# A Green Internet

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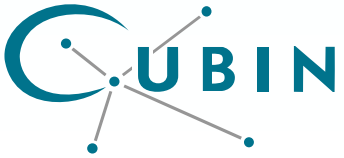
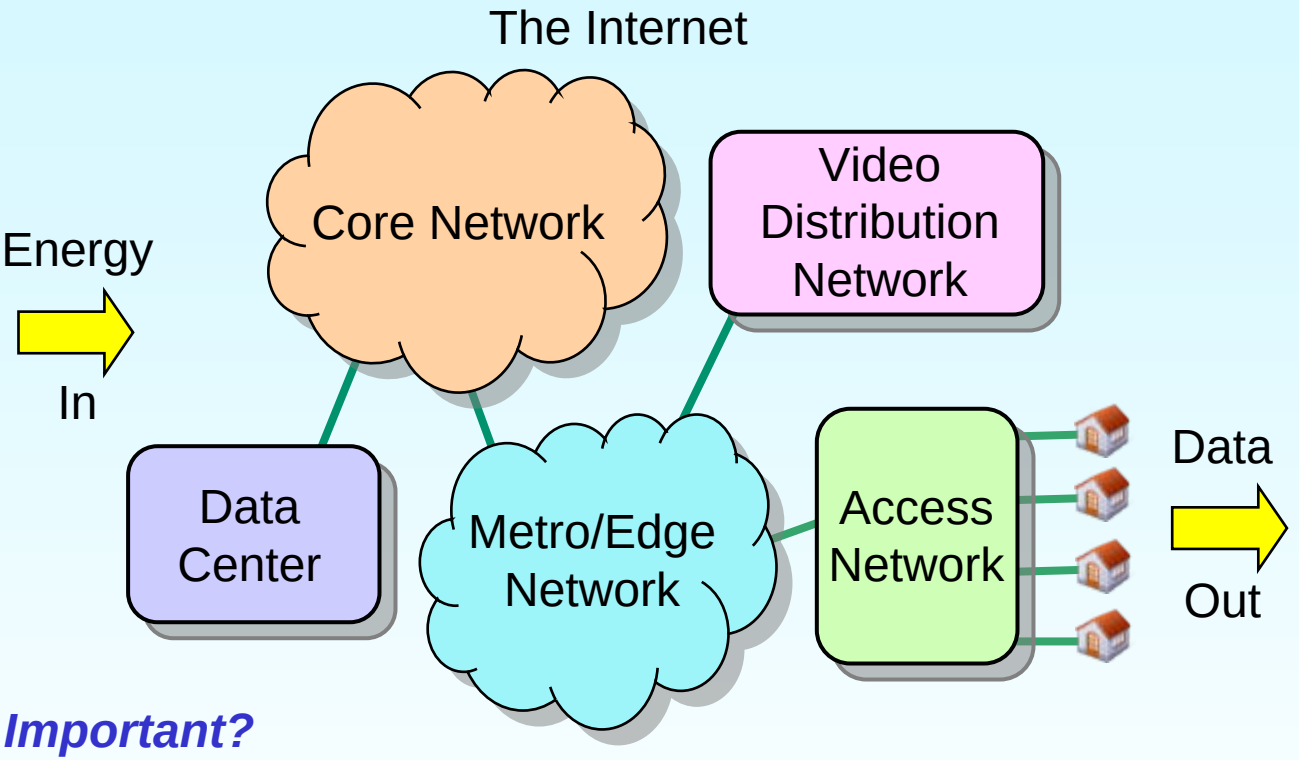


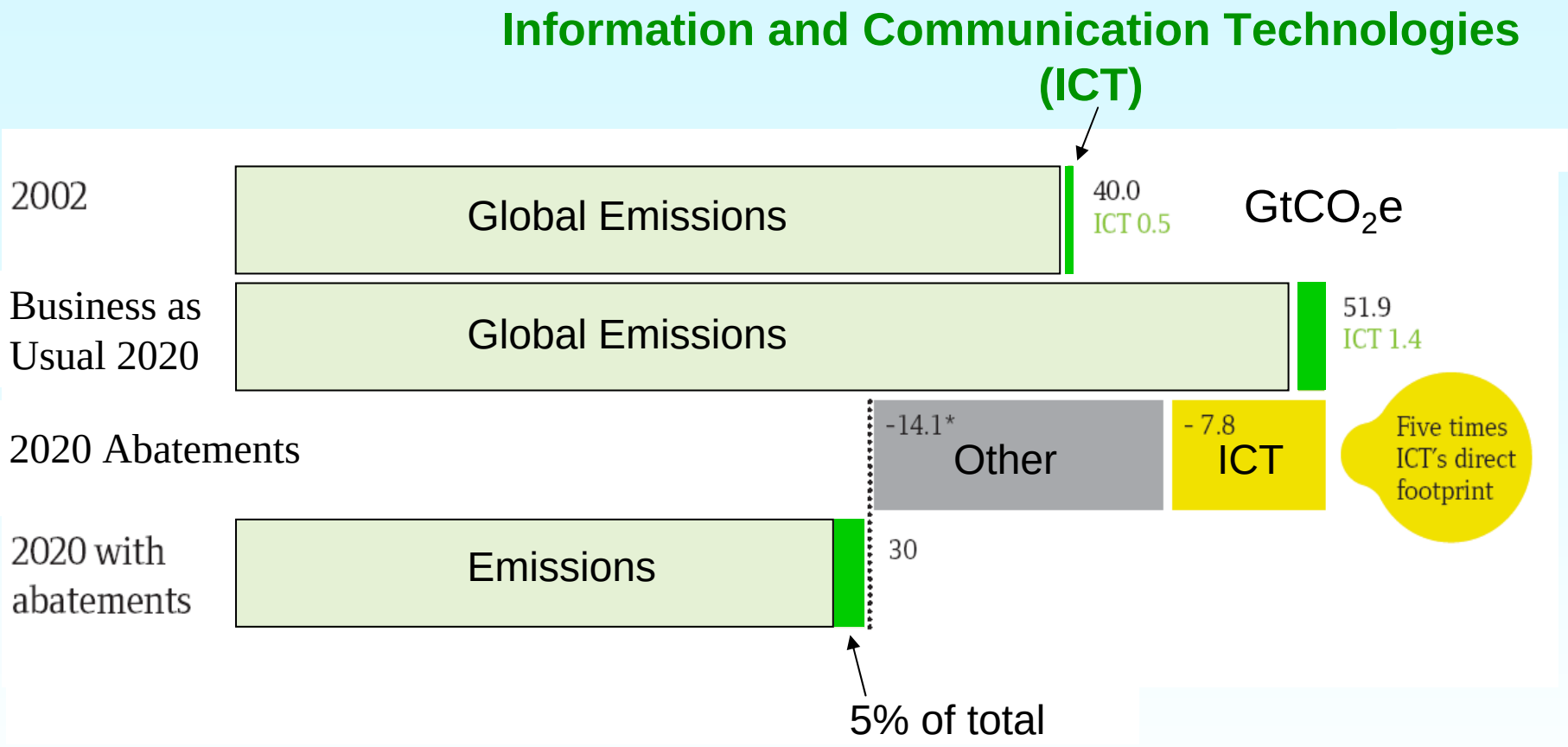
# Energy Consumption and Data




***Why is Energy Important?***

- OPEX
- Greenhouse Impact
- Energy-limited capacity bottlenecks (“hot spots”)
- Enabling energy efficiencies in other sectors

# Putting Things into Context




"SMART 2020: Enabling the low carbon economy in the information age," *GeSI, 2008* www.gesi.org

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# 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.”

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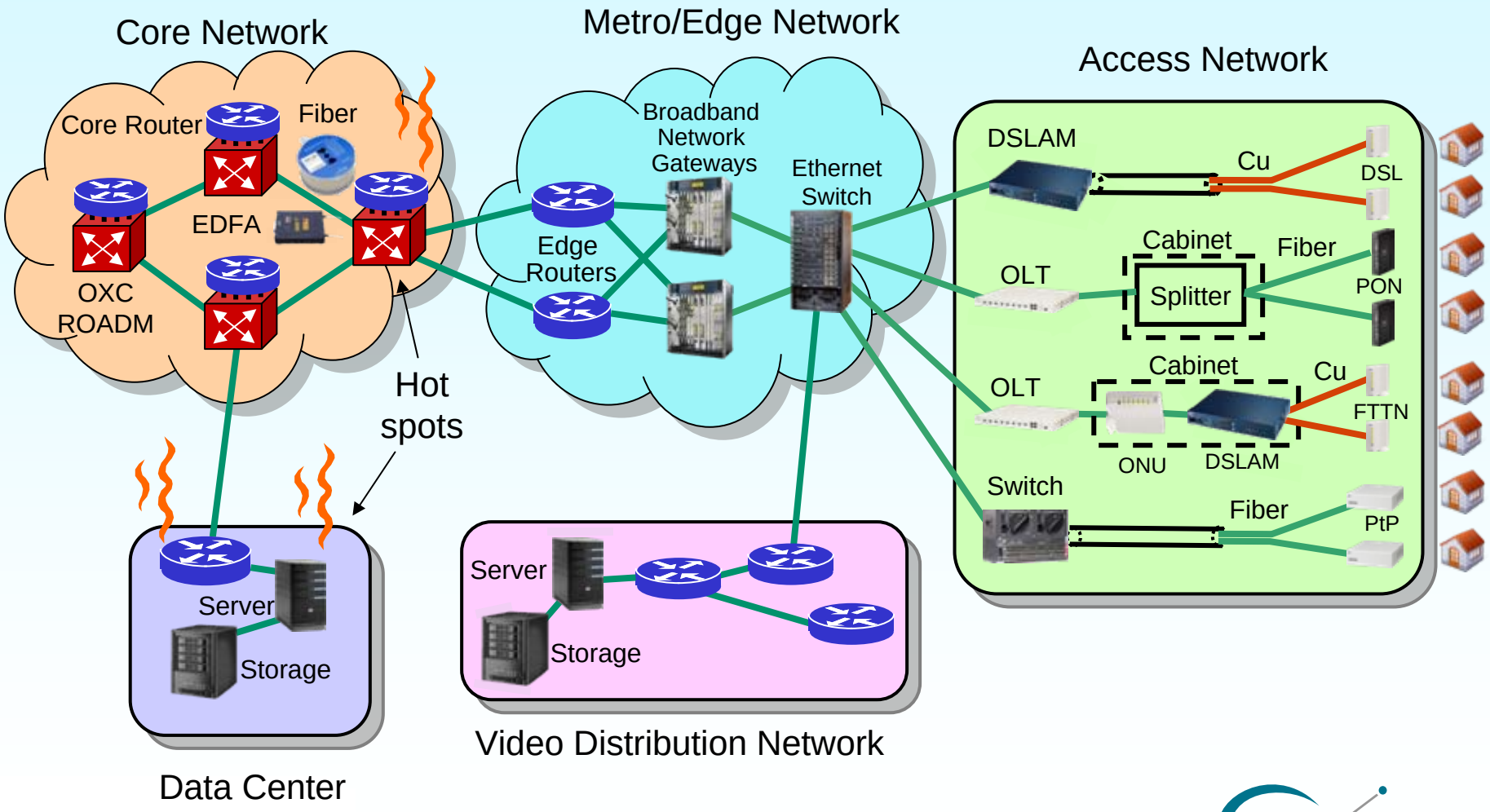
# Network Energy Model

## Tier 1 Network



# 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 Mb/s in 2008

$M = 25$

~ 0.1 Mb/s in 2008

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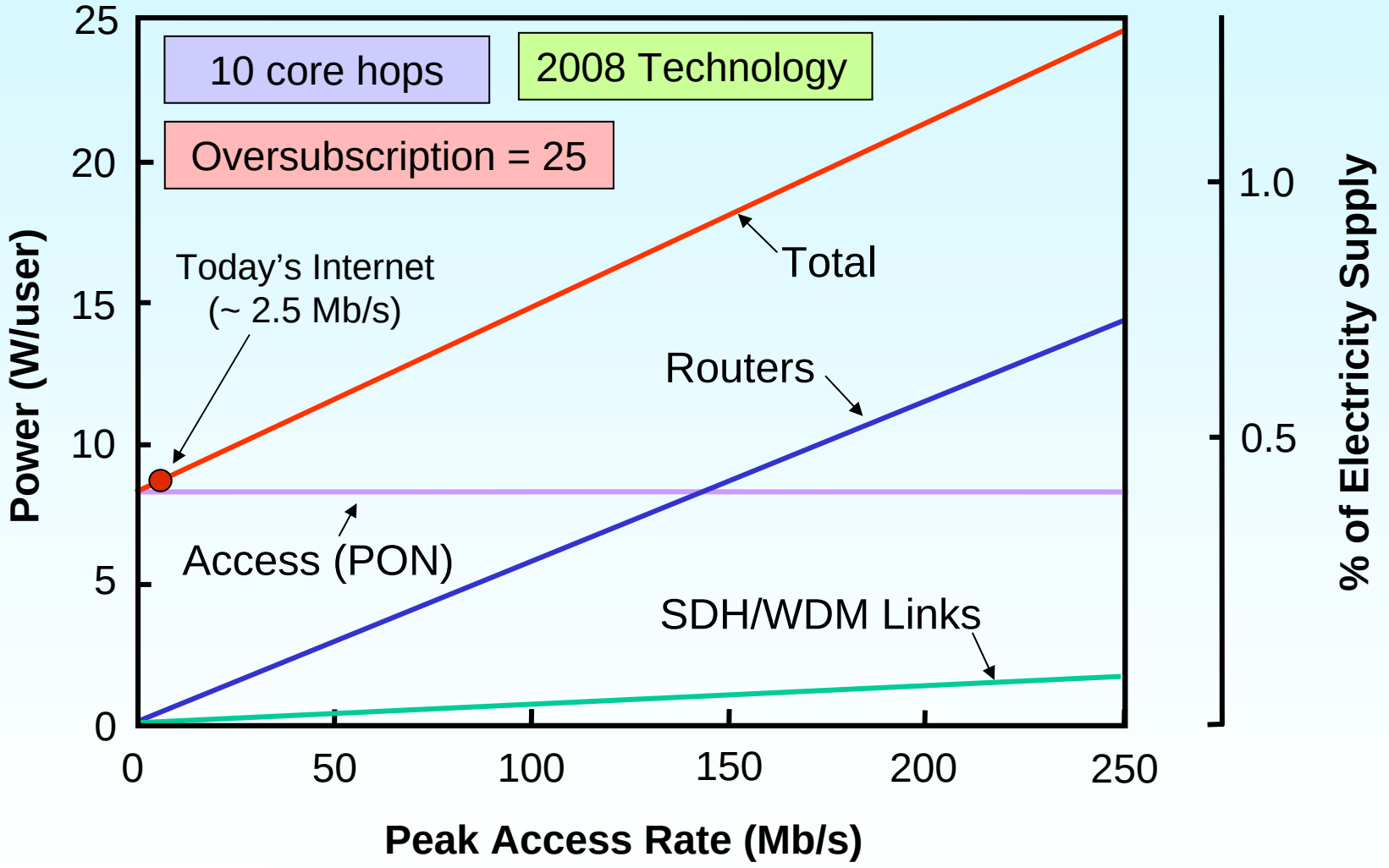
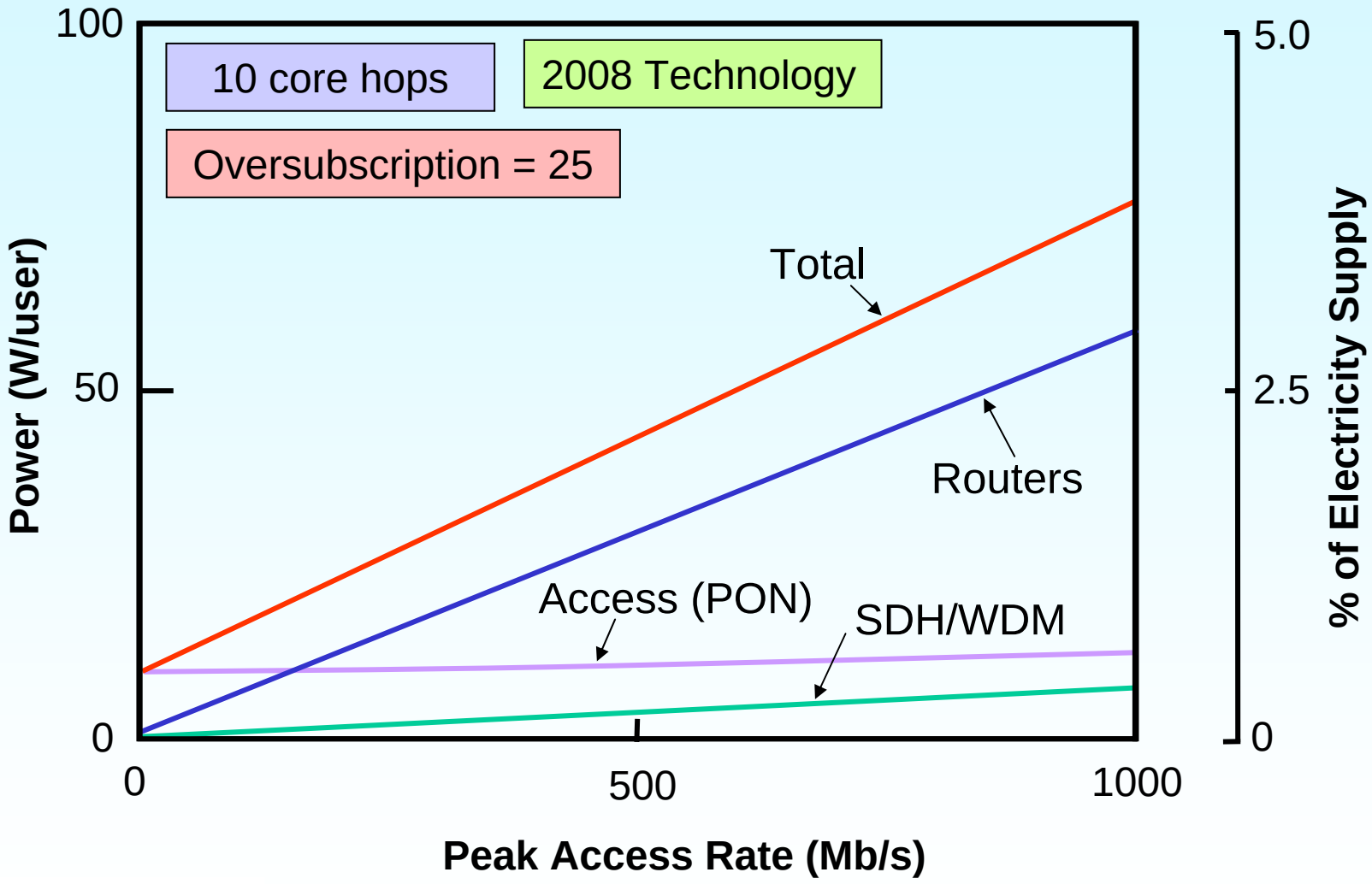
# Power Consumption of IP Network



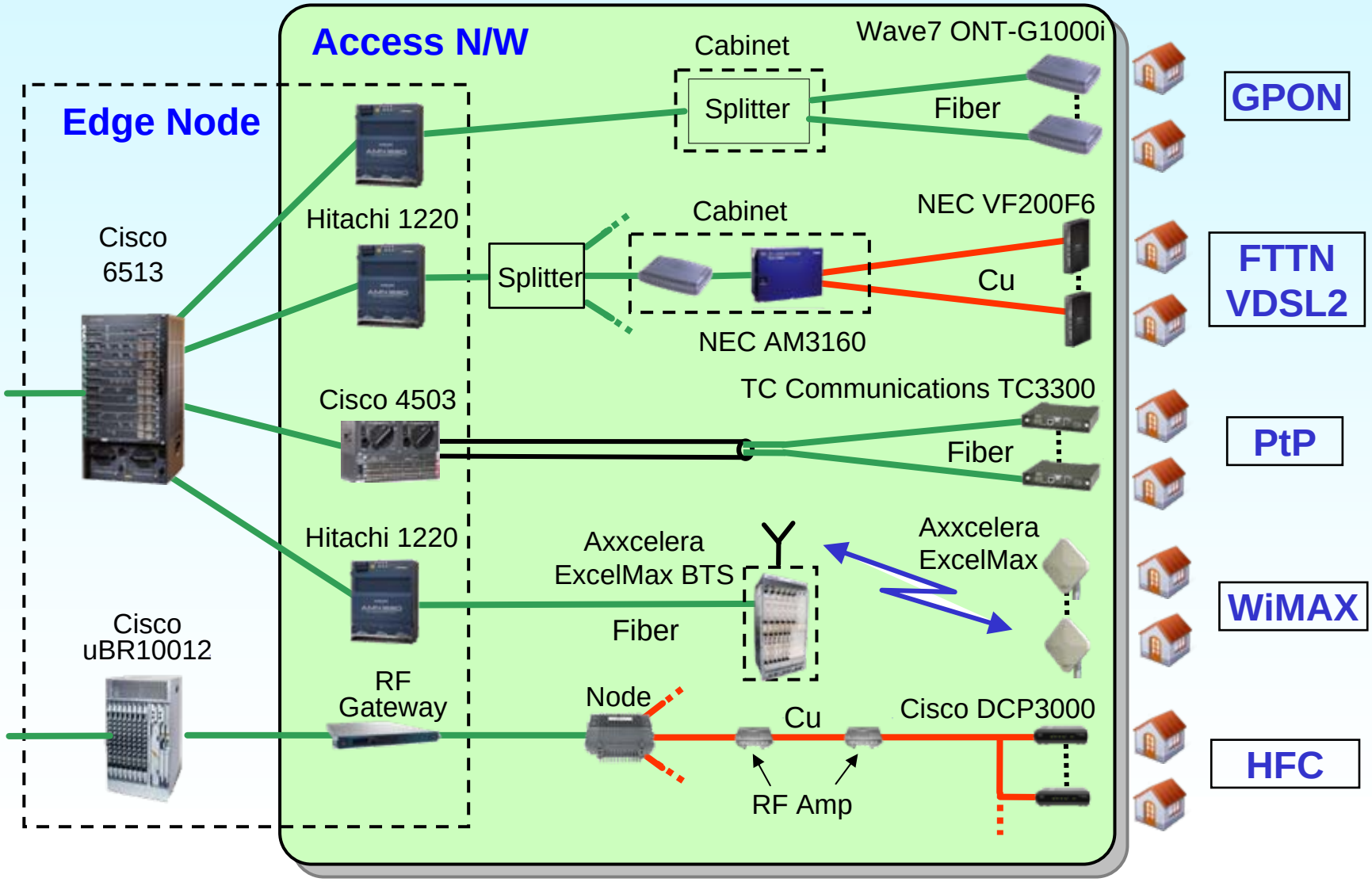

*Baliga et al., 2008*

# Ultra-Broadband Access

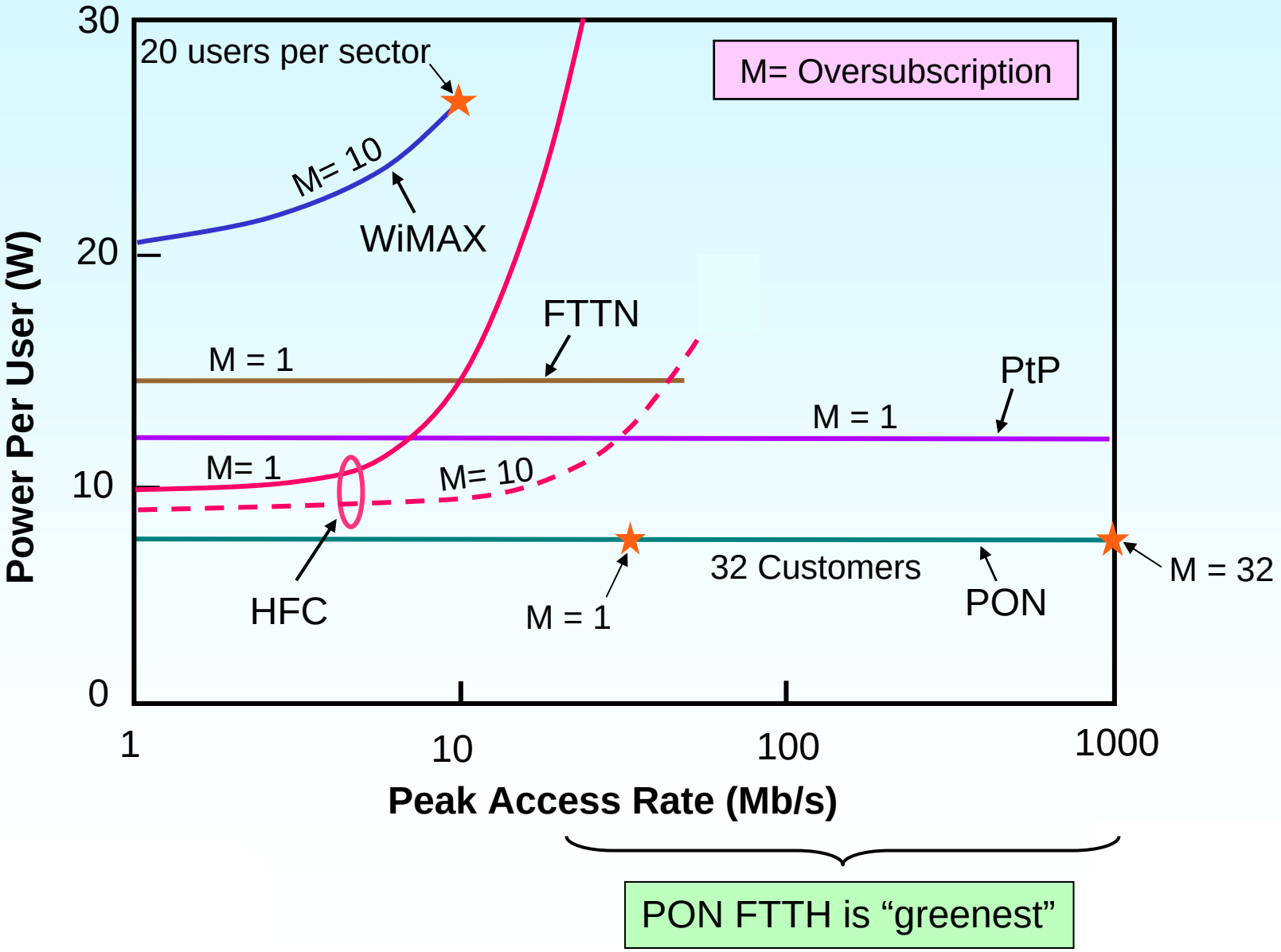



*Baliga et al., 2008*

# Power Consumption in Access Networks



# Power Consumption in Access Networks



# Low-Power States in User Modems

EUROPEAN COMMISSION
DIRECTORATE -GENERAL JRC
JOINT RESEARCH CENTRE
Institute for the Environment and Sustainability
**Renewable Energies Unit**

**Code of Conduct**
**on Energy Consumption of Broadband Equipment**

**Draft Version 3**
***Issue 15 – 17 July 2008***

"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."

**Extract:**

| | Off-State (W) | Low-Power State (W) | On-State (W) |
|---|---|---|---|
| **ADSL-CPE** | 0.3 | 3.5 | 4.0 |
| **VDSL2-CPE** | 0.3 | 4.5 | 6.0 |
| **GPON ONU** | 0.3 | 5.0 | 9.0 |
| **PtP ONU** | 0.3 | 3.0 | 5.0 |

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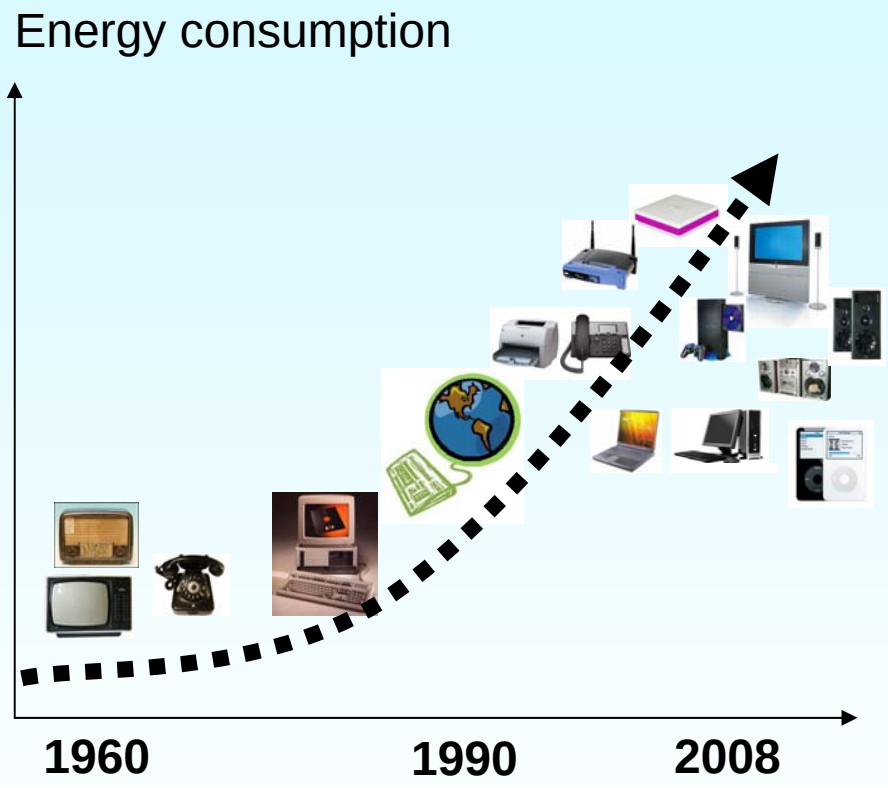
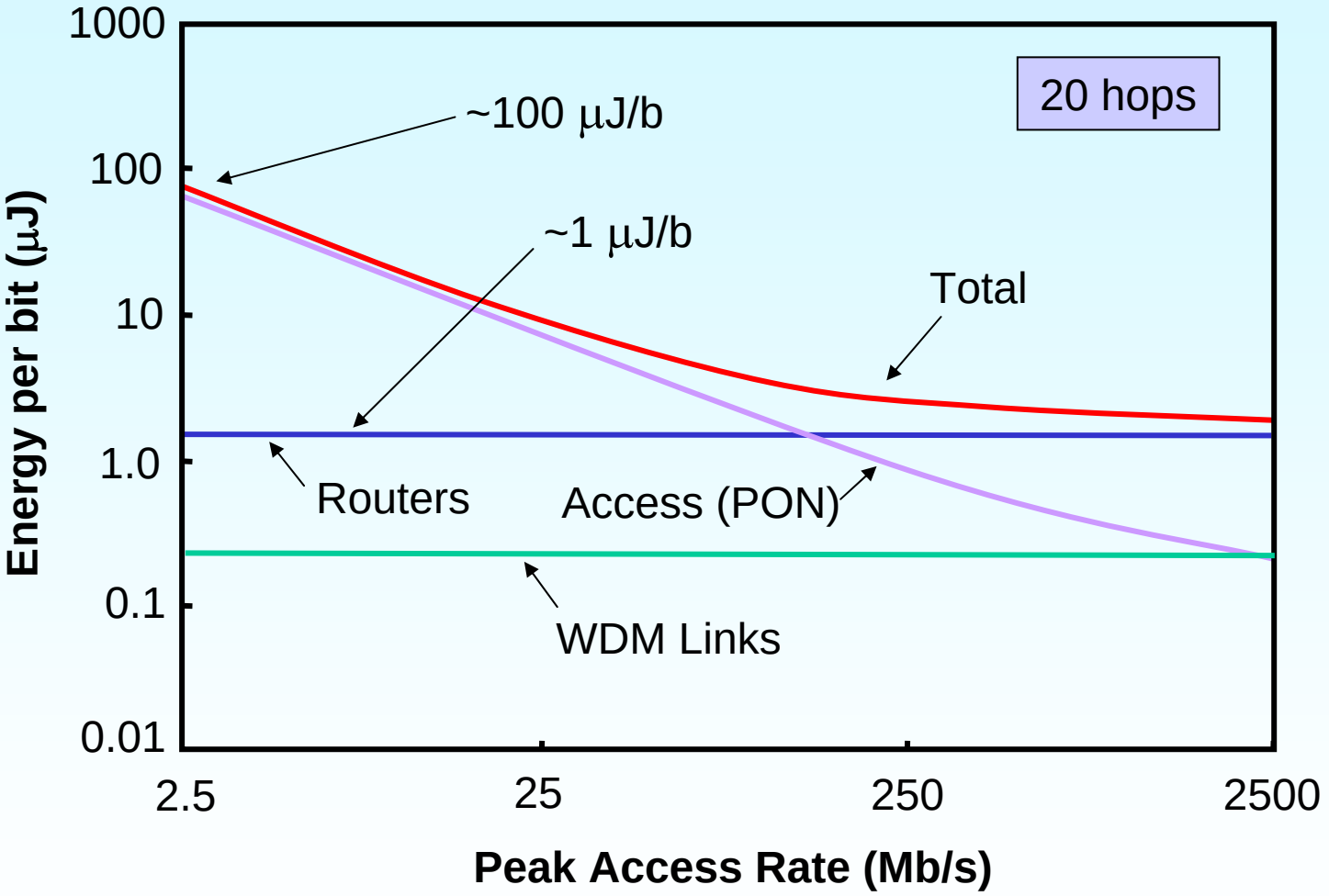
# Home Networks




- 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*

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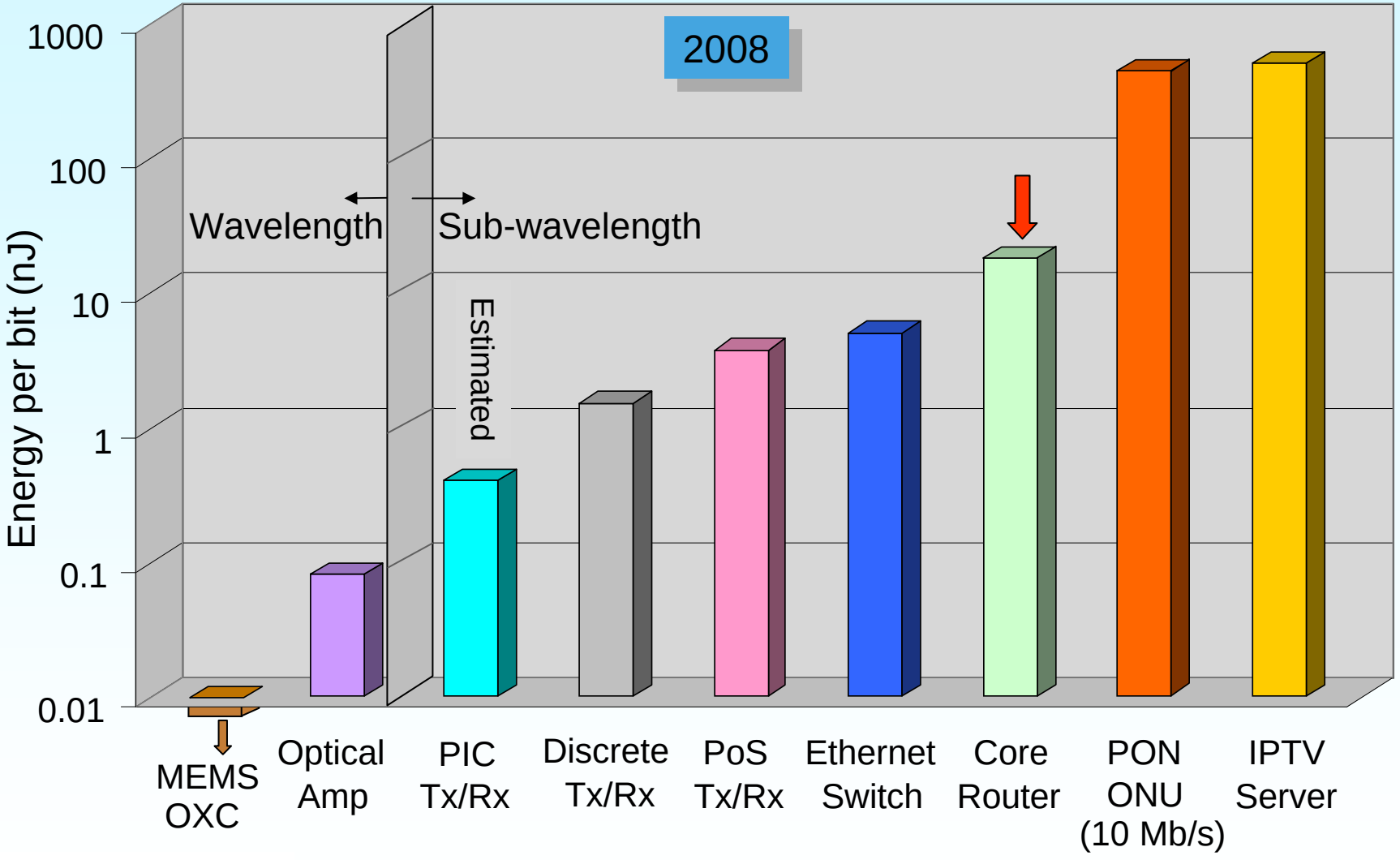
# Energy per Bit in Network Devices

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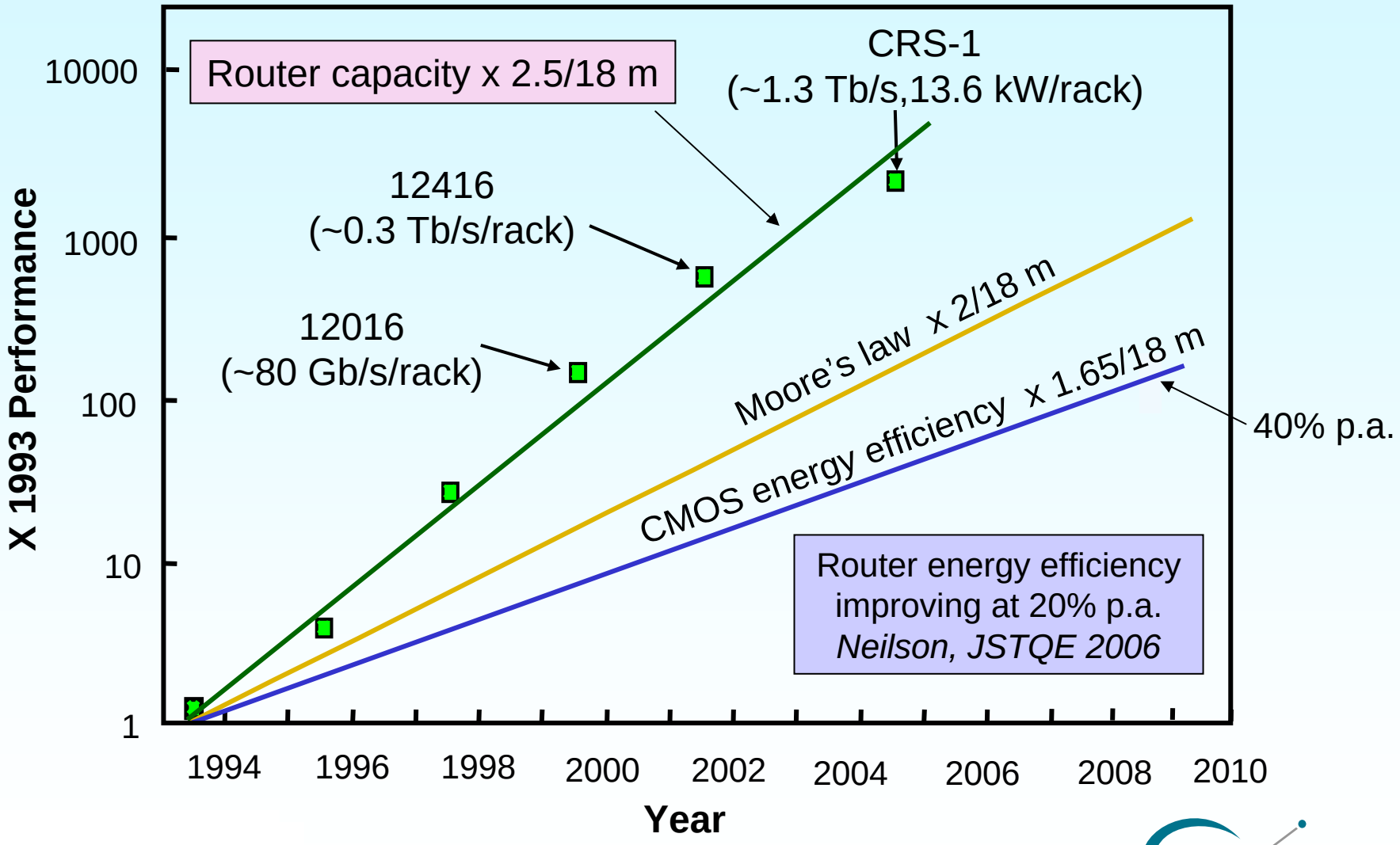
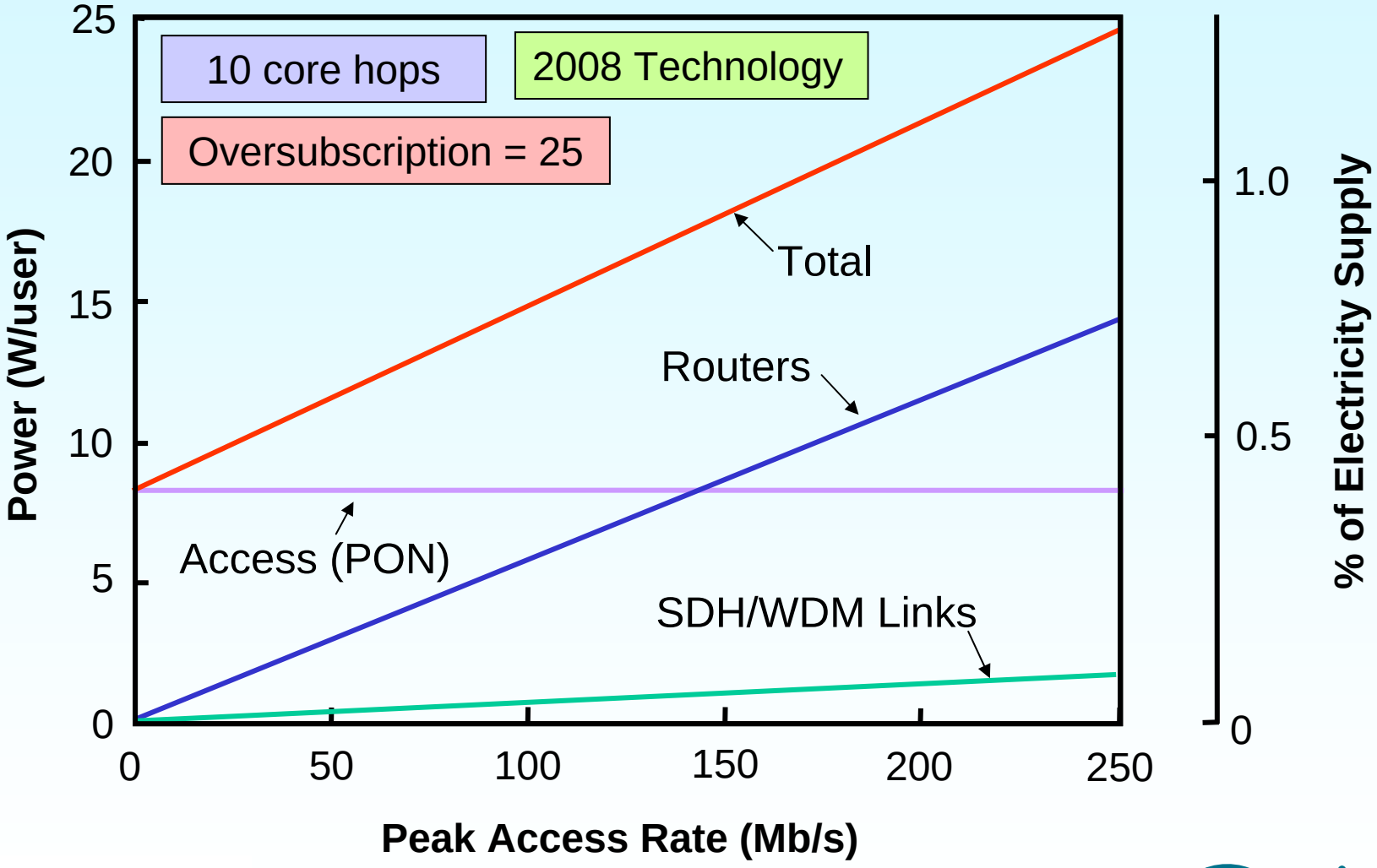
# Router Capacity Growth



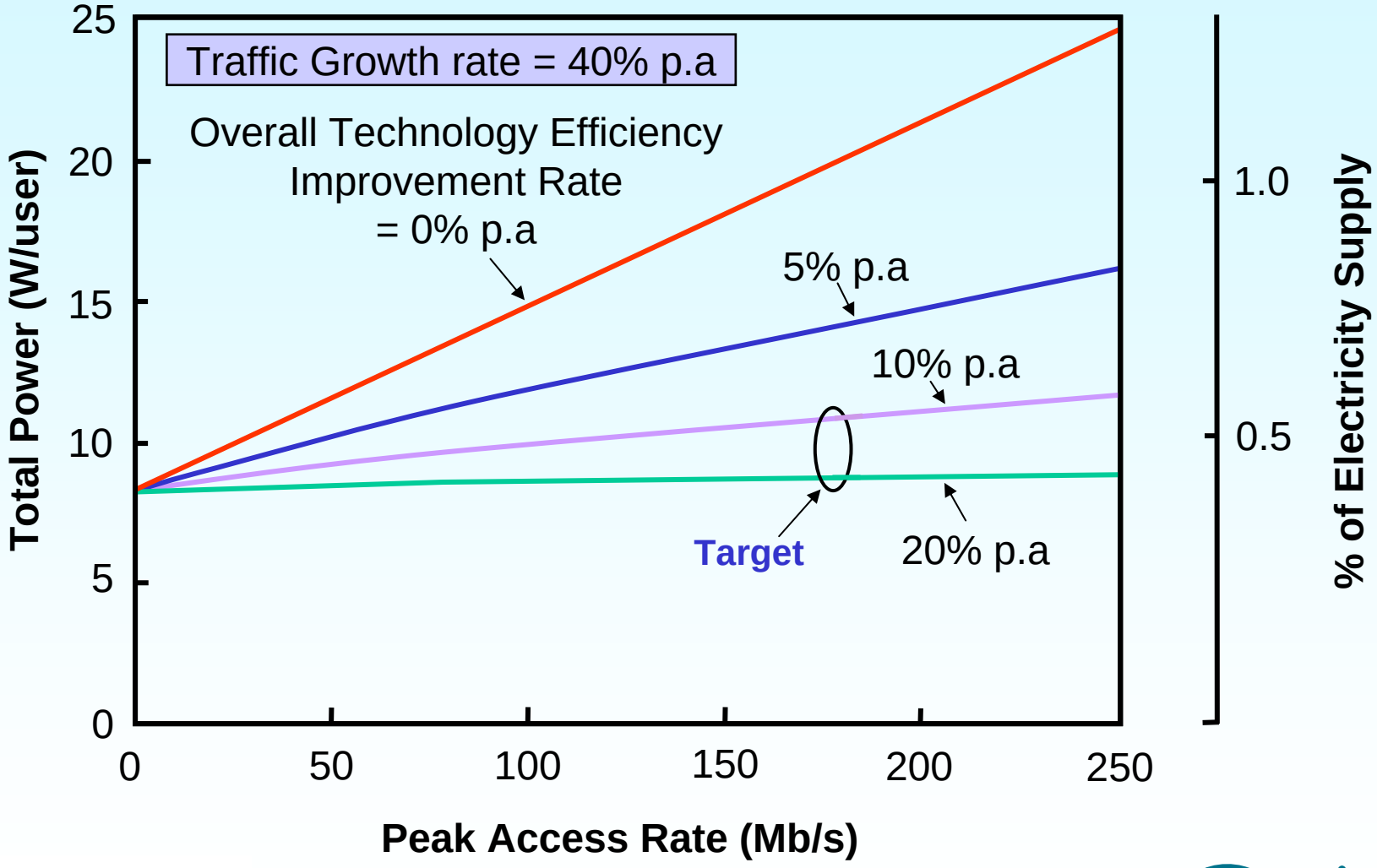

*Based on G. Epps, CISCO, 2006*

# Effect of Efficiency Gains?




*Baliga et al., 2008*

# Improvements in Technology Efficiency




*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

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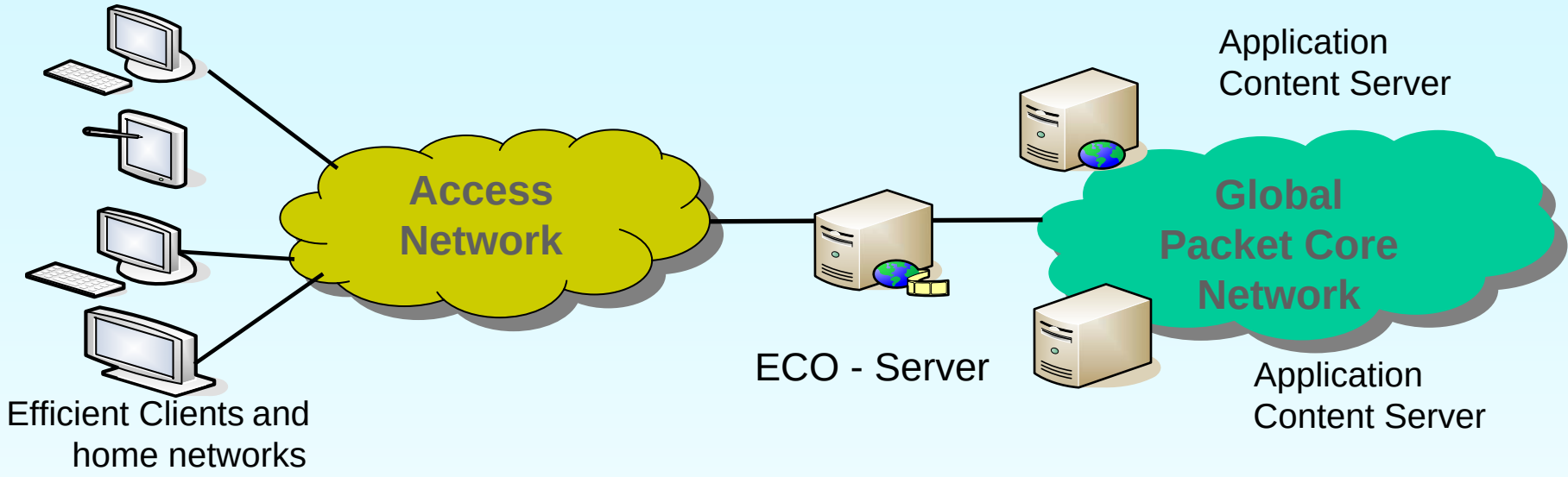
# Towards Energy-Efficient Networks




- 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 MW Data Center

[1]*Koomey, 2008*

[2]*Revolutionizing Data Centre Efficiency—Key Analyses" McKinsey & Company, April 2008.*

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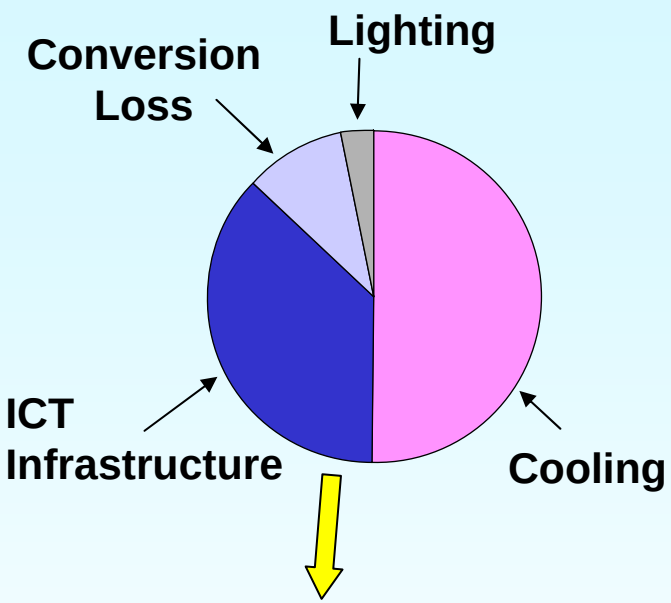
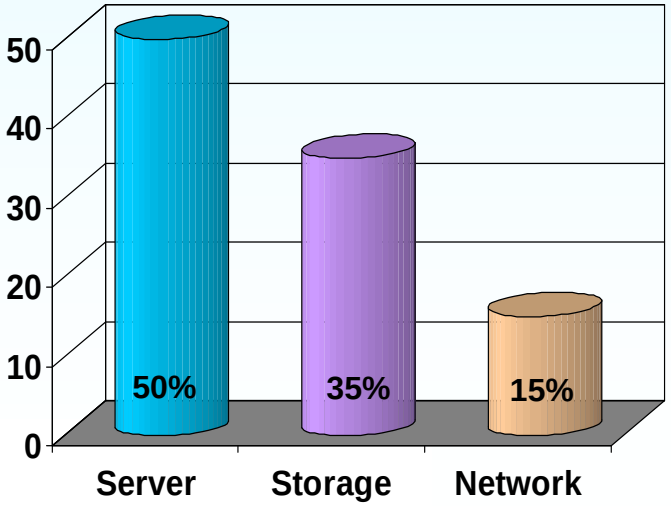
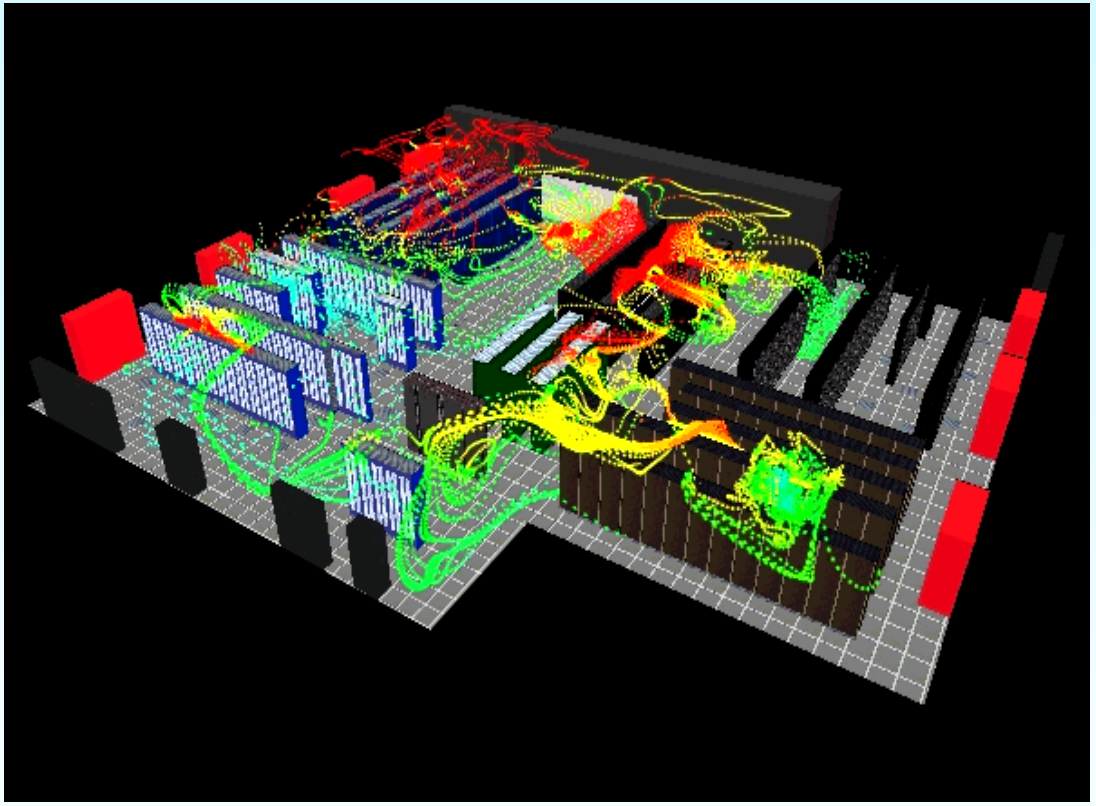
# Energy Consumption in a Data Center



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***

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# Using the Internet for Travel Replacement

## Video Conferencing

Source: CISCO, 2008

# Travel Replacement – Greenhouse Impact ($C0_2$)

## Air Travel

Home

Melbourne

~5,000 kg/person return

LEOS Meeting

Newport Beach

## Video Conferencing


2 X 1 Gb/s for 24 hours
= 20 TB

~100 kg/person

# Teleportation in place of Video Conferencing?

**How much information does the brain hold?**

**Brain Scans: Southern California Brain Research Institute (SCBRI)**

420 TB

Rod Tucker

580 TB

John Marsh

Average LEOS member: (420 + 580)/2 ~ 500 TB

2,000 kg/person return

(50 MW/person for 5 seconds to teleport in each direction)

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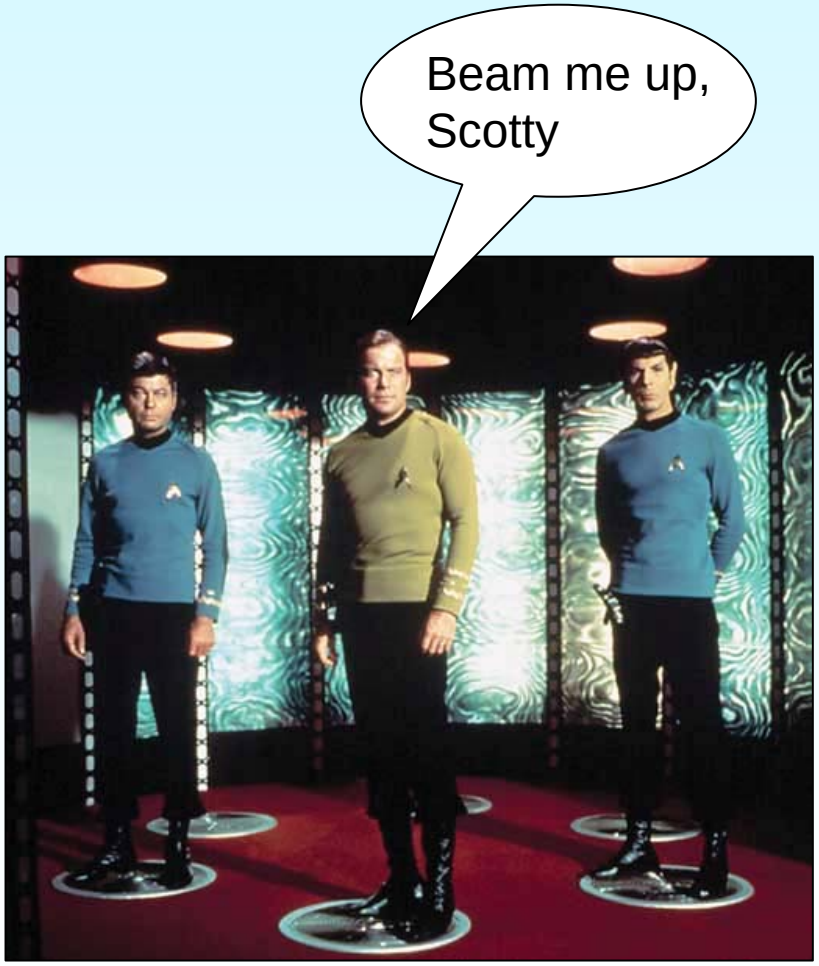
# Embarrassing Moments in Sci Fi

## Teleportation




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

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# Travel Replacement

Air Travel: 5,000 kg/person return

Melbourne

Teleportation: 2,000 kg/person return

Newport Beach

Video Conferencing: 100 kg/person

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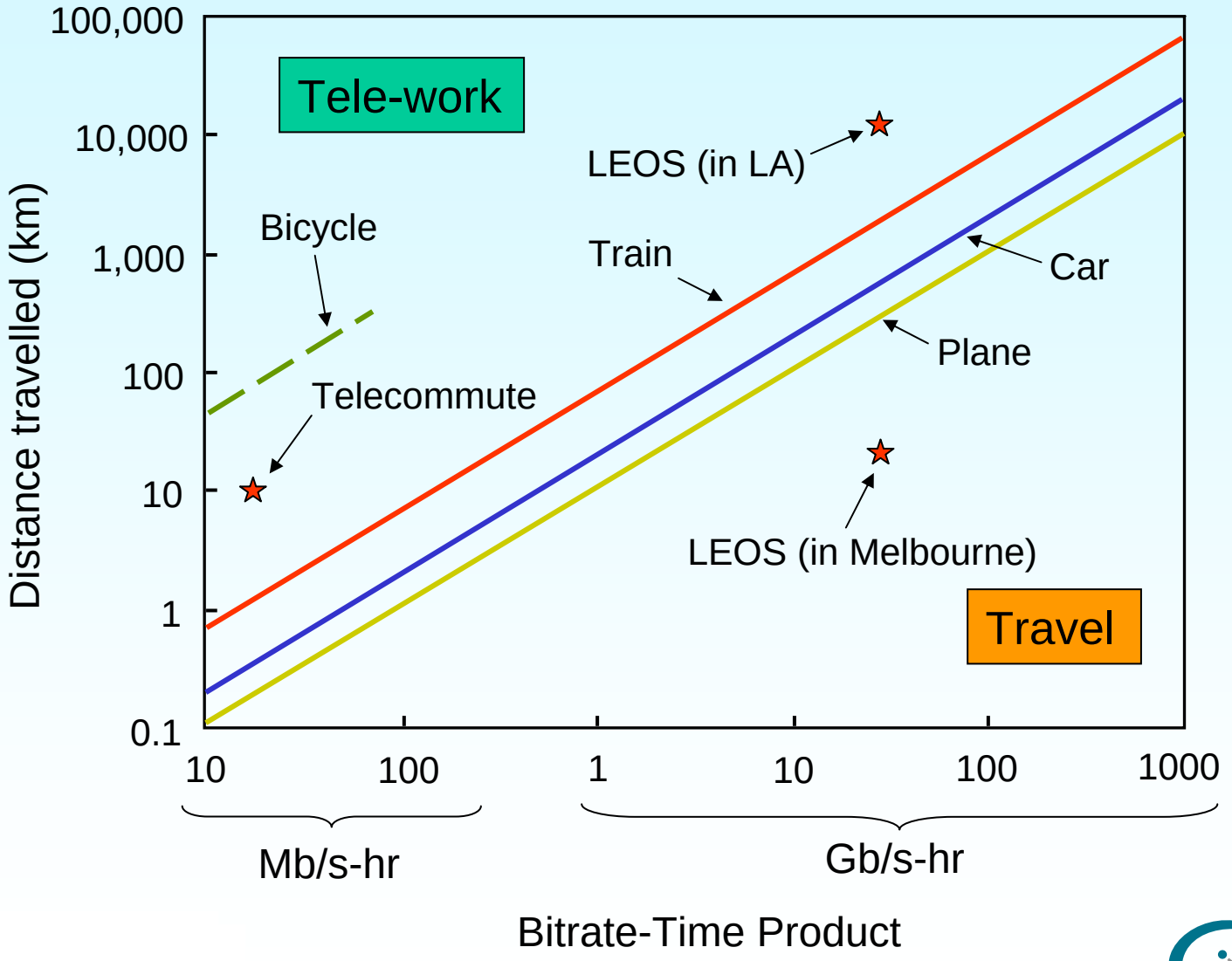
# Rod's Telecommute Calculator

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# Green Photonics

## Low Energy

- PON Access networks
  - GPON, EPON
  - WDM PON
- Optical circuit switching
- Optical bypass
  - low-energy cross connects
  - ROADMs
- Photonic integration
- Optical interconnects
  - Low power Tx/Rx
- Low-energy nanophotonics

## Not so Low Energy

- Non-PON Access networks
  - Wireless
  - HFC
  - FTTN
- Sub-wavelength optical switching
  - Optical packet switching
  - Optical burst switching
- Nonlinear optics for logic & DSP

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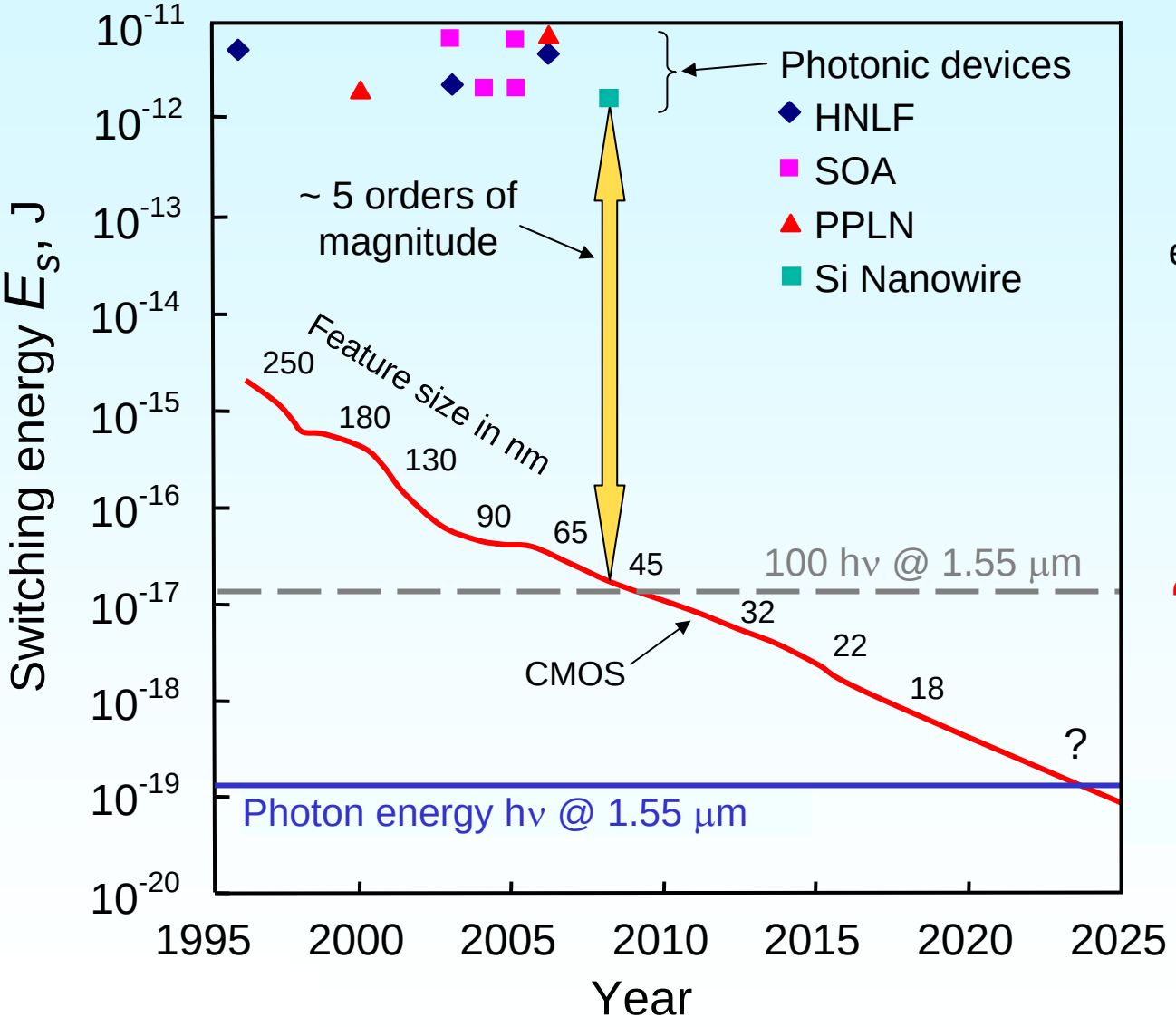
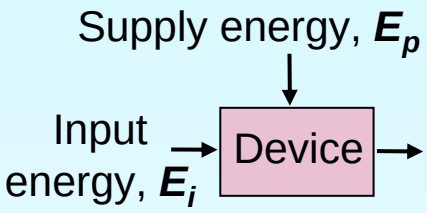
# Every bit Counts




Switching energy

$$E_s = E_i + E_p$$

**"If you are thinking of competing with CMOS, don't":**
***Tingye Li, ~1998***

Sources: ITRS '97-'06 Roadmaps; Hinton et al., JSTQE 2008

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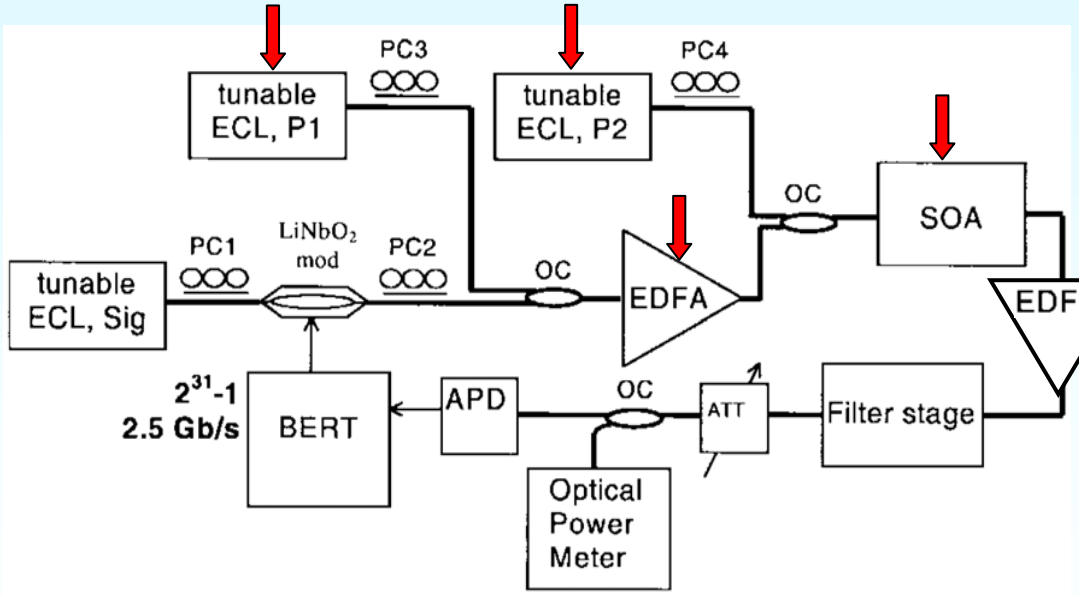
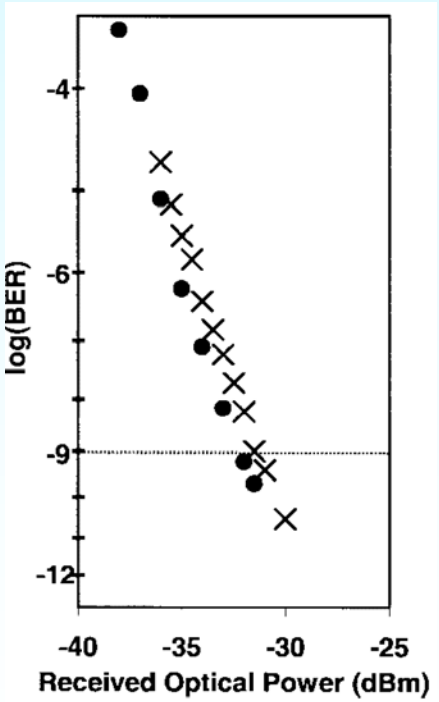
# I was Wrong

IEEE PHOTONICS TECHNOLOGY LETTERS, VOL. 11, NO. 8, AUGUST 1999

## All-Optical Wavelength Translation Over 80 nm at 2.5 Gb/s Using Four-Wave Mixing in a Semiconductor Optical Amplifier

Trefor J. Morgan, *Student Member, IEEE,* Rodney S. Tucker, *Fellow, IEEE,* and Jonathan P. R. Lacey, *Member, IEEE*




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

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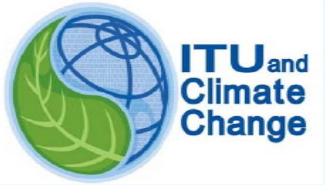
# Groups and Organizations


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/

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# 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:**

  http://www.ee.unimelb.edu.au/green_internet/

- **Workshop on Energy Footprint of ICT: Forecast and Network Solutions, OFC 2009**

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# 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

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