A Green Internet

Rodney S. Tucker
ARC Special Research Centre for Ultra-Broadband Information Networks (CUBIN)
University of Melbourne
r.tucker@ee.unimelb.edu.au
**Energy Consumption and Data**

Why is Energy Important?

- OPEX
- Greenhouse Impact
- Energy-limited capacity bottlenecks ("hot spots")
- Enabling energy efficiencies in other sectors
Putting Things into Context

Information and Communication Technologies (ICT)

2002
Global Emissions

Business as Usual 2020

2020 Abatements

2020 with abatements

Emissions

5% of total

“SMART 2020: Enabling the low carbon economy in the information age,”
GeSI, 2008  www.gesi.org
Summary

- Estimating energy consumption of the Internet
- Where does the energy go
  - Core, metro, access network?
- What will happen as traffic grows over time?
- Saving energy through travel replacement
- Can photonic technologies help to build a Green Internet?

Caveat: “Making predictions is difficult – especially about the future.”
Estimating Energy Consumption

- Choose an access data rate (capacity per user)
- Carry out paper design of network
- Calculate the power consumed by the network per user
- Repeat for all access rates

Oversubscription

\[ M = \frac{\text{Peak access rate sold to user}}{\text{Average access rate}} \]

- \(~ 2.5 \text{ Mb/s in 2008}\)
- \(~ 0.1 \text{ Mb/s in 2008}\)

\( M = 25 \)
Power Consumption of IP Network

- **Today’s Internet**: (~2.5 Mb/s)
- **2008 Technology**: 10 core hops
- **Oversubscription = 25**

- **Total Power Consumption**
  - Routers
  - Access (PON)
  - SDH/WDM Links

- **Power (W/user)** vs. **Peak Access Rate (Mb/s)**

- **% of Electricity Supply**

*Baliga et al., 2008*
Ultra-Broadband Access

- 10 core hops
- 2008 Technology
- Oversubscription = 25

Graph showing Power (W/user) vs. Peak Access Rate (Mb/s) with lines for Total, Routers, Access (PON), and SDH/WDM.

Baliga et al., 2008
Power Consumption in Access Networks

Access N/W

Edge Node

- Cisco 6513
- Hitachi 1220
- Cisco 4503
- Hitachi 1220
- RF Gateway
- Axxcelera ExcelMax BTS

Cabinet

- Splitter
- Fiber
- NEC VF200F6
- NEC AM3160
- TC Communications TC3300

Node

- Cu
- Fiber
- Axxcelera ExcelMax
- Cisco DCP3000
- RF Amp

Wave7 ONT-G1000i

- Fiber

GPON

FTTN

VDSL2

PtP

WiMAX

HFC
Power Consumption in Access Networks

- 20 users per sector
- M = 10 WiMAX
- M = 10 FTTN
- M = 1 HFC
- M = 32 PON
- 32 Customers
- M = Oversubscription

PON FTTH is “greenest”
“With implementation of this Code of Conduct the (network) electricity consumption could be limited to 25 TWh per year. This is equivalent to 5.5 Millions tons of oil equivalent (TOE) and to total saving of about € 7.5 Billions per year.”

<table>
<thead>
<tr>
<th></th>
<th>Off-State (W)</th>
<th>Low-Power State (W)</th>
<th>On-State (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADSL-CPE</td>
<td>0.3</td>
<td>3.5</td>
<td>4.0</td>
</tr>
<tr>
<td>VDSL2-CPE</td>
<td>0.3</td>
<td>4.5</td>
<td>6.0</td>
</tr>
<tr>
<td>GPON ONU</td>
<td>0.3</td>
<td>5.0</td>
<td>9.0</td>
</tr>
<tr>
<td>PtP ONU</td>
<td>0.3</td>
<td>3.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>
Energy consumption

• Dramatic growth of internet due to “multimedia” traffic
  – Any kind of video (on demand, time-shifted, faster than real time)
  – Broadband Internet
  – Audio
  – Voice

• Broadband services require home network equipment

• Size of home networks increases with increasing number of devices

• Home equipment often not used efficiently

Gladish et al., ECOC 2008
Network Energy Consumption per Bit

Energy per bit (μJ)

~100 μJ/b

~1 μJ/b

Total

Routers

Access (PON)

WDM Links

Peak Access Rate (Mb/s)

20 hops

~1 μJ/b per bit

~100 μJ/b per bit
Energy per Bit in Network Devices

Energy per bit (nJ)

- MEMS
- OXC
- Optical Amp
- PIC
- Discrete Tx/Rx
- PoS Tx/Rx
- Ethernet Switch
- Core Router
- PON ONU (10 Mb/s)
- IPTV Server

Wavelength
Sub-wavelength

Estimated

2008

Energy per bit (nJ)
0.01
0.1
1
10
100
1000

MEMS OXC
Optical Amp
PIC Tx/Rx
Discrete Tx/Rx
PoS Tx/Rx
Ethernet Switch
Core Router
PON ONU (10 Mb/s)
IPTV Server

UBIN
Router Capacity Growth

Based on G. Epps, CISCO, 2006

Table: CRS-1 (~1.3 Tb/s, 13.6 kW/rack)
- 12416 (~0.3 Tb/s/rack)
- 12016 (~80 Gb/s/rack)

- Router capacity x 2.5/18 m
- Moore's law x 2/18 m
- CMOS energy efficiency x 1.65/18 m

- 40% p.a.
- Router energy efficiency improving at 20% p.a.
  Neilson, JSTQE 2006
Effect of Efficiency Gains?

- 10 core hops
- 2008 Technology
- Oversubscription = 25

- Power (W/user)
- Peak Access Rate (Mb/s)
- % of Electricity Supply

1. Effect of Efficiency Gains?
2. Total
3. Routers
4. Access (PON)
5. SDH/WDM Links

Baliga et al., 2008
Improvements in Technology Efficiency

Traffic Growth rate = 40% p.a

Overall Technology Efficiency Improvement Rate = 0% p.a

5% p.a

10% p.a

10% p.a

5% p.a

Target

20% p.a

Peak Access Rate (Mb/s)

Total Power (W/user)

% of Electricity Supply

Baliga et al., unpublished
Some Observations

• Optical transport (WDM) consumes relatively little energy
  < 5% of energy   > 25% of CAPEX

• Access network dominates consumption at low rates
  – Standby/Sleep mode is key to reducing energy consumption
  – Energy efficiency may be a key driver for FTTH deployment

• Network routers dominate consumption at higher rates

• The “energy bottleneck” will replace the so-called “bandwidth bottleneck

• Electronics is excellent for switching and signal processing

• Photonics is excellent for transmission
Towards Energy-Efficient Networks

- Alternatives for complex PC
- Sleep mode and fast "wake up", adaptive modes of network and clients
- Power adaptive network
- Adaptive control of components based on communication requirements
- Adaptive sharing of content
- Highly efficient power adaptive processing
- Virtualization
- Energy management solutions e.g. optical/electronic bypass
- Energy-efficient routing protocols

After: Gladish et al., ECOC 2008
Data Centers

- Data center electricity consumption is ~1% of the global total\(^1\)
- Energy consumption of data centers worldwide doubled between 2000 and 2006 \(^2\)
- Incremental US demand for data centre energy between now and 2010 is the equivalent of 10 new power plants\(^2\)

\(^1\)Koomey, 2008
Each watt consumed by IT infrastructure carries a “burden factor” of 1.8 to 2.5 for power consumption associated with cooling, conversion/distribution and lighting.

Sources: EYP Mission Critical Facilities, Cisco IT, Network World, Customer Interviews, APC
Using the Internet for Travel Replacement

Video Conferencing

Source: CISCO, 2008
Travel Replacement – Greenhouse Impact (C0₂)

Air Travel

Home → Melbourne:
~5,000 kg/person return

Melbourne → Newport Beach

Video Conferencing

LEOS Meeting

~100 kg/person

2 X 1 Gb/s for 24 hours = 20 TB
Teleportation in place of Video Conferencing?

How much information does the brain hold?

Brain Scans: Southern California Brain Research Institute (SCBRI)

420 TB

580 TB

Average LEOS member: \( \frac{420 + 580}{2} \sim 500 \text{ TB} \)

2,000 kg/person return

(50 MW/person for 5 seconds to teleport in each direction)
Embarrassing Moments in Sci Fi

Teleportation

Beam me up, Scotty

Sorry, Captain.
The power company has a new energy-efficiency program.
Please use Skype.
Travel Replacement

Air Travel: 5,000 kg/person return

Teleportation: 2,000 kg/person return

Video Conferencing: 100 kg/person

Melbourne

Newport Beach
<table>
<thead>
<tr>
<th>Low Energy</th>
<th>Not so Low Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>• PON Access networks</td>
<td>• Non-PON Access networks</td>
</tr>
<tr>
<td>- GPON, EPON</td>
<td>- Wireless</td>
</tr>
<tr>
<td>- WDM PON</td>
<td>- HFC</td>
</tr>
<tr>
<td>• Optical circuit switching</td>
<td>- FTTN</td>
</tr>
<tr>
<td>• Optical bypass</td>
<td>• Sub-wavelength optical switching</td>
</tr>
<tr>
<td>- low-energy cross connects</td>
<td>- Optical packet switching</td>
</tr>
<tr>
<td>- ROADMs</td>
<td>- Optical burst switching</td>
</tr>
<tr>
<td>• Photonic integration</td>
<td>• Nonlinear optics for logic &amp; DSP</td>
</tr>
<tr>
<td>• Optical interconnects</td>
<td></td>
</tr>
<tr>
<td>- Low power Tx/Rx</td>
<td></td>
</tr>
<tr>
<td>• Low-energy nanophotonics</td>
<td></td>
</tr>
</tbody>
</table>
"If you are thinking of competing with CMOS, don’t!": Tingye Li, ~1998

Switching energy, $E_s = E_i + E_p$

Photonic devices:
- HNLF
- SOA
- PPLN
- Si Nanowire

Feature size in nm:
- 250
- 180
- 130
- 90
- 65
- 45
- 32
- 22
- 18
- ?

Photon energy $h \nu @ 1.55 \mu m$

Inputs:
- Input energy, $E_i$
- Supply energy, $E_p$

Sources: ITRS '97-'06 Roadmaps; Hinton et al., JSTQE 2008
Major flaw: no mention of energy consumption

Energy per bit > 10 nJ/bit
Some International Achievements

- BT has reduced carbon emissions by 60% since 1996
  - Management compensation linked to reductions in energy consumption

- NTT has a major focus on reducing energy consumption
  - “Total Power Revolution” saved 124 million kWh in 2007

- Other initiatives: GeSI, Green Grid, WattWatt, FTTH Council Europe, EU codes of conduct, CBI Task Force etc.

Source: Arthur Levin, ITU, 2008, S. Walker
Groups and Organizations

- http://www.atis.org/0050/
- http://www.gesi.org/
- http://www.itu.int/climate
- http://www.thegreengrid.org/home
- http://wattwatt.com/
- http://ictandclimatechange.com/
Workshops and Conferences

• ITU Symposium on ICTs and Climate Change, London, 16-17 June, 2008:
  http://www.itu.int/ITU-T/worksem/climatechange/index.html

• Network Solutions to Reduce the Energy Footprint of ICT, ECOC, Brussels, 21-25 September, 2008:
  http://www.ecoc2008.org/programme.asp#greenict

• Symposium on Sustainability of the Internet and ICT, University of Melbourne, November 25-26, 2008:

• Workshop on Energy Footprint of ICT: Forecast and Network Solutions, OFC 2009
Summary – The Way Forward

• Energy consumption of the Internet is small, but growing

• Internet energy consumption dominated by
  – Access network today
  – Core network in the future

• A multi-disciplinary approach is required to build a green Internet:
  – Improved efficiency in electronic and photonic devices
  – Low-energy switching techniques
  – Improved architectures
  – New protocols

• Photonics can play a key role
  – Think Energy