>Kilper</td>
<td>2011</td>
<td>Not given</td>
<td>USA</td>
<td>No</td>
<td>Yes</td>
<td>Transaction</td>
</tr>
<tr>
<td>Pickavet</td>
<td>2007</td>
<td>Not given</td>
<td>Global</td>
<td>Yes</td>
<td>Yes</td>
<td>Users and equipment estimate</td>
</tr>
</tbody>
</table>
Design and dimensioning approach

1. Split network into
   - Access
   - Metro/Edge
   - Core
   - Data centres, content storage

2. Model with representative architecture and equipment

3. Dimension network to accommodate expected traffic

4. Calculate power consumption per customer for network

*Baliga et al., 2007*
Key model parameters

• Peak vs average access speed
  – Contention & aggregation

• Network dimensioning
  – Traffic growth
    • Deployed capacity > demanded capacity
    – Equipment redundancy
      • Multi-homing, back-up storage
    – Service protection
      • 1 + 1, 1:1, 1:N protection

• Router hops between source and destination

• Data centre Power Usage Effectiveness (PUE)
**Network segmentation**

- **Core Network**
  - Core Router
  - Fiber
  - Hot spots
  - Data Center
  - Storage
  - Server

- **Metro/Edge Network**
  - Broadband Network Gateways
  - Ethernet Switch
  - Edge Routers
  - Content Distribution Network
  - Storage
  - Server

- **Access Network**
  - DSLAM
  - Cu
  - DSL
  - Fiber
  - FTTP
  - PON
  - FTTP
  - ONU
  - DSLAM
  - Cabinet
  - Cu

**Key Terms**
- Ethernet Switch
- OLT
- Splitter
- FTTP
- DSLAM
- PON
- FTTN
Access network energy consumption

Baliga et al., OFC 2009
Data centers and content servers

- **Racks of Servers**
- **Aggregation Switches**
- **Load-Balancing Switches**
- **Border Routers**

- 80% of traffic stays in data center
- 15% of traffic to users
- 5% of traffic to other data centers

Diagram showing the flow of traffic through the data center with different components and their connections.
Power consumption of equipment

• Which metric(s) are appropriate?
  – Power consumption per “throughput”
  – Power consumption per “good put”
  – Energy per bit, power per bit rate
  – Energy per customer bit
  – etc.

• Different metrics provide different optimal solutions to energy efficiency

• Total power and energy/bit are widely used
Power consumption in routers

\[ P = C^{2/3} \]

where \( P \) is in Watts
where \( C \) is in Mb/s

Sources: METI, 2006, Nordman, 2007
Energy efficiency of equipment

2010 Data

- Sub-wavelength
- Wavelength

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Energy per bit (nJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core Router</td>
<td>0.001</td>
</tr>
<tr>
<td>Ethernet Switch</td>
<td>0.01</td>
</tr>
<tr>
<td>WDM Tx/Rx</td>
<td>1</td>
</tr>
<tr>
<td>PIC Tx/Rx</td>
<td>10</td>
</tr>
<tr>
<td>FEC Chip</td>
<td>100</td>
</tr>
<tr>
<td>Optical Amp</td>
<td>100</td>
</tr>
<tr>
<td>MEMS OXC</td>
<td>100</td>
</tr>
</tbody>
</table>

Tucker et al., 2010

[Diagram showing energy per bit for various equipment.]
Equipment Energy Consumption Trends

Router Energy Efficiency

Linear fit gives ~25% improvement per annum

Actual improvement may be declining

Cisco AGS
Wellfleet BCN
Cisco GSR 12000
Cisco GSR 12000b
Avici TSR
Cisco CRS 1
Cisco CRS 3
ALU7750

NIelsen, ECOC 2011
Trends in transport energy consumption

~15% improvement p.a.

Tucker, JSTQE 2011
Putting it all together

• Design and dimensioning approach
• 40% p.a. growth in network traffic
• 10% p.a. growth in user numbers
• 15% p.a. improvement in all technologies
• Projections of data centre traffic
Power consumption of the global Internet

- **Power Consumption (W)**
  - Year
  - 2010: $10^{10}$
  - 2015: $10^{11}$
  - 2020: $10^{12}$

- **Global electricity supply (3% p.a.)**
- **Total (2010 Technology)**
- **Total**
- **Servers**
- **Access (PON)**
- **Core and Metro Switches/Router**
- **Data Center Switches**
- **Global Optical Transport**

- **15% p.a. technology improvement**
Network energy per user bit

Energy per User bit (μJ)

Year

2010
2015
2020

Total
Core and Metro Switches/Routers
PON
Data Center Switches
Optical Transport

Average Access Rate (Mb/s)

0.1
1
10
100

0.01
0.1
1
10
100
Gap between theory and practice

- Access
- Routers and Switches
- GreenTouch
- Transport
- Switches
- Lower Bounds
- Global Network

- Network Energy per Bit (J)

- Year:
  - 2010
  - 2015
  - 2020
  - 2025

Tucker, JSTQE 2011
Gap between theory and practice

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

Management and control overheads, interconnects, power supplies, etc.

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

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

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

Subsystem

Inefficiency

Overhead

Function

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

Management and control overheads, interconnects, power supplies, etc.

Power consumption

Energy per bit

Ideal

Traffic (b/s)

Ideal

Traffic (b/s)
Improving network energy efficiency

• Many ideas for improving energy efficiency
  – Insufficient time to cover all of them

• Key approaches
  – Technologies
  – Architectures
  – Protocols
  – The cloud
A. Technologies

• Fundamental physical technologies for telecommunications:
  – Electronics: primarily CMOS for signal and data processing and storage
  – Improvements by Moore’s Law
  – Optics/photonics, primarily used to transport data
  – More than 99% of network energy is consumed by electronics

• Advances are needed in
  – Optical and electronic switch technologies
  – Optical and electronic interconnects at all levels
B. Architectures

• Architectures that reduce the number of network hops
• Optical bypass
• Layer 2 rather than Layer 3 where possible
• Dedicated content-delivery networks
Bypass options

Without bypass:
• All traffic goes to IP layer for processing
• \(\approx 10\) nJ per bit
• Allows aggregation of incoming traffic flow
• Statistical multiplexing increases utilisation of paths
Bypass options (cont’d)

With bypass:

• TDM Layer
  – Some traffic streams processed at TDM level
  – ~ 1 nJ per bit

• WDM layer
  – Some traffic switched at WDM layer
  – < 0.1 nJ per bit
C. Protocols

- Service transactions and protocols
- Efficiency of multi-layer protocol suite
- XGPON framing
- Sleep and standby states
- Energy-efficient Ethernet
- Dynamic rate adaptation
Service transactions & protocols

Service based energy model reflects how services are transported through the network

Source: Zhong et al., OFC 2012
Efficiency of multi-layer protocol suite

Combining boxes for multi-layer protocol suites can improve efficiency

\[
\text{Efficiency} = \frac{\text{Customer payload} \times \text{IP layer energy}}{\text{Total multi-protocol suite packet energy}}
\]

Source: Zhong et al., OFC 2012
XG-PON framing protocols

Chow et al., ECOC 2012

H – XGEM frame header
P – FEC parity
Solution: BiPON

Bit-Interleaved PON

Conventional PON

Chow et al., ECOC 2012
Energy-efficient protocols

• Sleep & standby states
  – Network devices enter low power state when not in use
  – Can apply to systems and sub-systems
  – Need to ensure network presence is retained
    • Use Network Connection Proxy with sleep protocol
  – Need to account for state transition energy and time
  – May have multiple lower energy states

• IEEE Energy Efficient Ethernet (802.3az)
  – Low power idle mode when no packets are being sent
  – Approved Sept. 2010
  – Currently applies to copper interface only; not optical
PON burst-mode laser driver

Koizumi et al., ECOC 2012

- Driver turned off between bursts
- Power reduced by 93%

![Diagram of PON burst-mode laser driver]

- Power consumption graph showing
  - w/o power saving: 1006 mW (LD on)
  - Power saving: 64 mW (LD off)

- Duty ratio of Tx_EN pulse
  - 0% to 100%
  - 32 branches
Energy-efficient protocols

- Dynamic rate adaptation
  - Modify capacity of network devices in response to traffic demands
  - Change clock frequency, processor voltage
    \[ \text{Power} = C \times \text{Voltage}^2 \times \text{Frequency} \]
  - Slower speed to reduce power consumption
  - Need to allow transition time between rates

- Dynamic rate adaptation and standby states can be combined

\[ \text{Power} = \text{C} \times \text{Voltage}^2 \times \text{Frequency} \]

Bolla et al., 2011
D. The cloud

• Cloud services widely promoted as greener than on-site facilities:
  – Cloud Computing – The IT Solution for the 21st Century
    • Carbon Disclosure Project Study 2011
  – Salesforce.com & the Environment
    • WSP Environment & Energy 2011

• Strong case for enterprise private cloud

• What about the public cloud?
  – Apple iCloud
  – Google drive
  – Microsoft sky drive
Example: Public storage as a service (SaaS)

Storage of application & data “in the cloud” compared with storing on a local disk. 50 MBytes per download. Modern laptop-style HDD 20% read/write and 80% idle.

Baliga et al., Proc IEEE, 2011
Rethinking the “Green Cloud”

• Need to improve access energy efficiency
  – Small wireless cells
  – PON
• Keep some processing power in user’s device
• Reduce the number of router hops
  – Avoid public Internet
  – Use optical layer by-pass of routers
• Improve protocol efficiency
  – Less overhead bytes
  – Smart scheduling
IPTV over the public Internet

Direct optical link to edge router

- Location of movies is a trade off between energy for storage and energy for delivery
- Each movie is replicated on R servers throughout the network
IPTV over the public Internet

Energy per download (Wh) (log scale)

Downloads per hour

R = 20
R = 200
R = 2000
P2P

R = 2

Baliga et al., OFC, 2009
IPTV over the public Internet

Baliga et al., OFC, 2009
Conclusions

• Energy consumption of the network is growing

• Access network energy dominates
  – Servers in data centres are likely to become dominant in ~2015
  – 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
  – Architectures
  – Protocols

• If you are inspired, join one of the networks or consortia:
  www.greentouch.org, www.fp7-trend.eu