A Green Internet

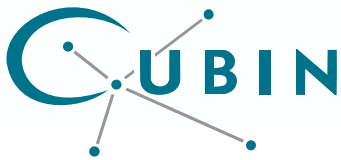
Information Logistics and Energy

Rod Tucker

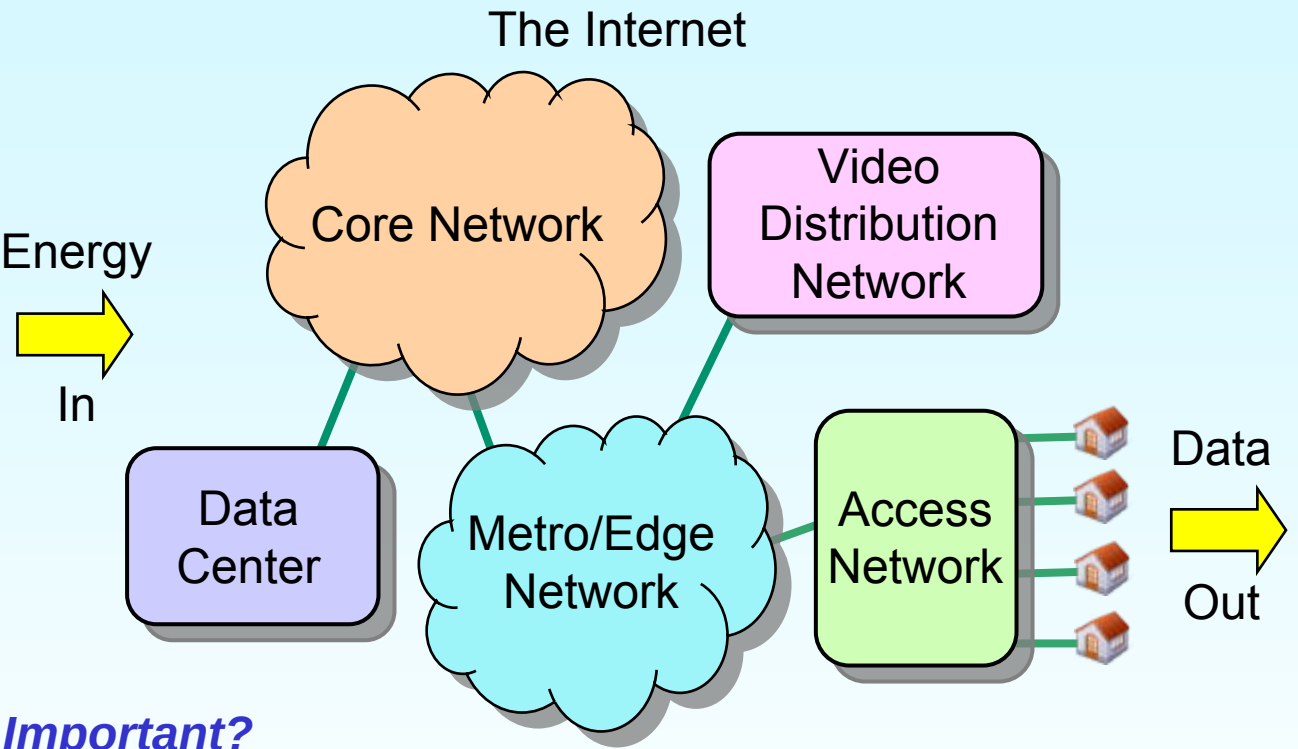
ARC Special Research Centre for
Ultra-Broadband Information Networks (CUBIN)

My Friends:
Jayant Baliga, Kerry Hinton, Rob Ayre

22 April 2009



Energy and the Internet

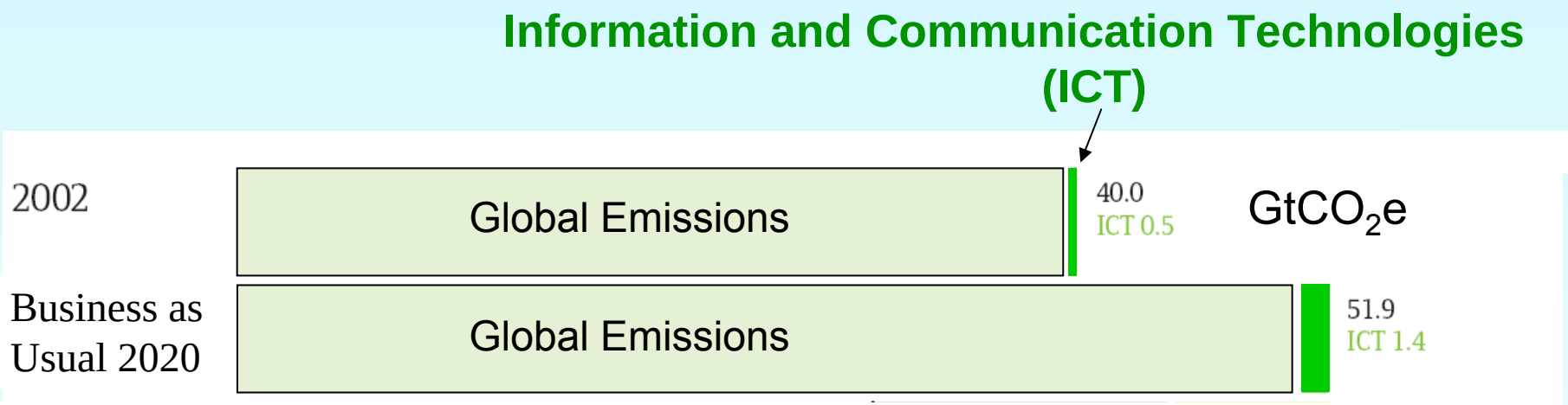


Why is Energy Important?

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

UBIN

Putting Things into Context



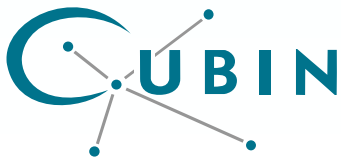
"SMART 2020: Enabling the low carbon economy in the information age," *GeSI, 2008* www.gesi.org

UBIN

Summary

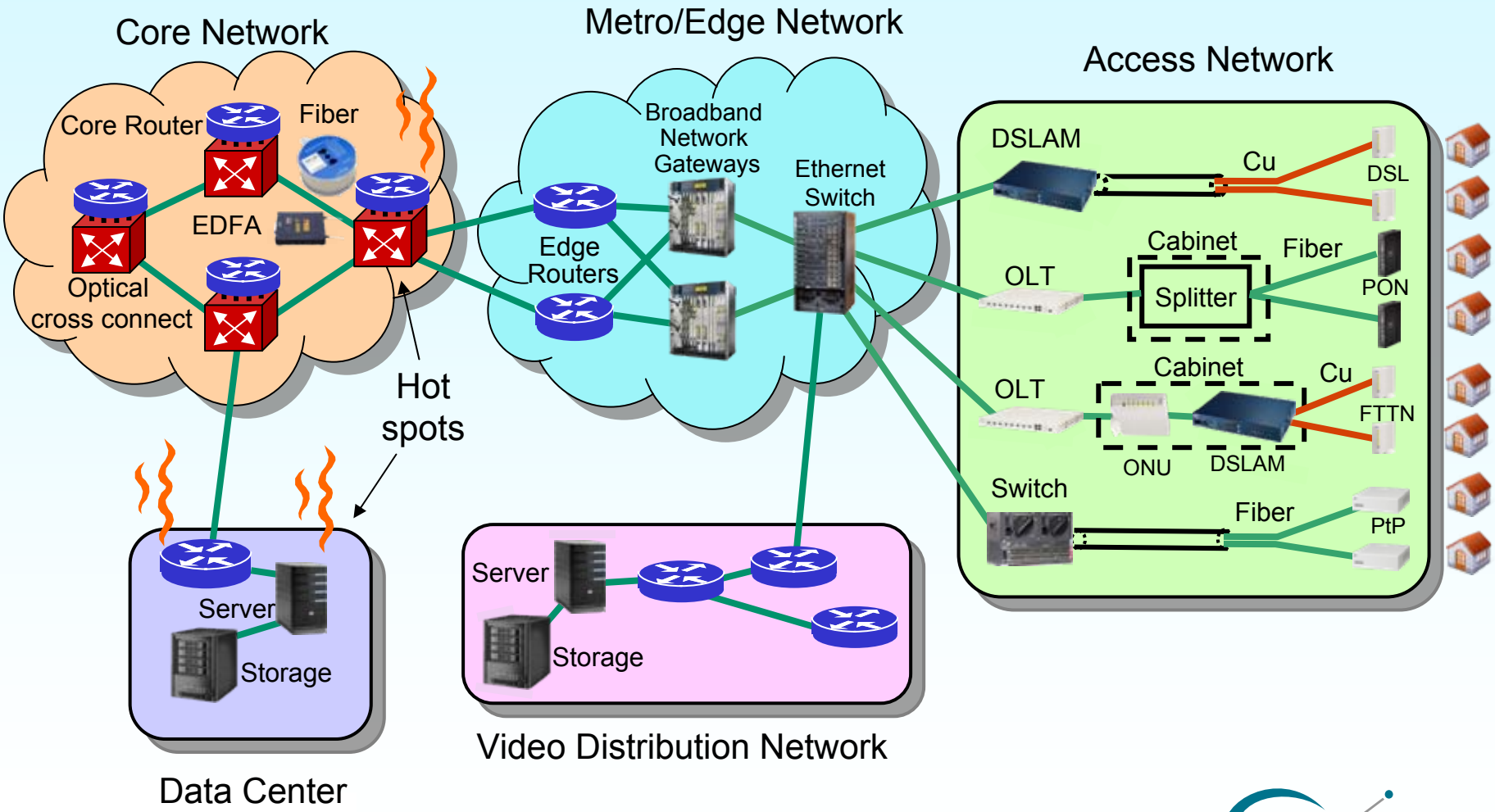
- Estimating energy consumption of the Internet
- Where is the energy consumed
  - Core, metro, access network, data centres?
- Information Logistics
  - Cloud Computing
  - Travel Replacement
  - Airmail vs. Internet
- The Khazzoom-Brookes postulate

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

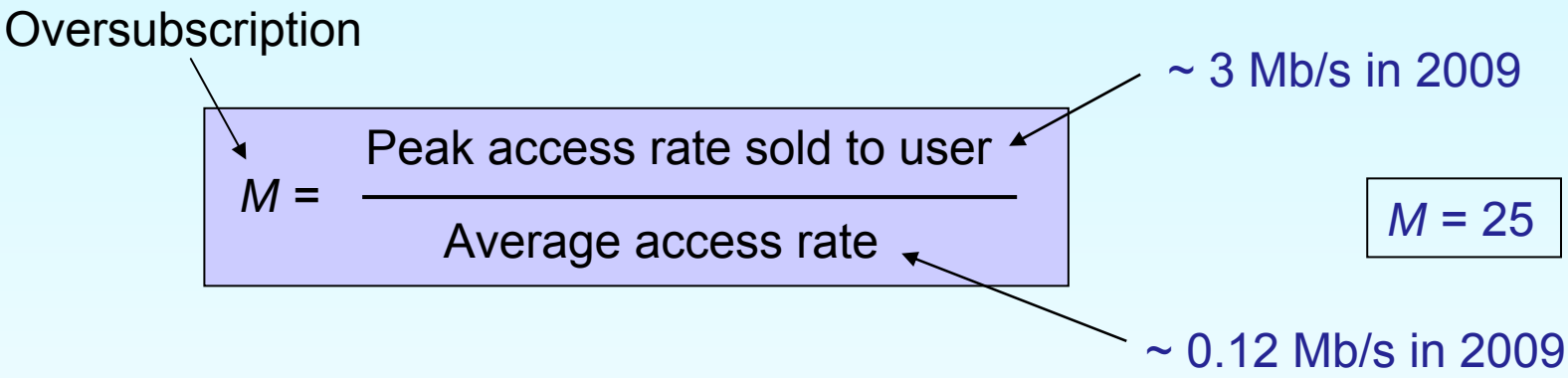


Network Energy Model

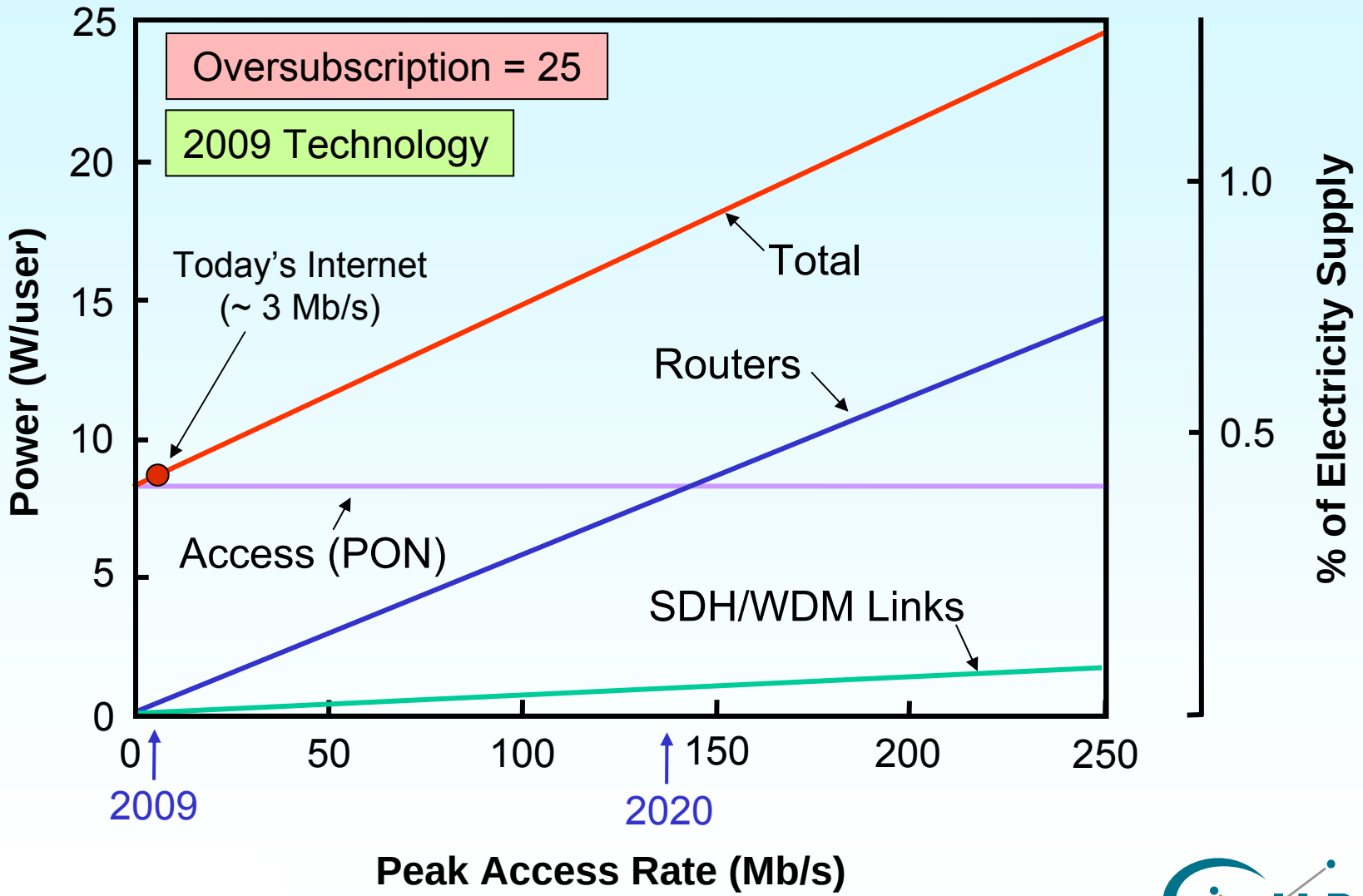
Tier 1 Network



Oversubscription



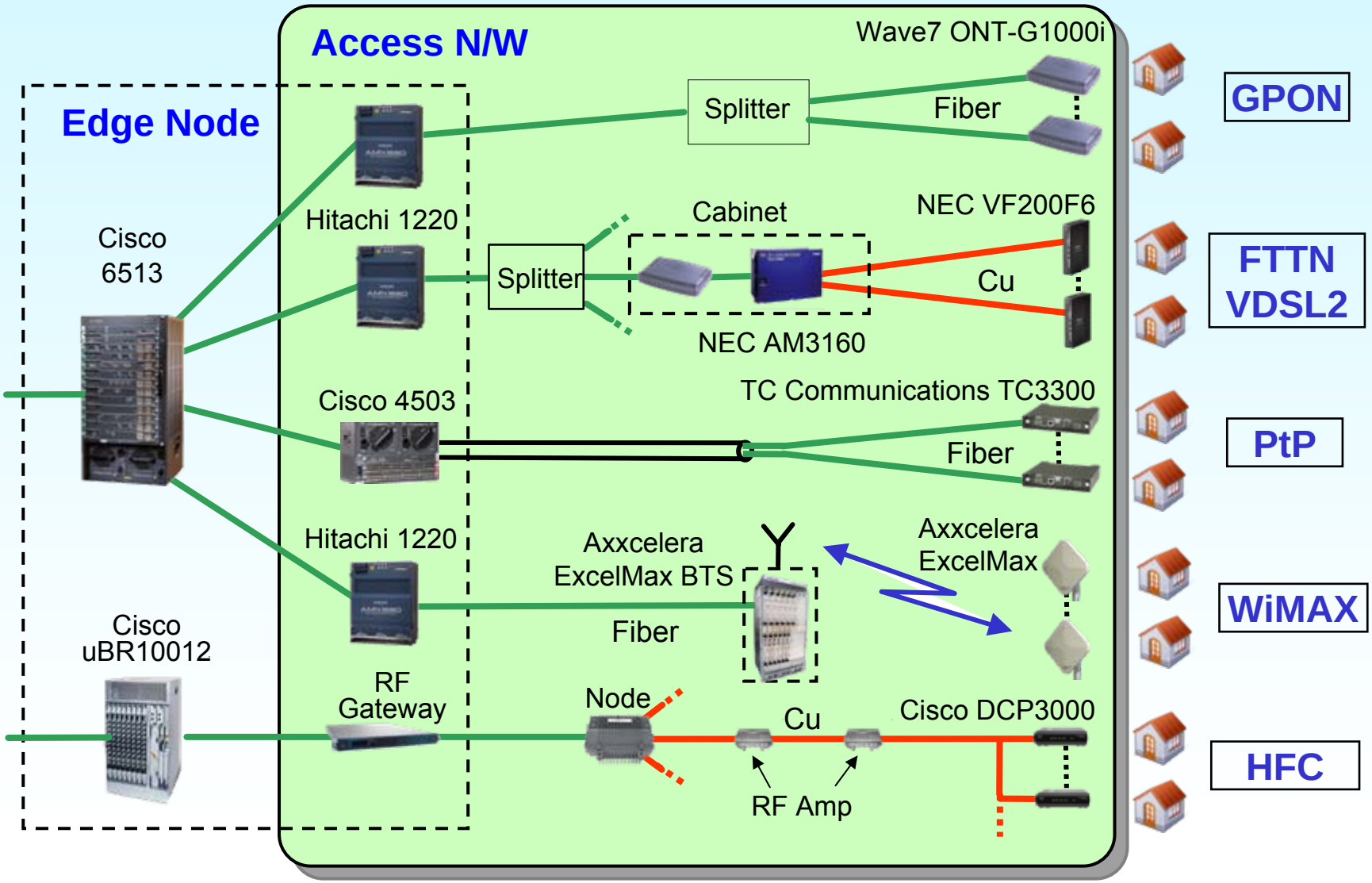
Power Consumption of IP Network



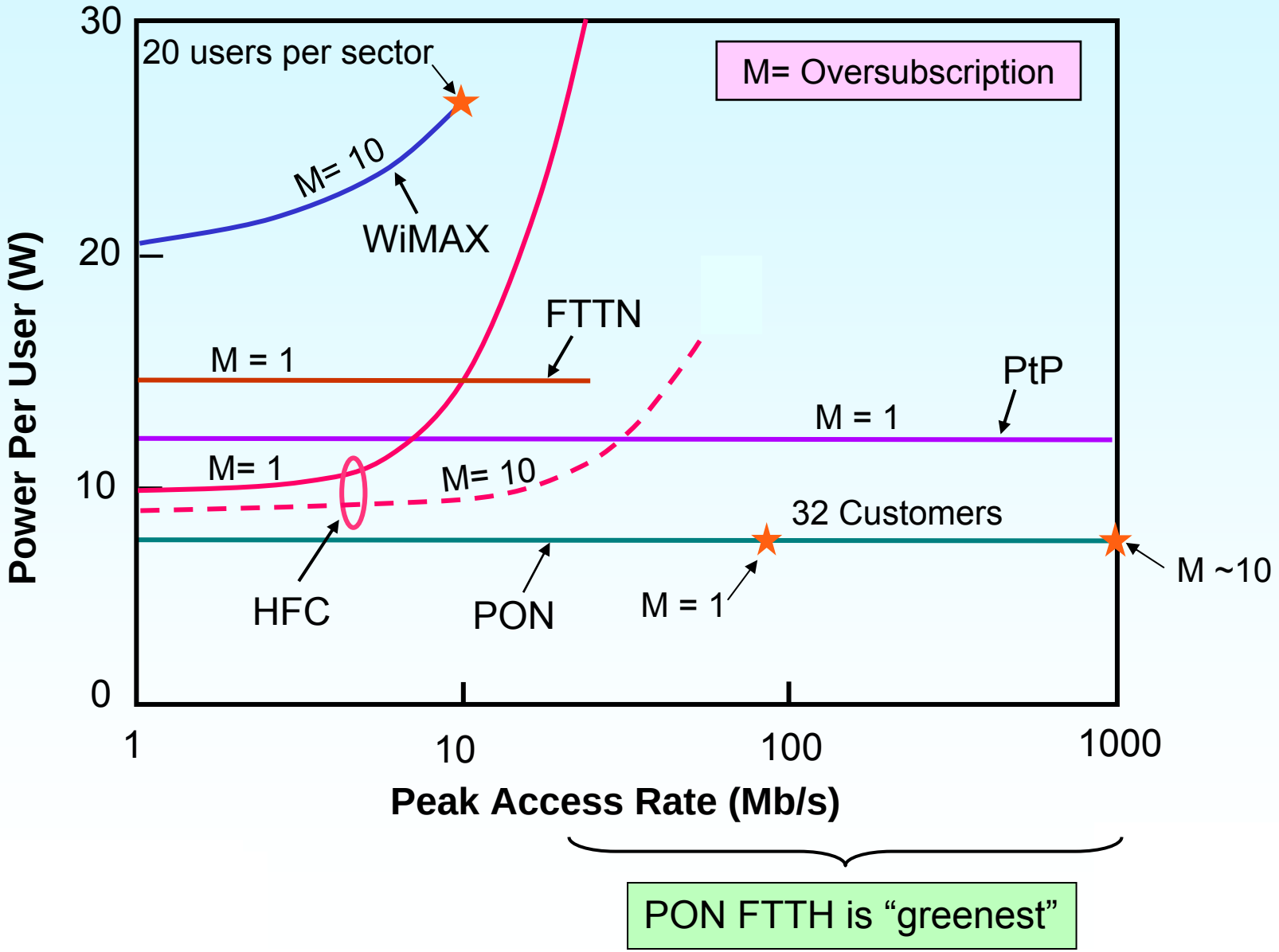
Traffic Growth = 40% p.a

UBIN

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

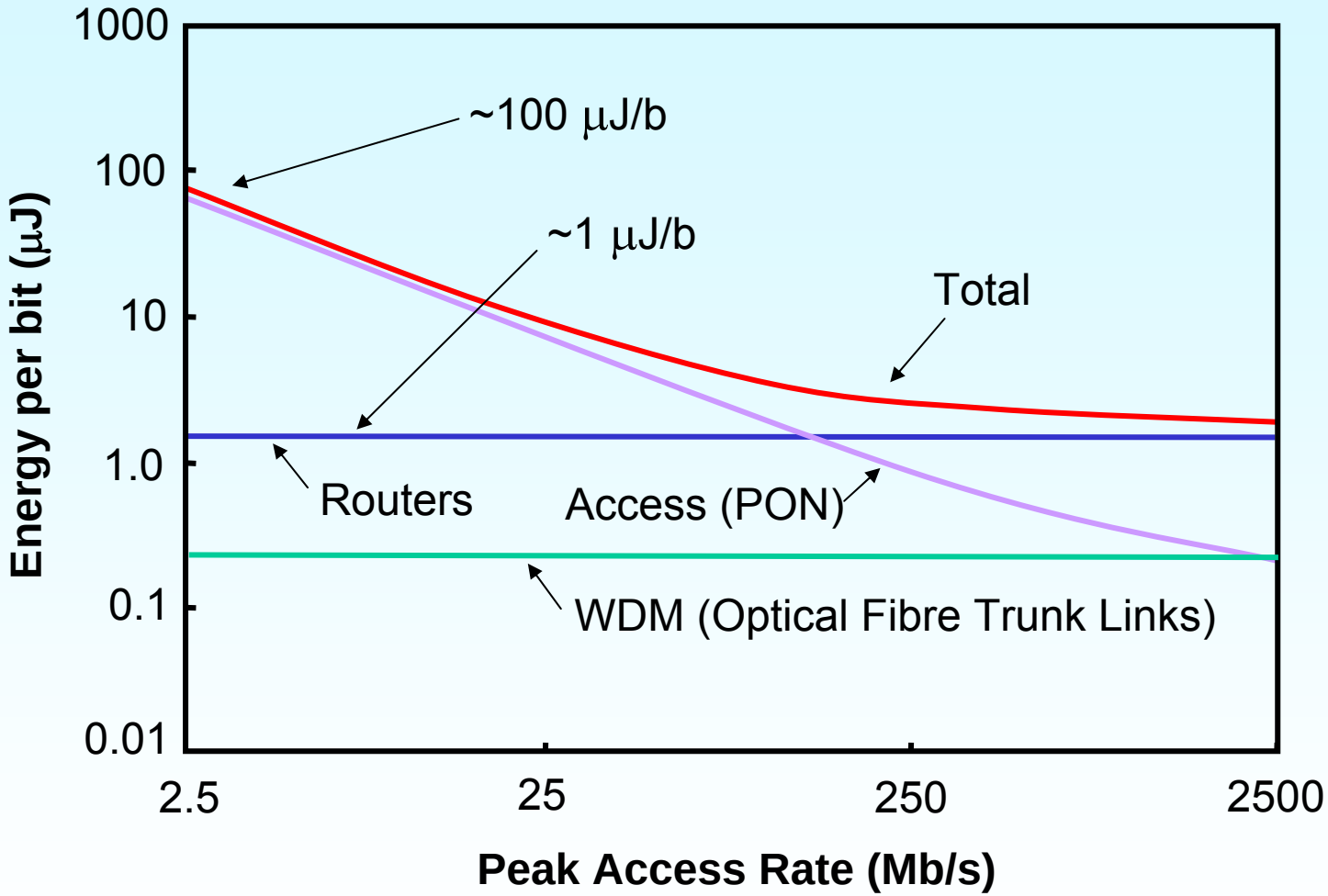
Draft Version 3
Issue 15 – 17 July 2008

"With implementation of this Code of Conduct,… 5.5 Millions tons of oil equivalent (TOE) will be saved per year."

Extract:

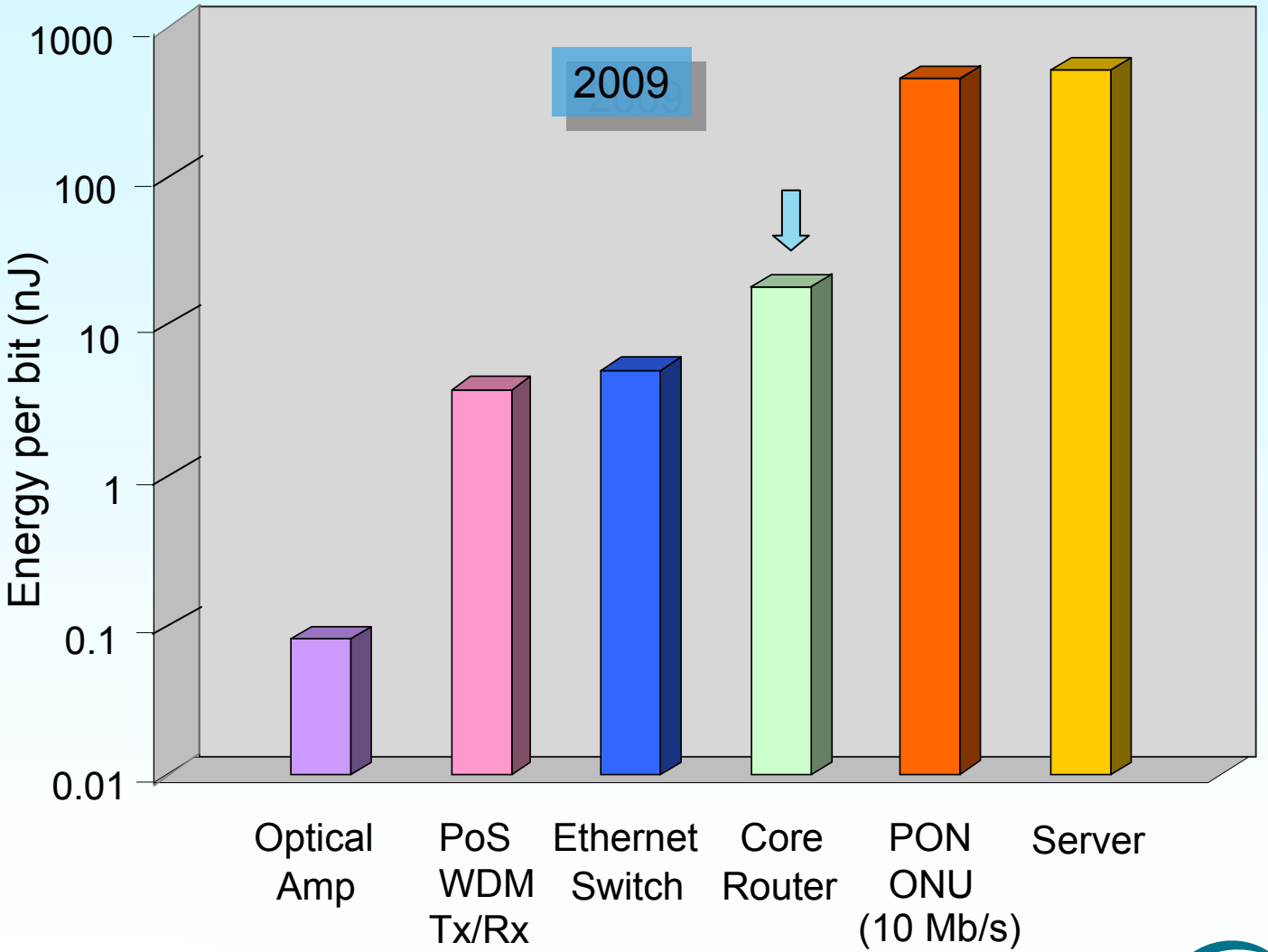
	Off-State (W)	Low-Power State (W)	On-State (W)
ADSL-CPE	0.3	3.5	4.0
VDSL2-CPE	0.3	4.5	6.0
GPON ONU	0.3	5.0	9.0
PtP ONU	0.3	3.0	5.0

Network *Energy* Consumption *per Bit*



UBIN

Energy per Bit in Network Devices

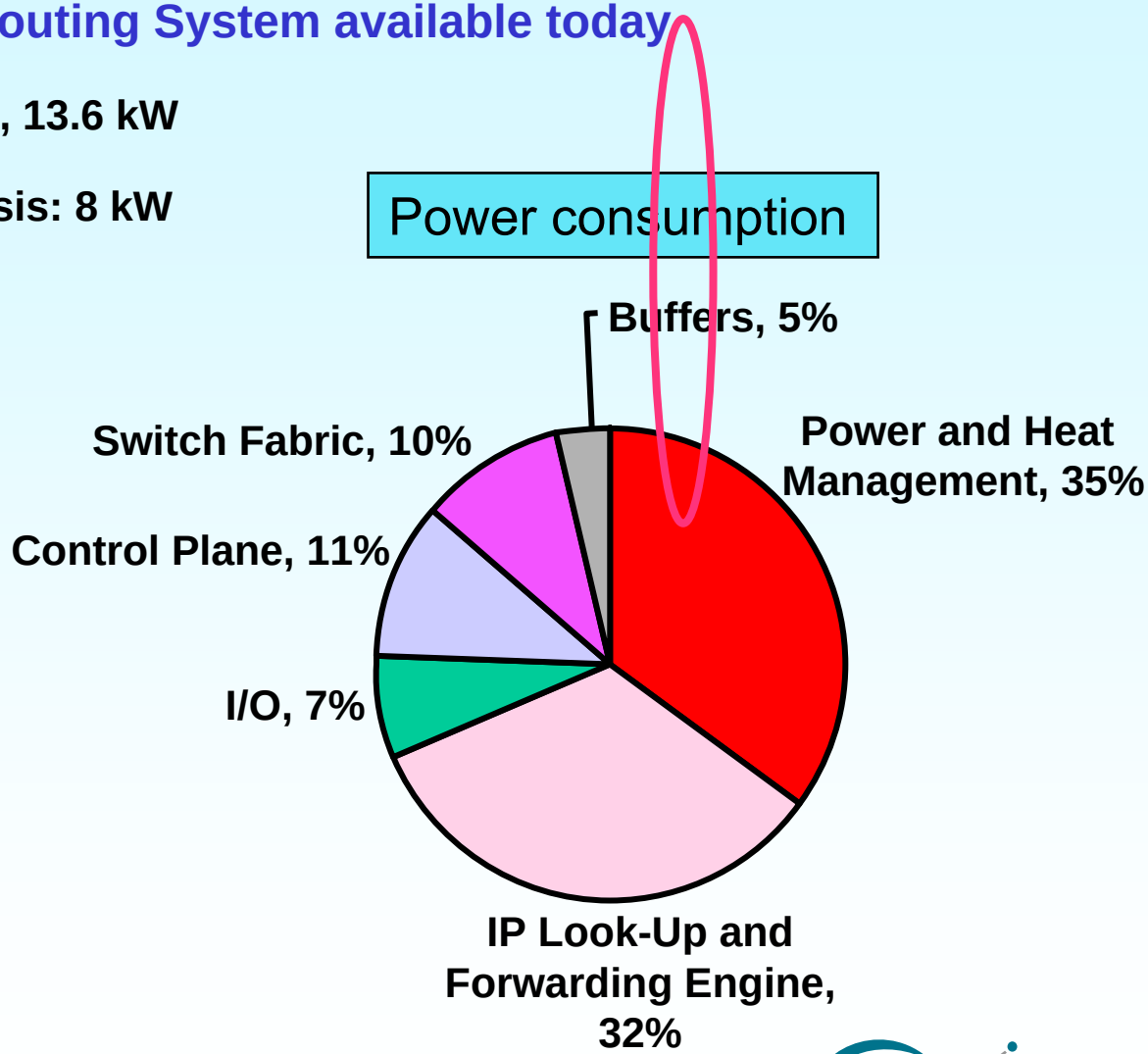


Cisco CRS-1 Router

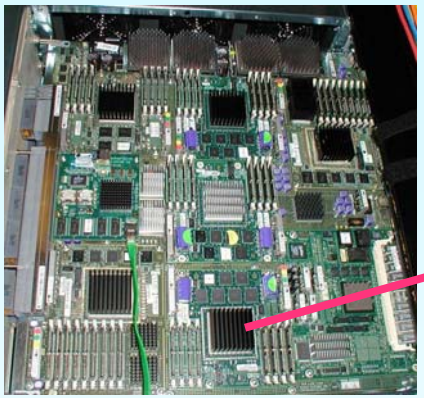
Largest Routing System available today

Linecard Chassis: 1.28 Tb/s, 13.6 kW

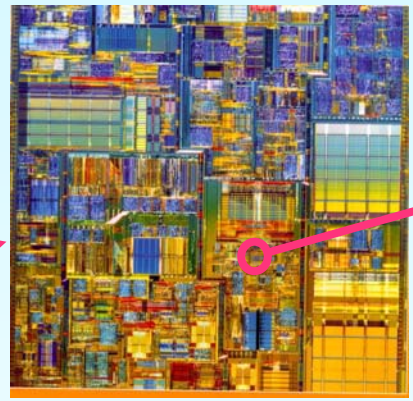
Switch Fabric Chassis: 8 kW



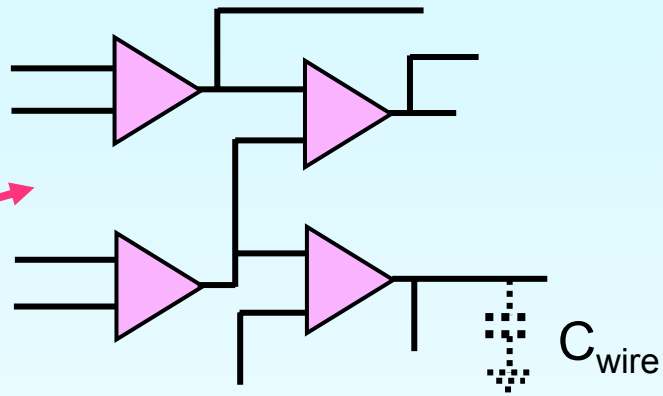
Energy in Electronic Integrated Circuits



Linecard



CMOS ASIC

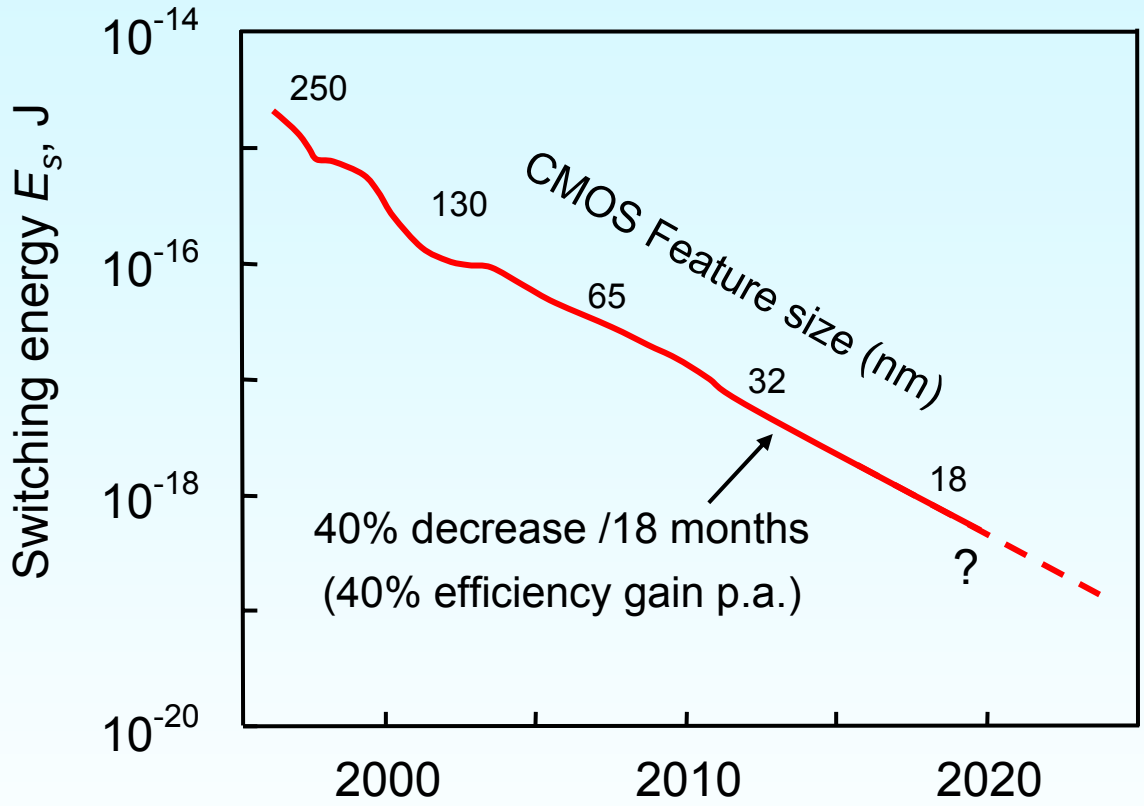


CMOS Gates

$$\text{Energy} = \sum E_{gate} + \frac{1}{2}\left[\sum C_{wire}\right]V^2$$

Power = Energy x Bit Rate

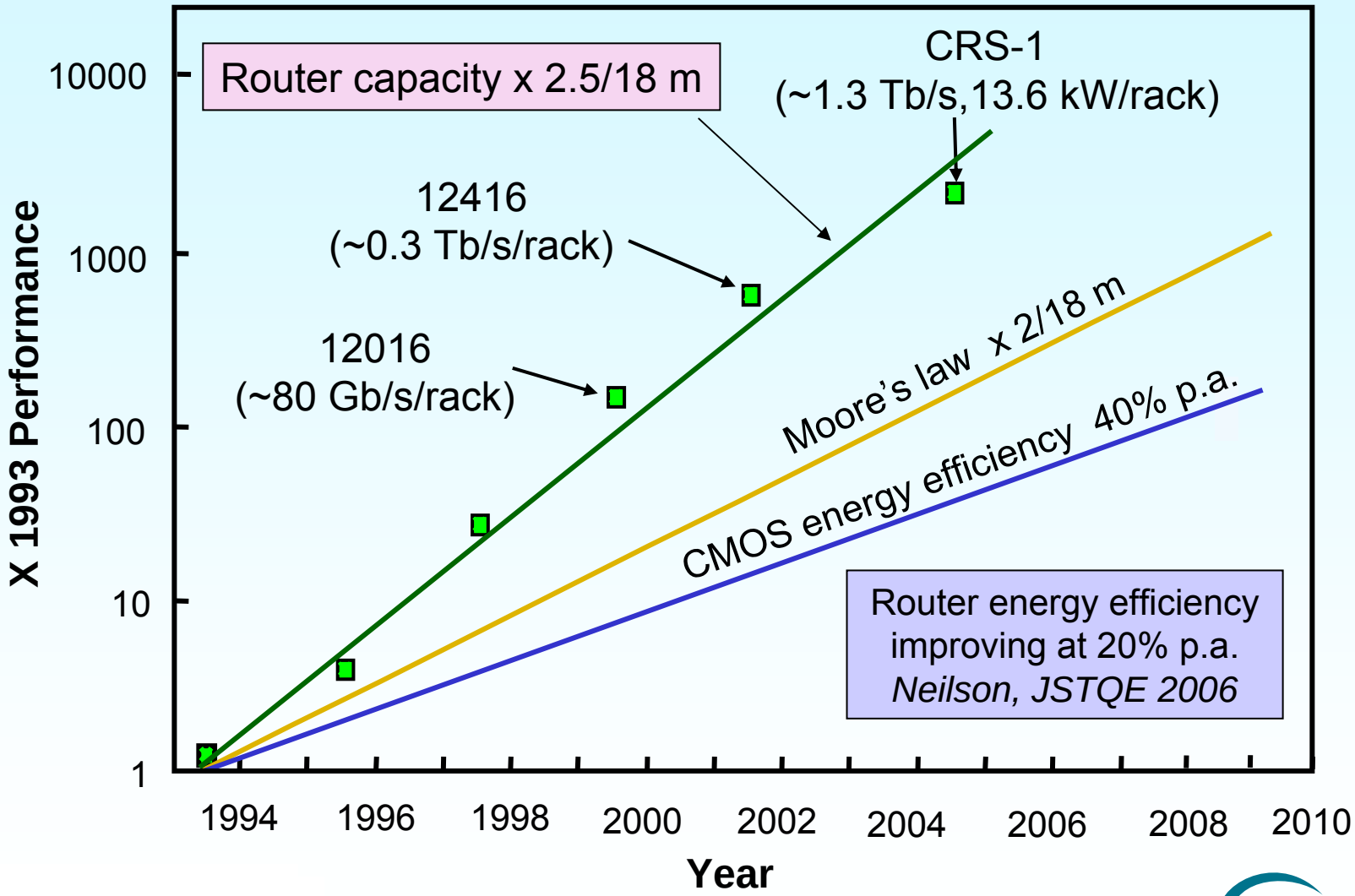
Switching Energy in CMOS



Moore's Law: Number of transistors x 2 each 18 months

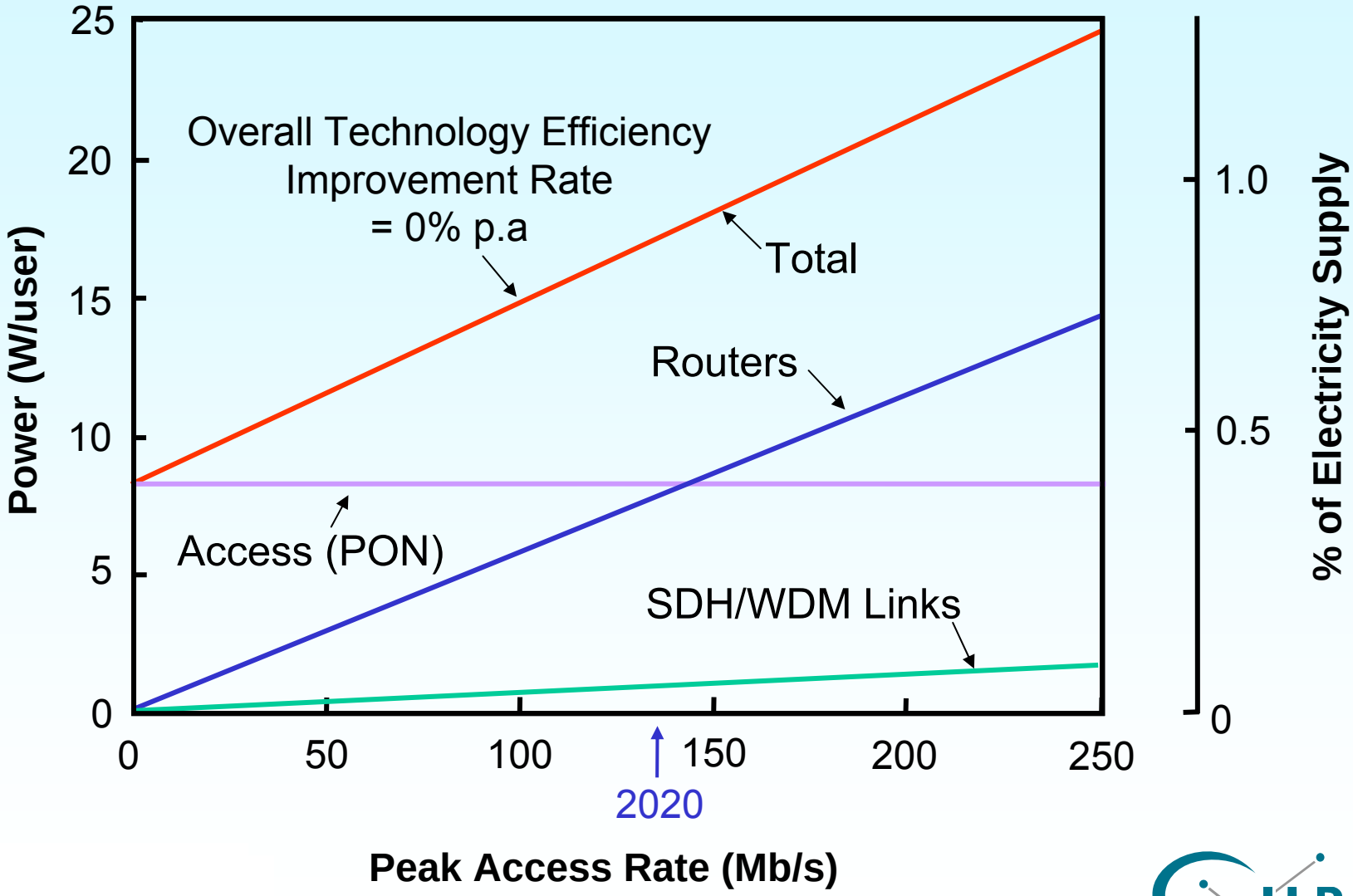
Source: ITRS '97-'06 Roadmaps

Router Capacity Growth



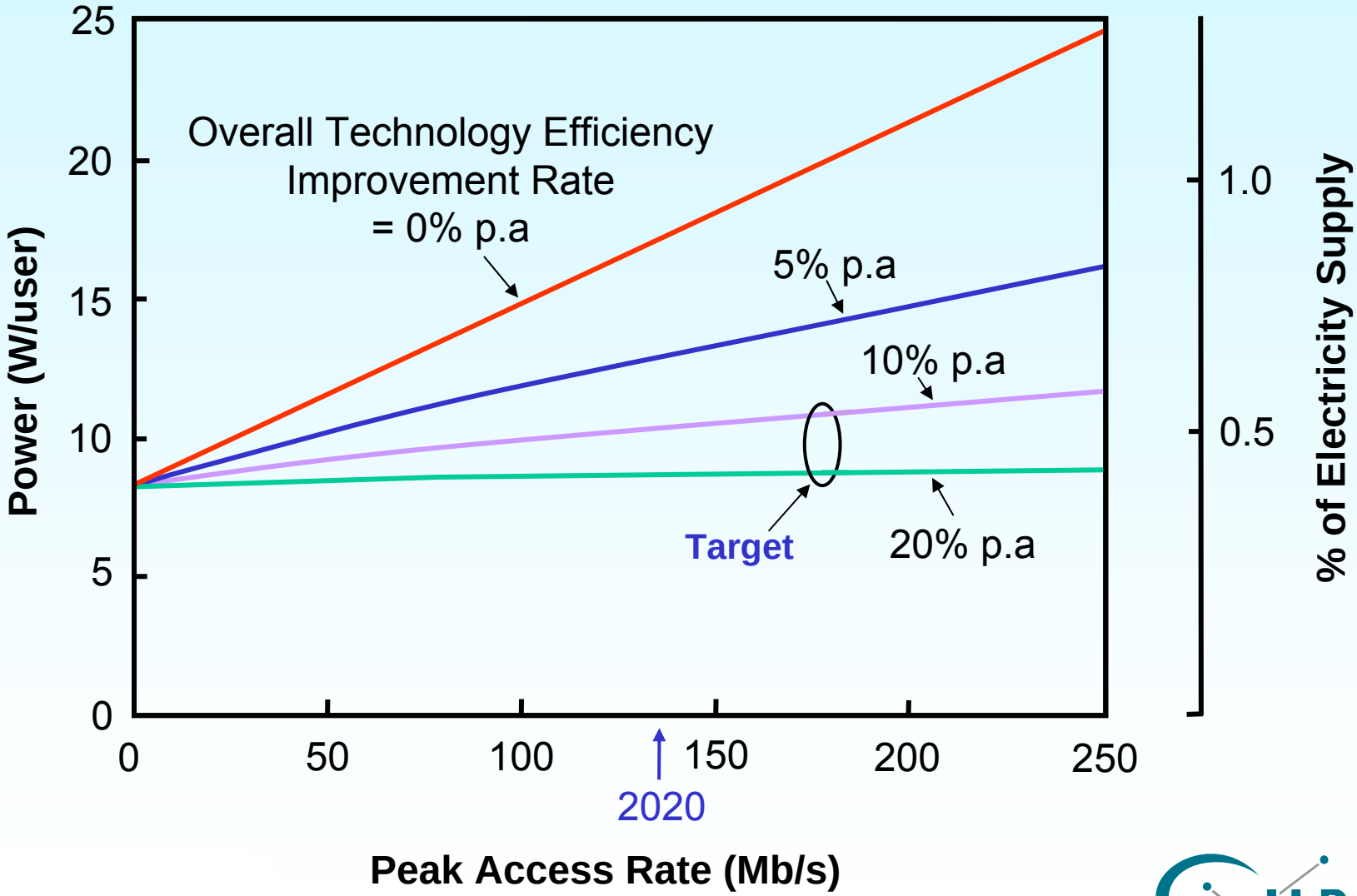
Based on G. Epps, CISCO, 2006

Effect of Efficiency Gains



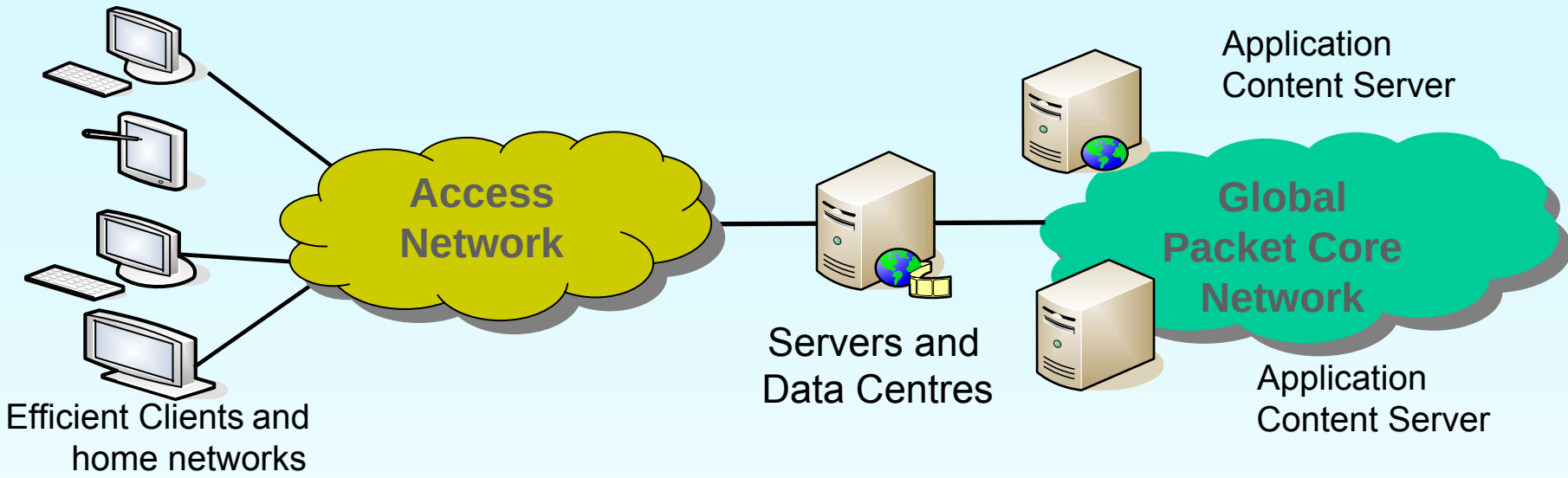
Baliga et al., 2008

Effect of Efficiency Gains



Baliga et al., JLT, 2009

Towards Energy-Efficient Networks



- Alternatives for complex PC
- Sleep mode and fast “wake up”, adaptive modes of network and clients

- Sleep mode
- 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
- Content delivery networks (e.g. IPTV)

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 2008 and 2010 is the equivalent of 10 new power plants[2]

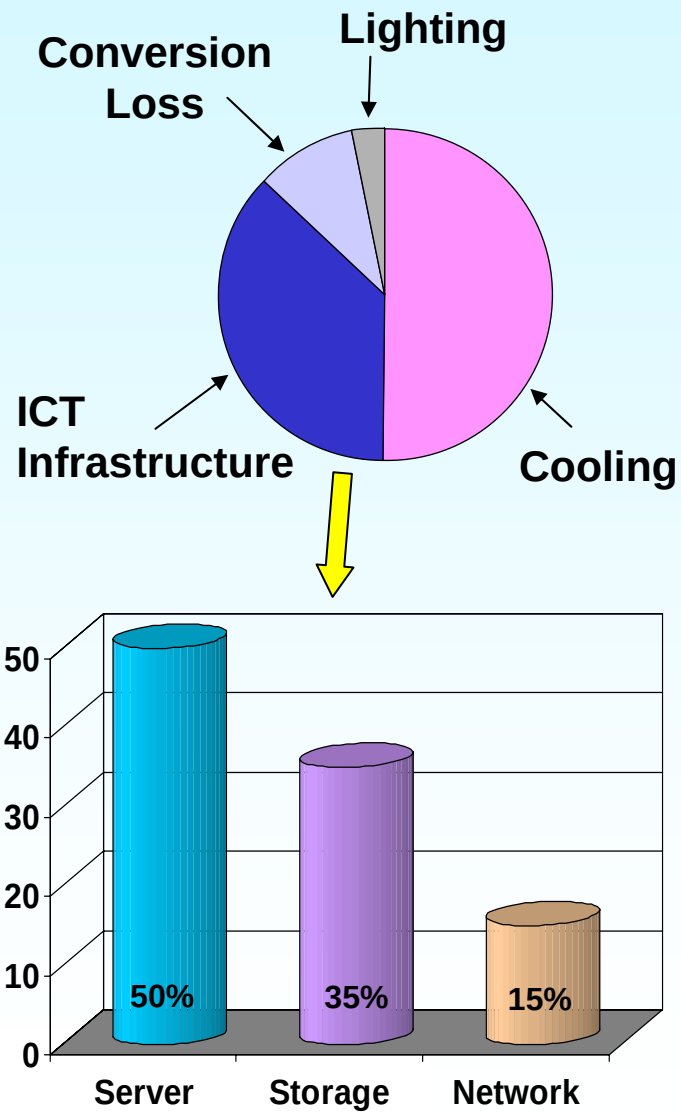
1 MW Data Center

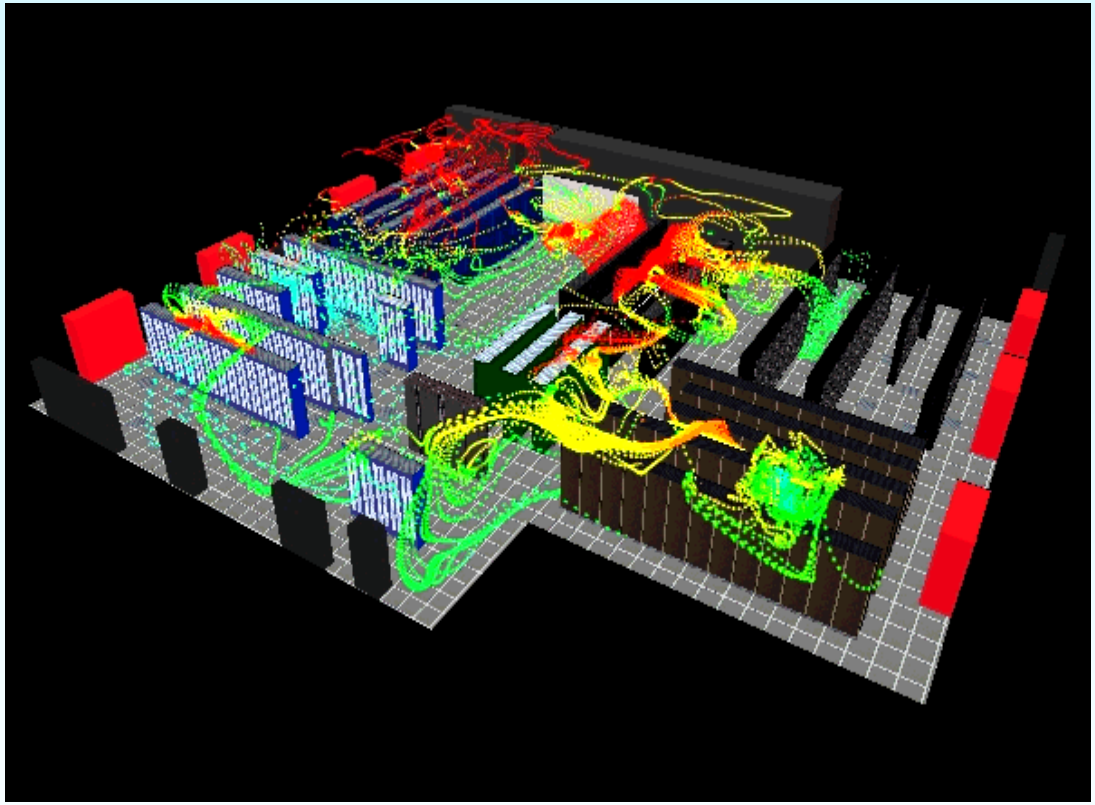
[1]*Koomey, 2008*

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

CUBIN

Energy Consumption in a Data Centre





"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

CUBIN

Information Logistics

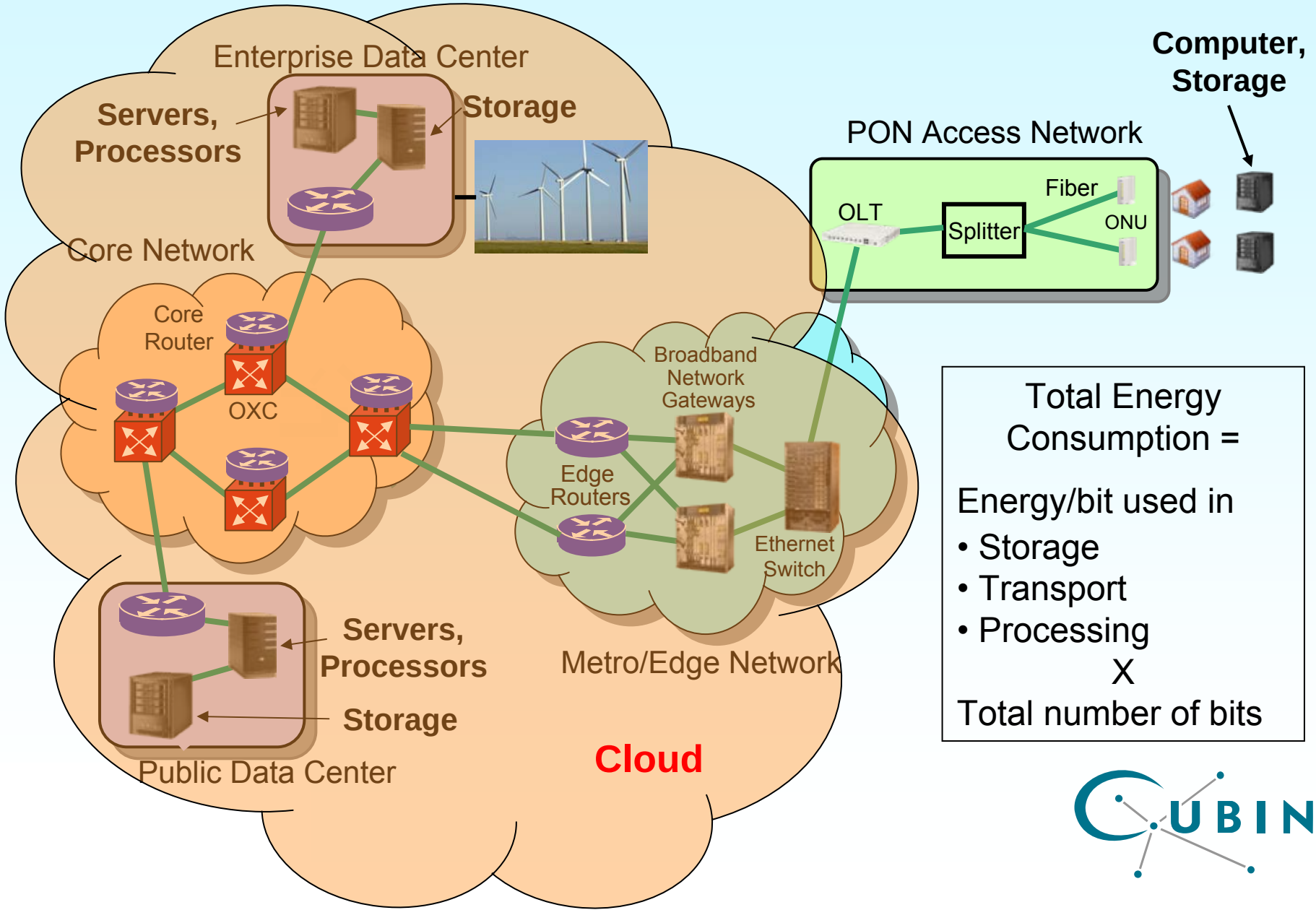
Management of data, including, transport, storage, and processing

Some typical issues/questions:

- **Wired vs. wireless broadband access**
- **Can Cloud Computing save energy?**
- **Renewable energy sources**
- **Physical vs. Internet delivery of data**
- **Can Internet Travel replacement save the planet?**
- **Optimum design of Video on Demand systems**

CUBIN

Cloud Computing



Total Energy Consumption =

Energy/bit used in
- Storage
- Transport
- Processing

X

Total number of bits

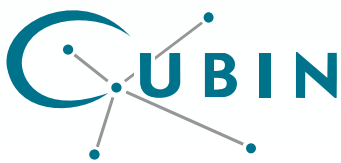
Three Cloud Computing Scenarios

- **Software-as-a-Service**
  - **Stored on user's computer with updates downloaded regularly**

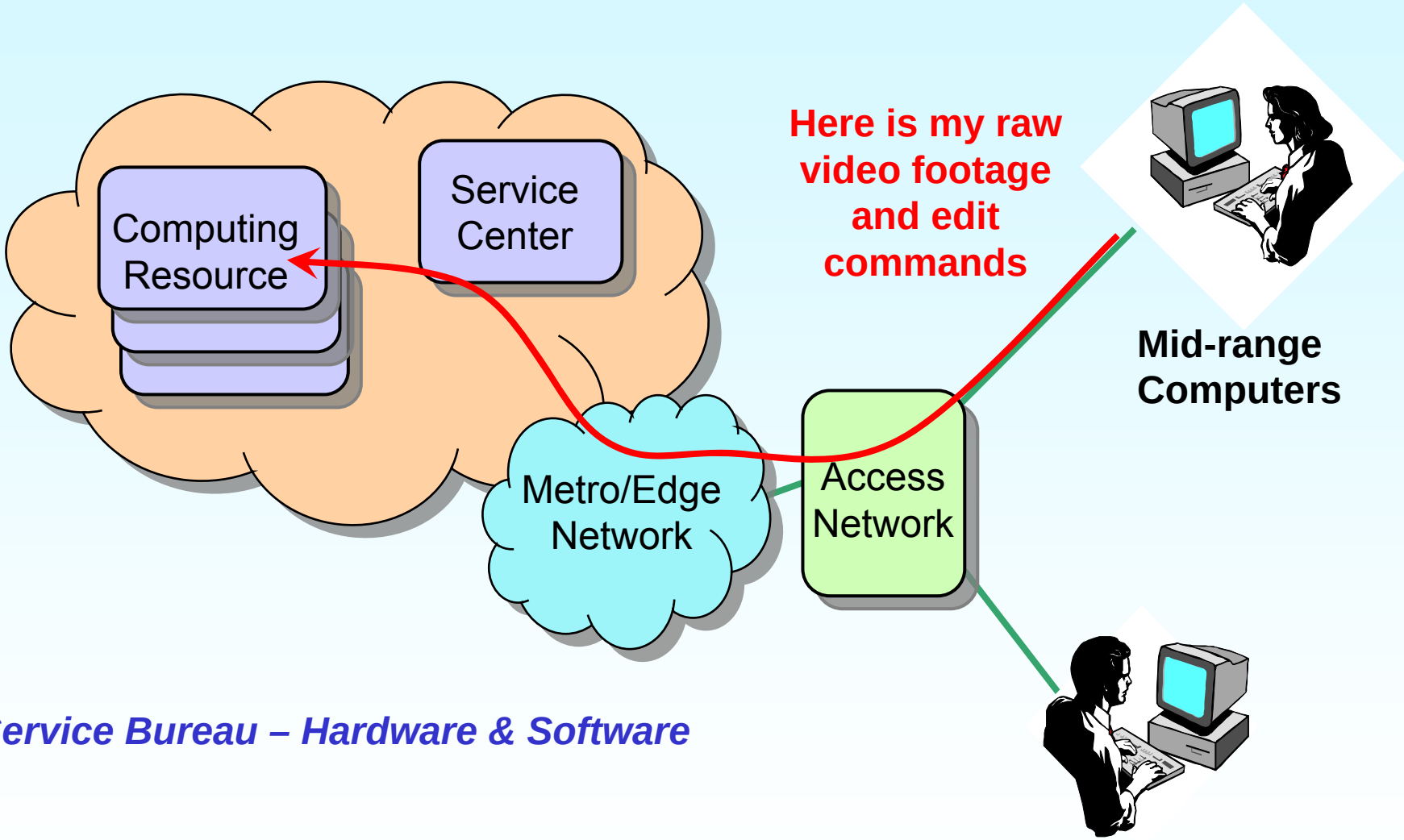
- **Service Bureau**
  - **Most tasks done on lower end user machine, outsource the "big" jobs**

- **Computing-as-a-Service**
  - **Hosted and run on provider computer "farm" with data initially uploaded from user (Thin client model)**

Can cloud computing save energy ?

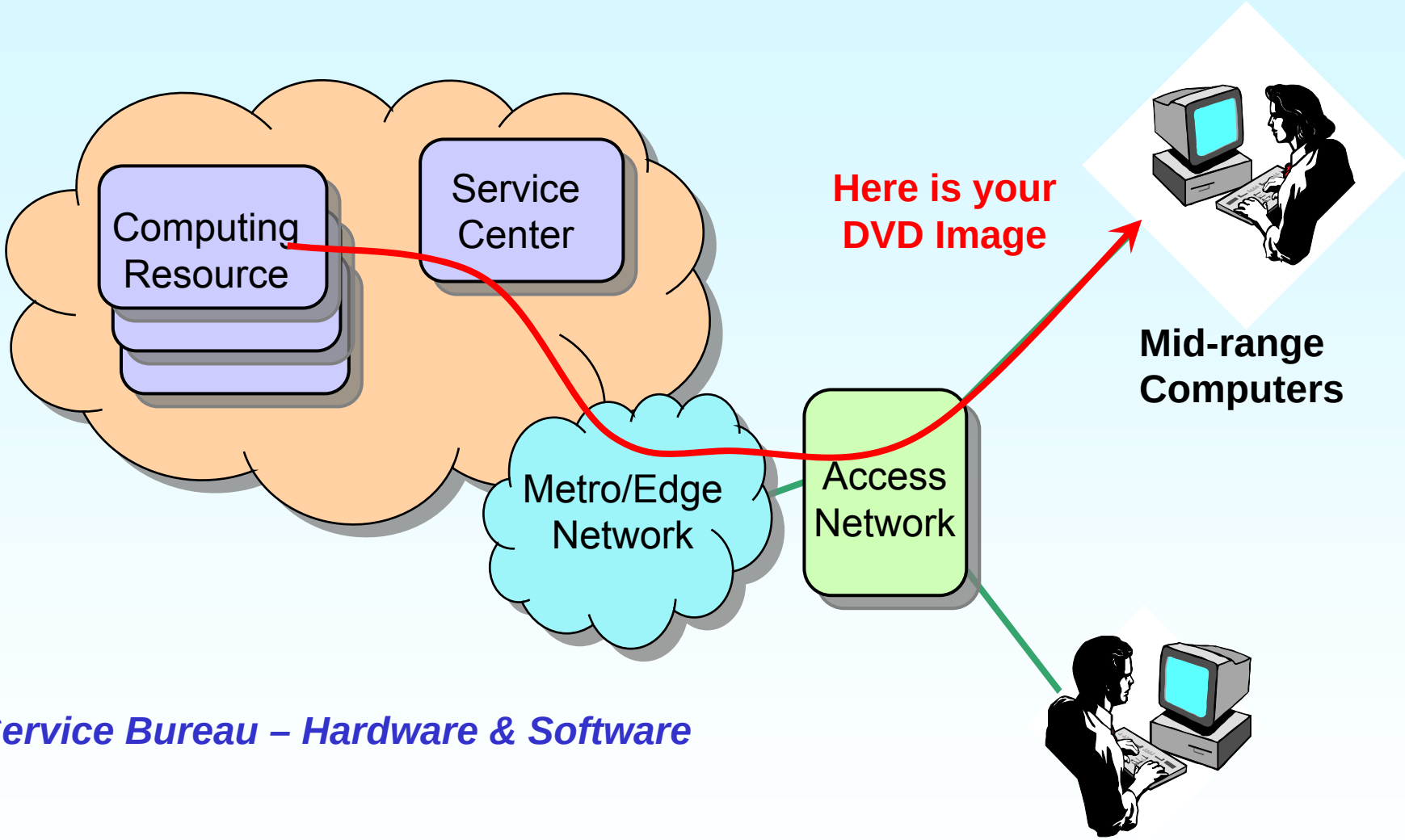


Service Bureau



Service Bureau – Hardware & Software

Service Bureau

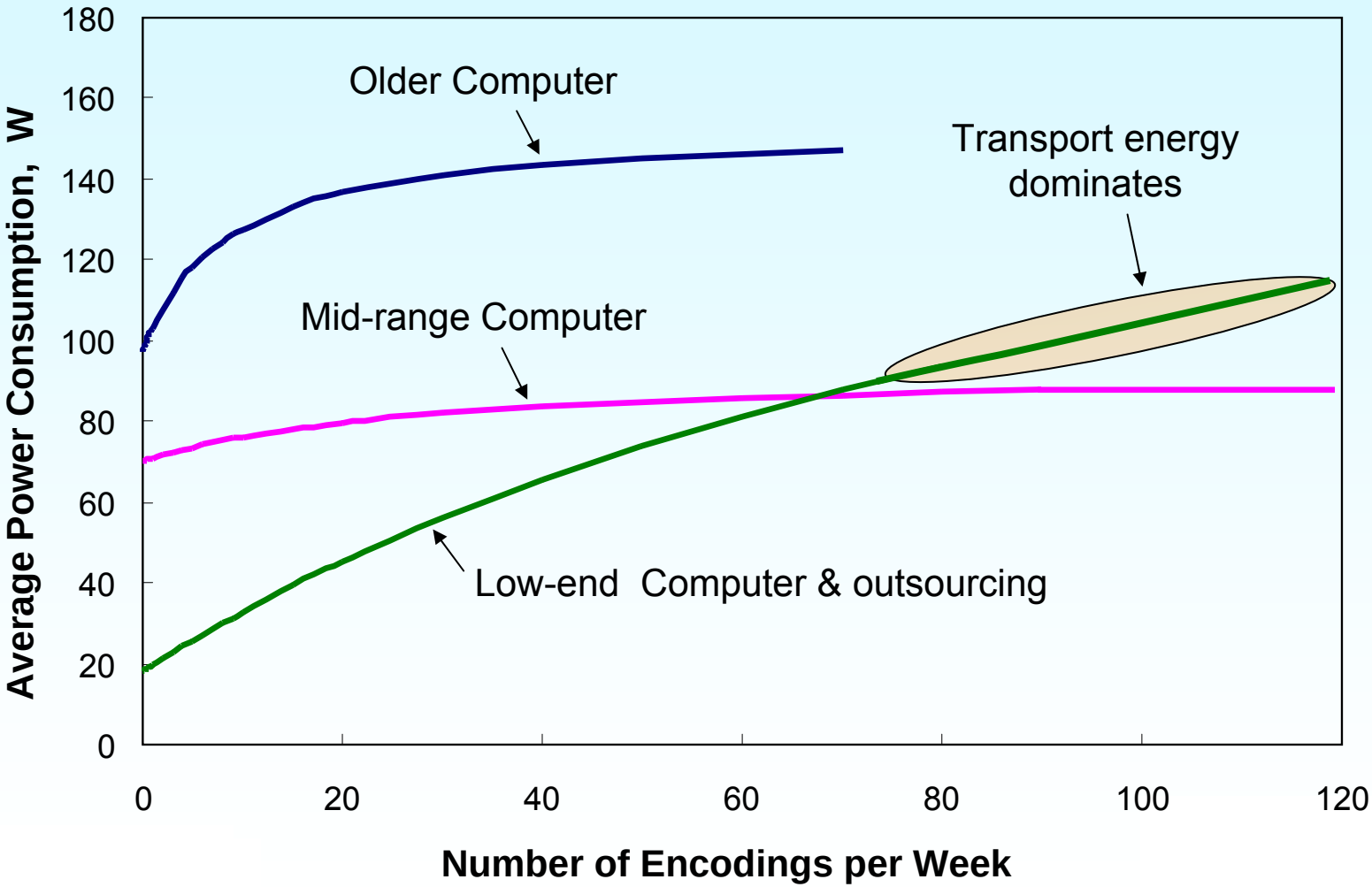


Service Bureau – Hardware & Software

CUBIN

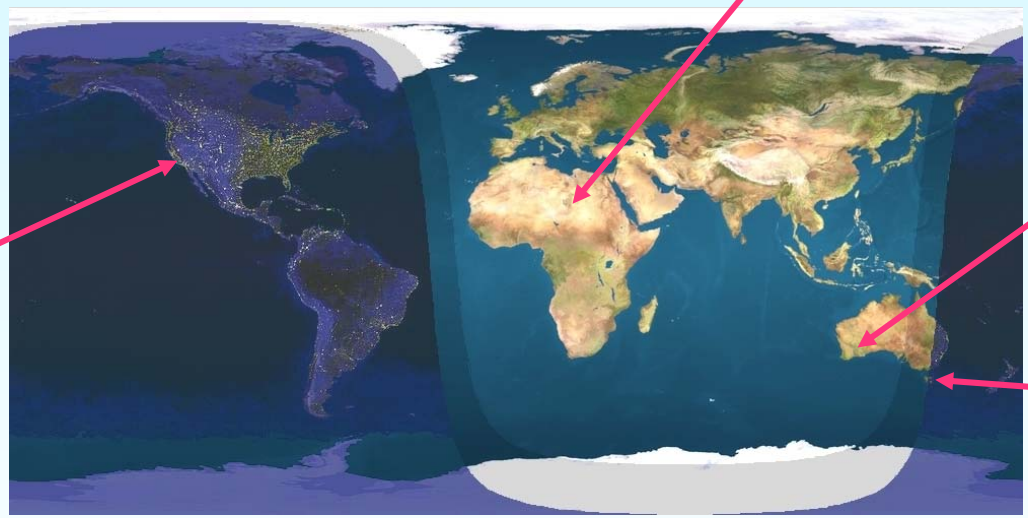
Energy Consumption of Service Bureau Model

Computer used for 20 hrs/week, plus some video encoding of ½ hour videos

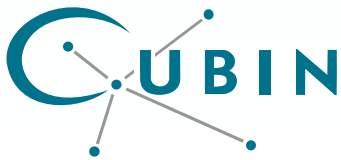


Following the Sun and the Wind

Making best use of renewable energy



- Locate computing and storage resources near sources of renewable energy
- Move data to follow the sun and winds
- Requires many orders of magnitude increase in a data transport capacity
- Transport/efficiency trade-off



Data by Airmail vs. Data by the Internet

Data by Airmail:

Melbourne

$3x10^5$ 32-GB flash drives

Cargo Jet

Sydney

10^7 GB

10^3 kg CO_2

20 nJ/b

(24 hours)

Data by Internet:

10^7 GB

1000 Gb/s for 24 hours

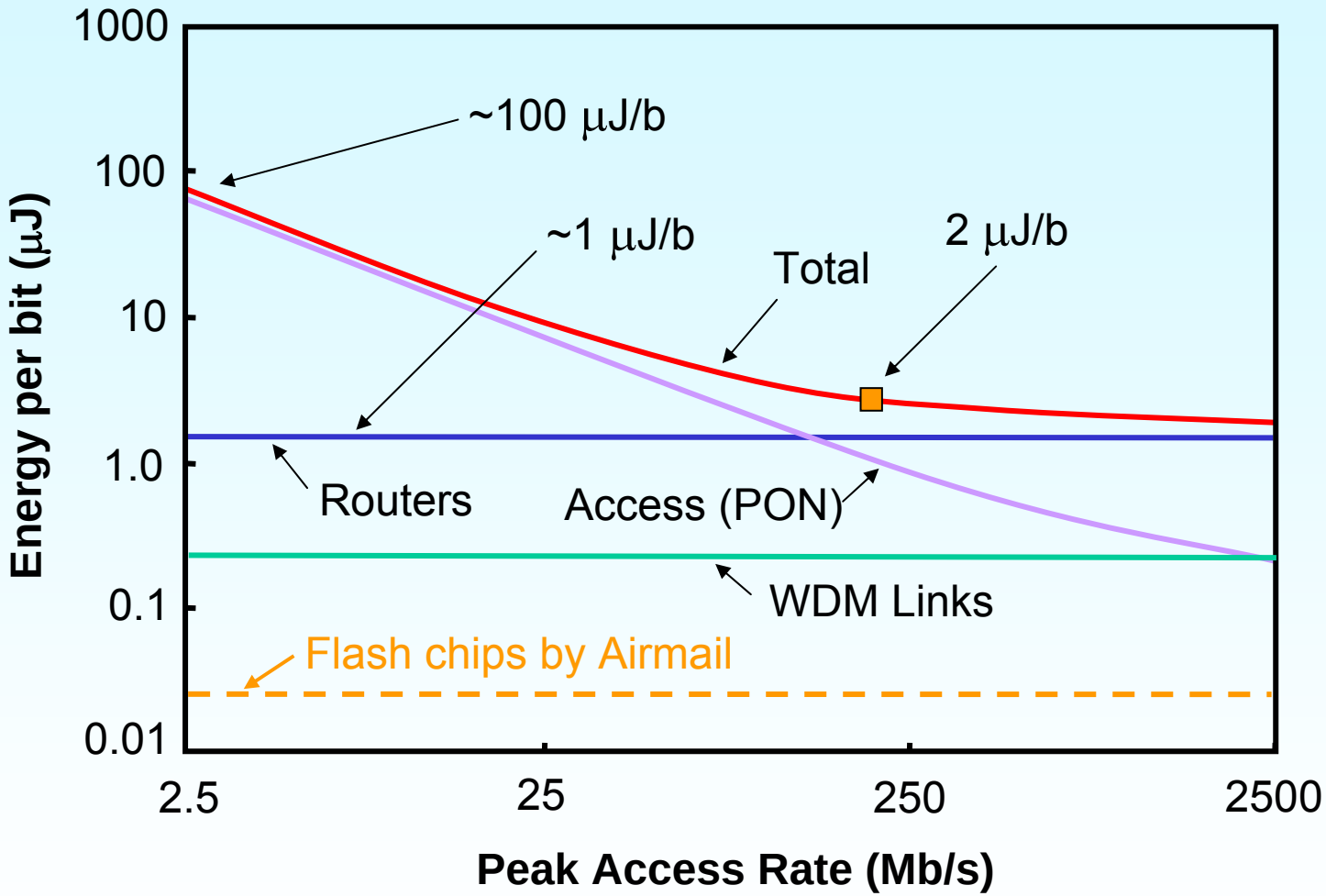
The Internet

2 µJ/b

10^5 kg CO_2

UBIN

Energy Consumption *per Bit*



UBIN

Using the Internet for Travel Replacement

Video Conferencing

Source: CISCO, 2008

Travel Replacement – Greenhouse Impact ($C0_2$)

Air Travel

Melbourne

~500 kg/person return

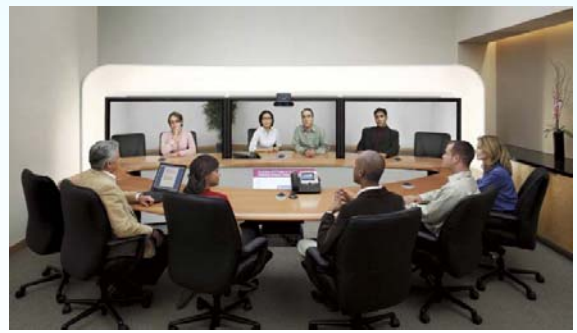
Business Meeting

Sydney

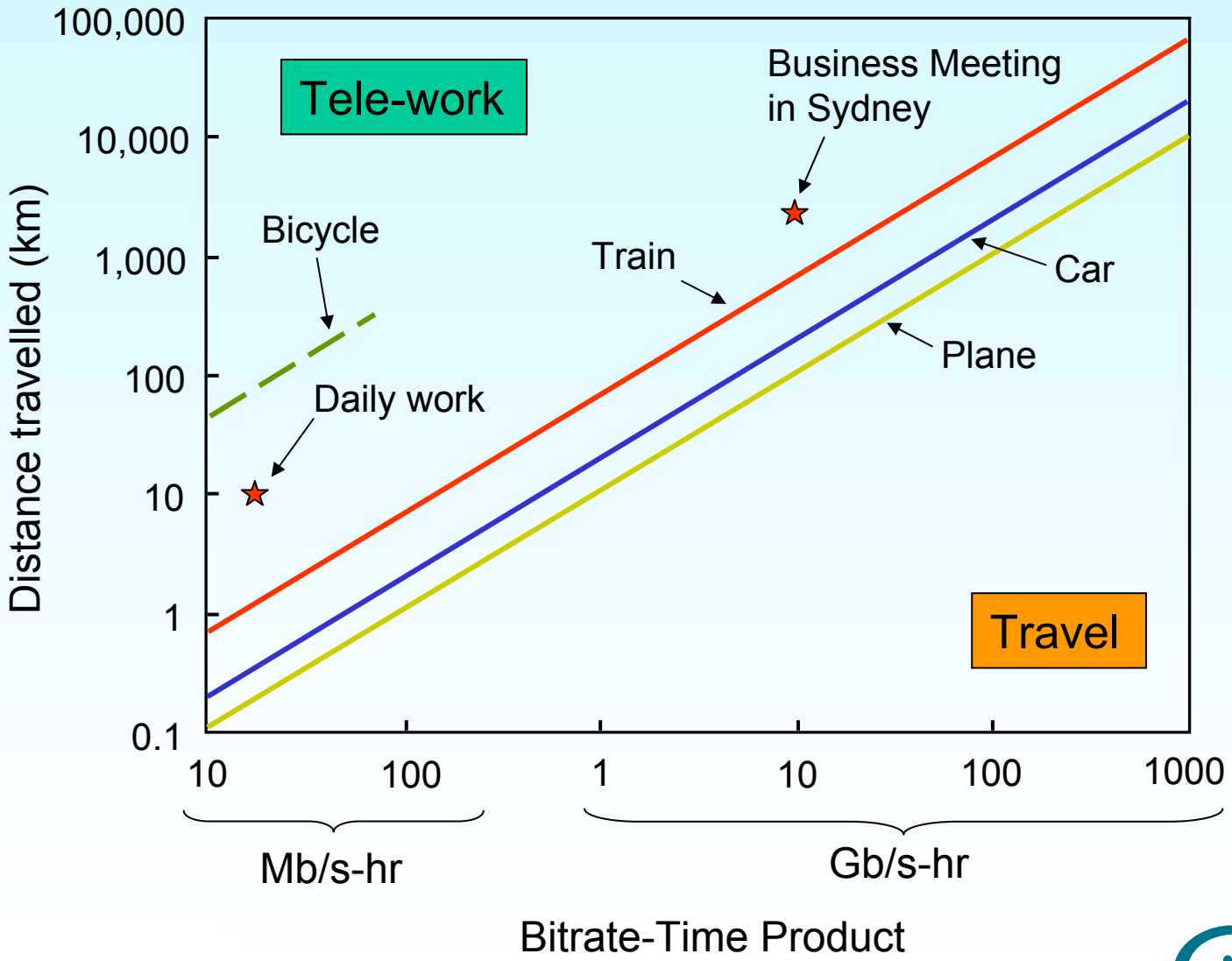
Video Conferencing

2 X 1 Gb/s for 6 hours
= 4 TB

~5 kg/person



Rod's Telecommute Calculator



UBIN

The Khazzoom-Brookes Postulate

- Energy efficiency at micro level ➡ reduction of energy use at this level
- *But* leads to an increase in energy use, at the macro level
- Example:

  Wide bodied passenger aircraft ➡ lower costs per passenger ➡ large increase in air travel ➡ increased greenhouse emissions

"Energy efficiency is absolutely the wrong approach to network design.

The objective should be to make the network carbon neutral"

- Bill St. Arnaud, CANARIE

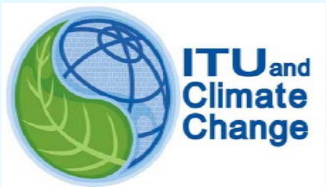
D. Khazzoom *Energy Journal*,10,1987, L. Brookes *Energy Policy*, 20,1992
Inhaber, "Why *Energy Conservation Fails"*, Quorum, 2002
H. Herring, http://technology.open.ac.uk/eeru/staff/horace/kbpotl.htm

CUBIN

Some Interest Groups and Organizations

http://www.atis.org/0050/

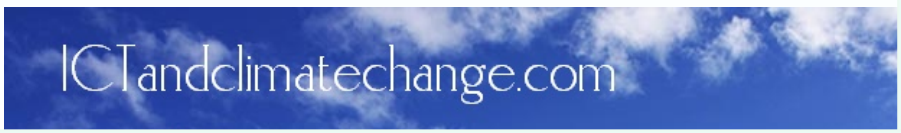
http://www.gesi.org/



http://www.itu.int/climate

http://www.thegreengrid.org/home

http://wattwatt.com/



http://ictandclimatechange.com/

UBIN

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-faceted approach needed to build a green Internet:
  - Improved efficiency in electronic and photonic devices
  - Low-energy switching techniques
  - Improved architectures
  - New protocols
- Information Logistics
  - A new approach to network design and management

Melbourne Information Logistics Centre (MILC)?

Centre for Information LOgistics (CILO)?

CUBIN