Energy Consumption in IP Networks

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Why should we be interested in energy?

- OPEX
- Greenhouse Impact
- Managing “Hot Spots”
  - Getting the energy in
  - Getting the heat out
- Energy-limited capacity bottlenecks
- Enabling energy efficiencies in other sectors
Where are We Heading?

- More users
- More data-intensive applications, e.g. video
- More often and for longer periods
- Increasing demand $\rightarrow$ operators provide faster access and increased core capacity
- New applications enabled by faster access

Energy Consumption Grows
Summary

- Modeling energy consumption of the Internet
  - Core, metro, and access networks

- Where does the energy go?

- Will (can) optical switching technologies help to reduce energy consumption?

- A Word of Warning
What is the Carbon Footprint of Telecoms?

Adapted from “SMART 2020: Enabling the low carbon economy in the information age,” GeSI, 2008 www.gesi.org
Where does the Energy Go?

- Core
- Edge
- Curb

- CRS-1: ~ 10 kW / rack
- 12816 Edge: ~ 4 kW
- OLT: 100W
- ONU: ~ 5-10W

Packet over Sonet
Fibre Amps
WDM

0.1 - 1000 Mb/s to the user

Baliga et al., 2007
Number of Hops in the Internet

Power Consumption of IP Network

- Today's Internet (~ 2.5 Mb/s)
- 20 router hops
- Contention ratio = 25
- 2007 Technology

Baliga et al., 2007
Ultra-Broadband Access

20 router hops
Contention ratio = 25

2007 Technology

Power (W/user)

% of Electricity Supply

Peak Access Rate (Mb/s)

Access (PON)
Routers
SDH/WDM
Total

Baliga et al., 2007
Energy Consumption in Access Networks

Edge Node
- Cisco 12816
- NEC CM7700S
- Cisco 4503
- NEC VF200F6
- NEC GM100
- Axxcelera ExcelMax BTS

Access N/W
- NEC CM7710T
- Zyxel VES-1616F-34
- PtP
- FTTN with VDSL2
- WiMAX

Cabinet

Splitter
Power Consumption in Access Networks

- Wireless access consumes more energy than optical access
- PON FTTH is “greener” than FTTN
Observations

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

• Eliminating the O/E/O converters provides no significant benefit

• Access network dominates at low rates
  – Standby/Sleep mode is key to reducing energy consumption

• Network routers dominate at higher rates
  – Need to
    • reduce hop count
    • improve router efficiency (technology)
    • manage routers better (sleep states)
    • develop better network architectures using fewer routers
    • manage distribution and replication of content (IPTV)
Power Consumption in Routers

\[ P = C^{\frac{2}{3}} \]
where \( P \) is in Watts
where \( C \) is in Mb/s

- \( P \approx 10 \) at 1 Gb/s
- \( P \approx 100 \) nJ/bit at 1 Gb/s
- \( P \approx 100 \) nJ/bit at 1 Tb/s
- \( P \approx 1 \) Pb/s

Energy Bottleneck

High-end router: Cisco CRS-1

- Linecard Chassis
  - Capacity: 0.64 Tb/s
  - Power: 13.6 kW

- Switch Fabric Chassis
  - Power: 8 kW

- Fully equipped: Multi-rack router
  - Capacity: 41 Tb/s
  - Power ~ 1 MW

Per Rack

- Energy Bottleneck

Source: Neilsen, 2006; Deutsche Telekom, 2007

Router Capacity

- 100 Tb/s
- 1 Tb/s
- 10 Gb/s

Year


X2 every 18 months

Source: Neilsen, 2006; Deutsche Telekom, 2007

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Electronic Routers

- Fibers
- Demultiplexers
- O/E Converters
- Switch Fabric
- Buffers
- Multiplexers
- Forwarding Engine

Reduced bit rate (i.e. parallel processing)
Speed (throughput) is not a limitation
Energy in Electronic and Optical Routers

Buffer
Forwarding Engine
Routing Tables
Routing Engine
Power supply inefficiency
Fans and blowers

Electronic (2008)
- 0.7 nJ
- 3.2 nJ
- 0.5 nJ
- 1.0 nJ
- 1.1 nJ
- 3.5 nJ
- Total 10 nJ

Electronic (2018)
- 10 pJ
- 65 pJ
- 10 pJ
- 20 pJ
- 25 pJ
- 80 pJ
- Total 210 pJ

Optical (2018)
- 20 pJ
- 65 pJ
- 20 pJ
- ?
- 20 pJ
- 25 pJ
- 80 pJ
- Total 220 pJ

Optical Packet Switching is not a compelling alternative

Contestation Resolution in the Wavelength Domain

Fatal Flaw: **Require large \( n \)** for low blocking probability \( (n \sim 3 \text{ - } 10 \times) \)

- Optical Burst Switch
- Optical Label Switch

![Diagram](image)
The Challenge

10% - 20% p.a. continuous improvement in efficiency

Efficiency Improvement Rate = 0% p.a

Total Power Per User (W)

% of Electricity Consumption

Peak Access Rate (Mb/s)

Summary

• Energy consumption currently dominated by the access network

• The energy bottleneck in routers is looming
  - More significant than the so-called “electronic speed bottleneck”

• Key strategies for efficient network design
  - Control energy in the access network (e.g. sleep mode in modems)
  - Reduce the hop count (i.e. “agile” optical bypass)
  - Energy-efficient network architectures
  - Continuous improvement in (electronic) router efficiency
  - Caching and content distribution networks
  - O/E/O conversions not necessarily a problem