Energy Efficiency in Cloud Computing and Optical Networking

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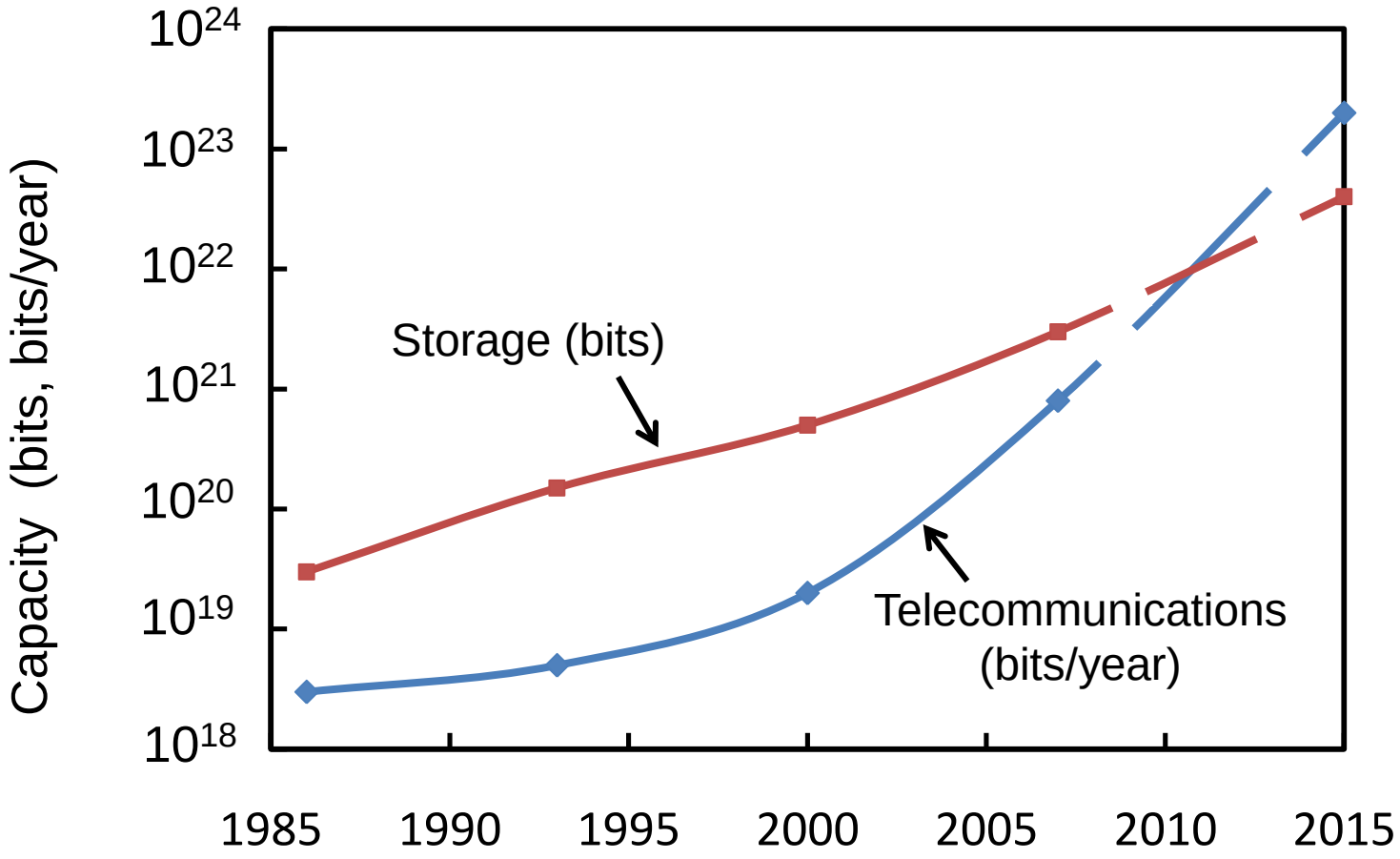
Outline

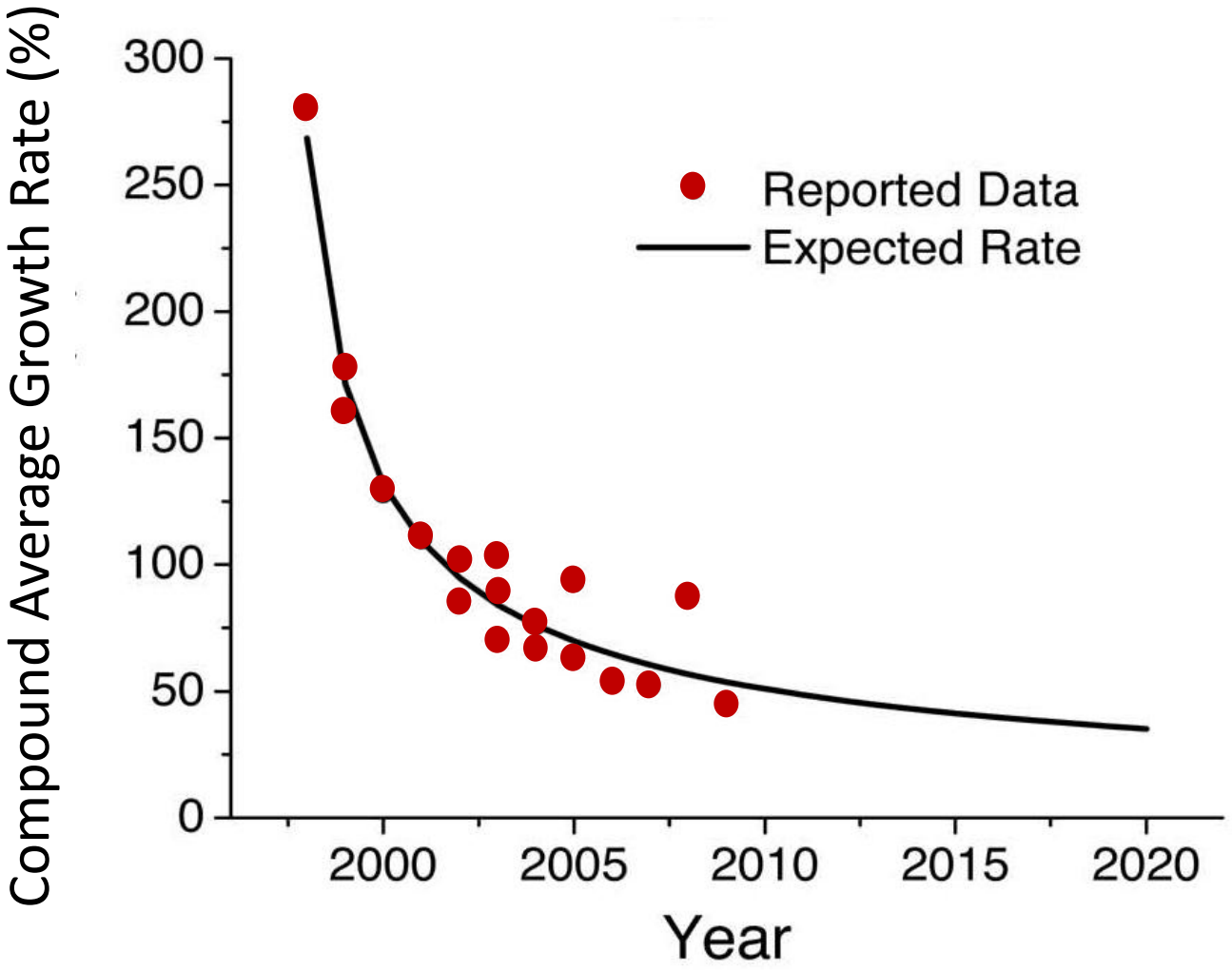
- Introduction and overview of energy consumption and efficiency in communications networks
- Estimating energy consumption in ICT equipment
  - Telecommunications
  - The “cloud”
- Improving network energy efficiency
  - Technologies
  - Architectures
  - Protocols
  - The cloud

World's technology capacity



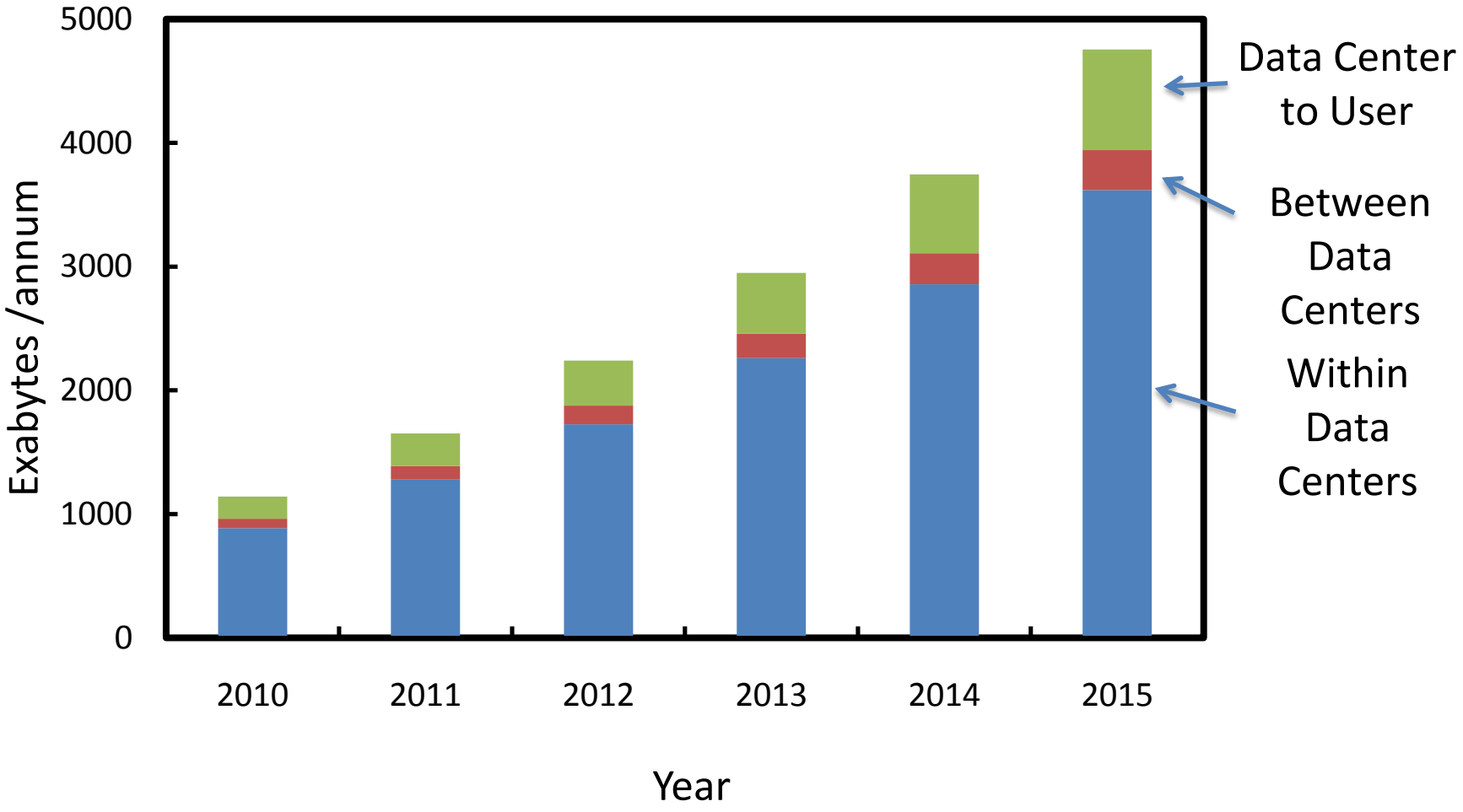
Source: M. Hilbert, P. Lopez, Science, 2011

Internet traffic growth trends



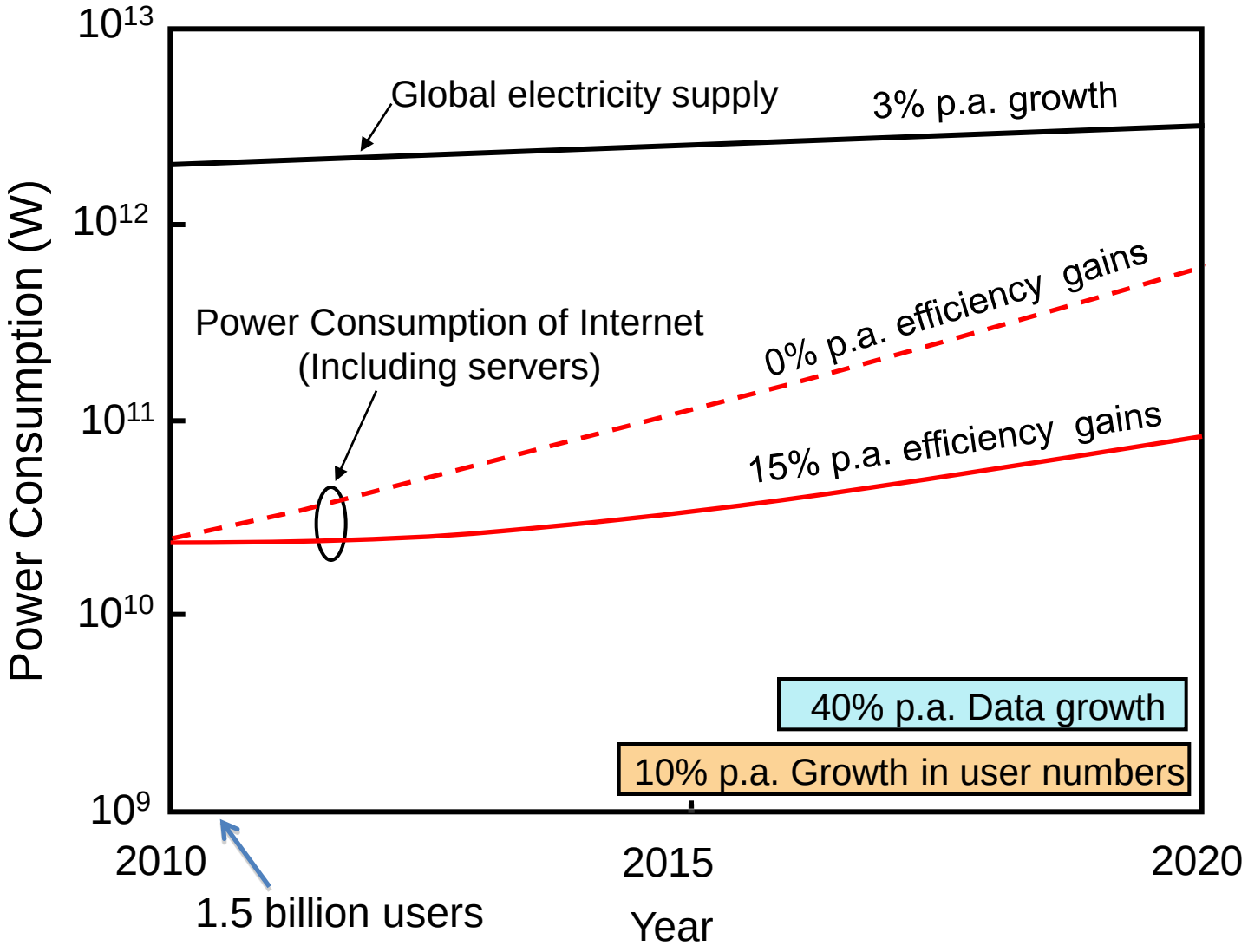
Source: Kilper et al., JSTQE 2011

Projections of data centre traffic



Source : Cisco Cloud Index 2011

Power consumption of the global Internet



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

Author	Year	% national electricity use	Country	PC's, office equip. & servers	Wireless access	Notes
Huber	1999	13%	USA	Yes	No	Severe over estimate
Koomey	1999	2%	USA	Yes	No	Users & equipment estimate
Kawatomo	2001	3%	USA	Yes	No	Users & equipment estimate
Turk	2001	0.5 - 1.7%	Germany	Yes	No	Users & equipment estimate
Barthel	2001	0.9 – 1.5%	Germany	Yes	Yes	Users & equipment estimate
Roth	2002	< 2.3%	USA	Yes	Yes	Users & equipment estimate
Cremer	2003	7.1%	Germany	Yes	Yes	Users & equipment estimate
Baliga	2007	0.5%	OECD	No	No	Network design & dimensioning
Vereecken	2010	Not given	Not given	No	No	Network design & dimensioning
Lange	2010	Not given	Not given	No	Yes	Network design & dimensioning
Kilper	2011	Not given	USA	No	Yes	Transaction
Pickavet	2007 2012		Global	Yes	Yes	Users and equipment estimate

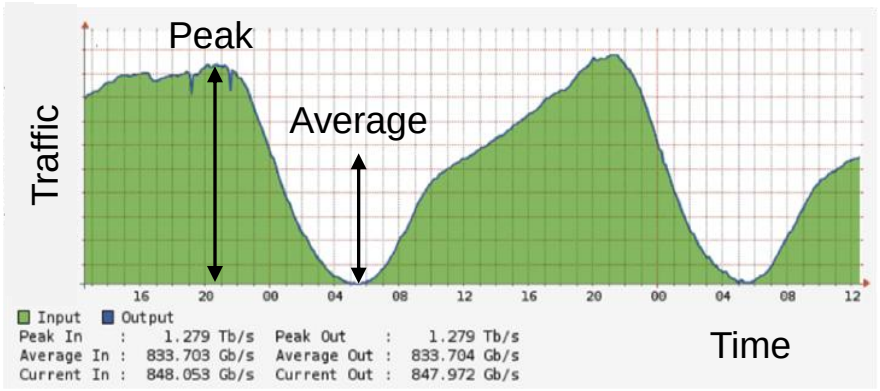
Design and dimensioning approach

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

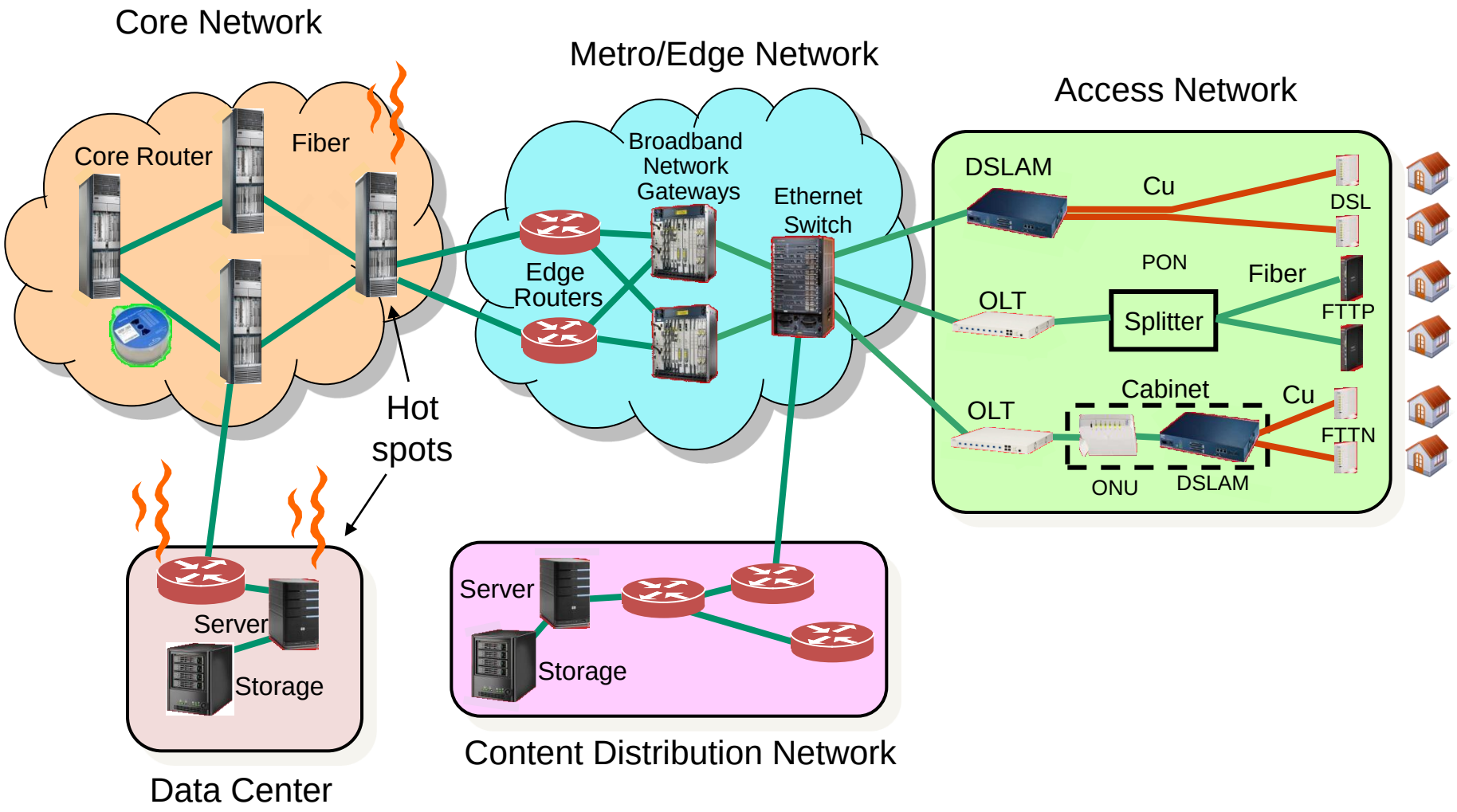
Baliga et al., 2007

Key model parameters

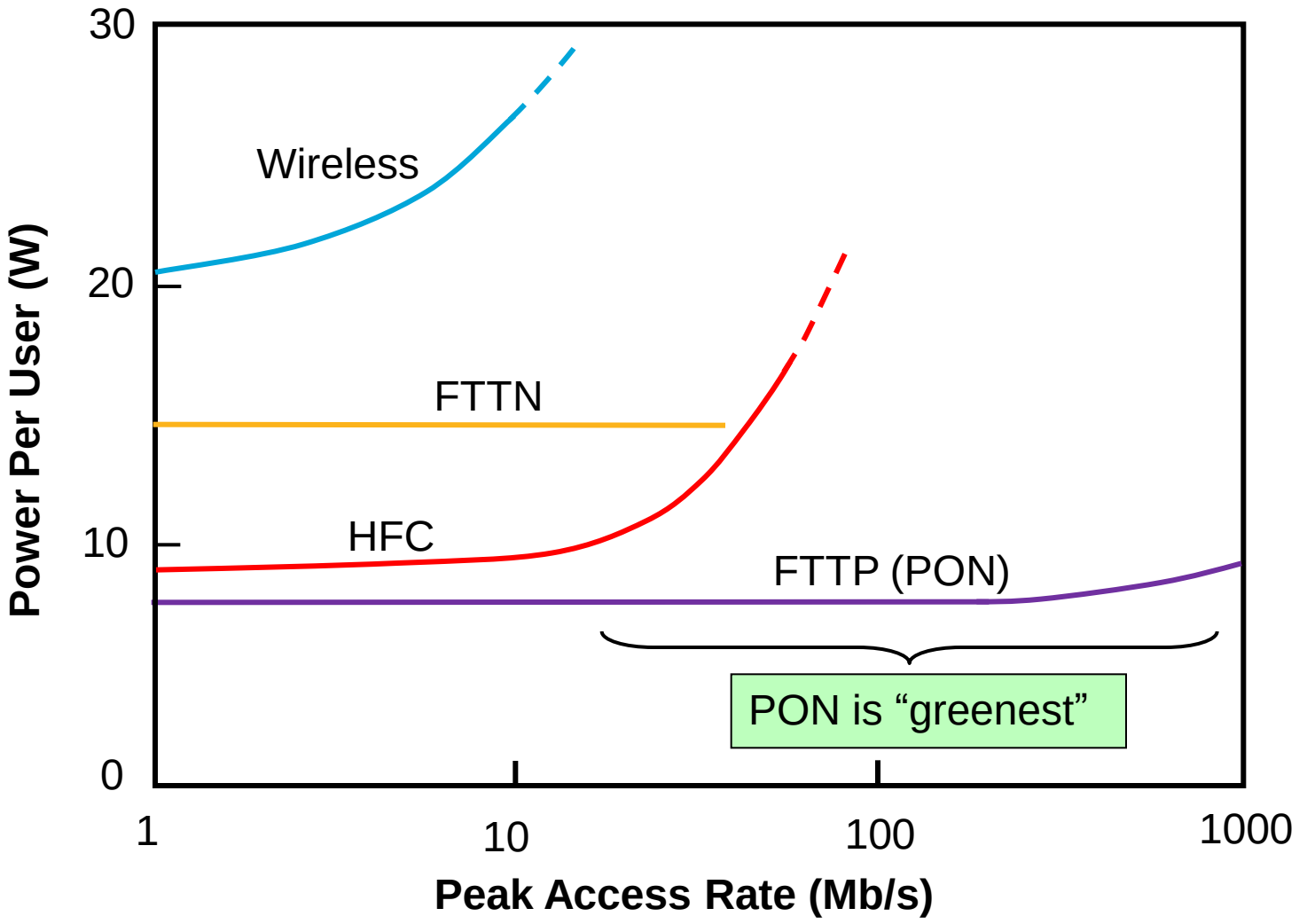
- Peak vs average access speed
  - Contention & aggregation
- Network dimensioning
  - Traffic growth
    - Deployed capacity > demanded capacity
  - Equipment redundancy
    - Multi-homing , back-up storage
  - Service protection
    - 1 + 1, 1:1, 1:N protection
- Router hops between source and destination
- Data centre Power Usage Effectiveness (PUE)



Network segmentation

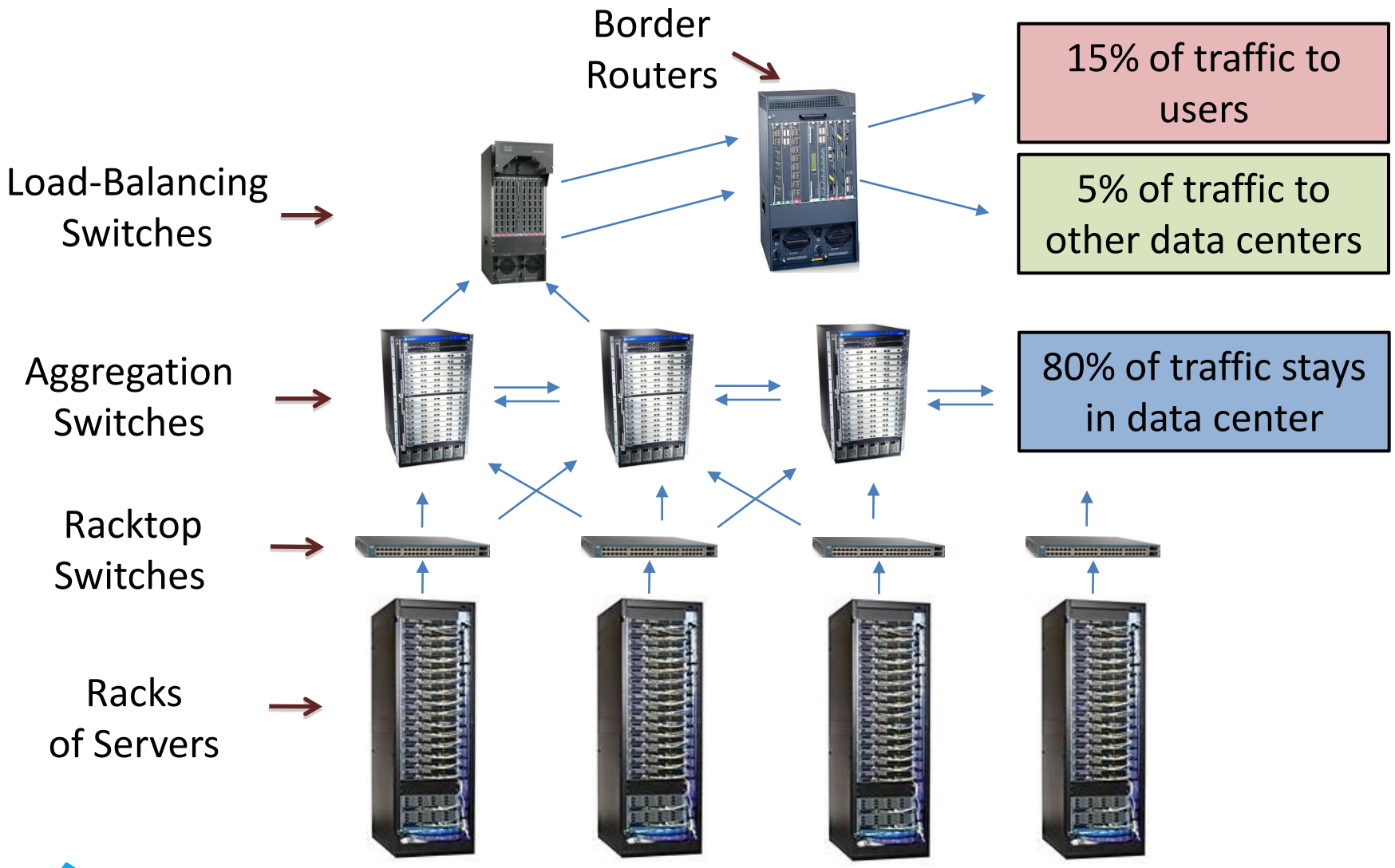


Access network energy consumption



Baliga et al., OFC 2009

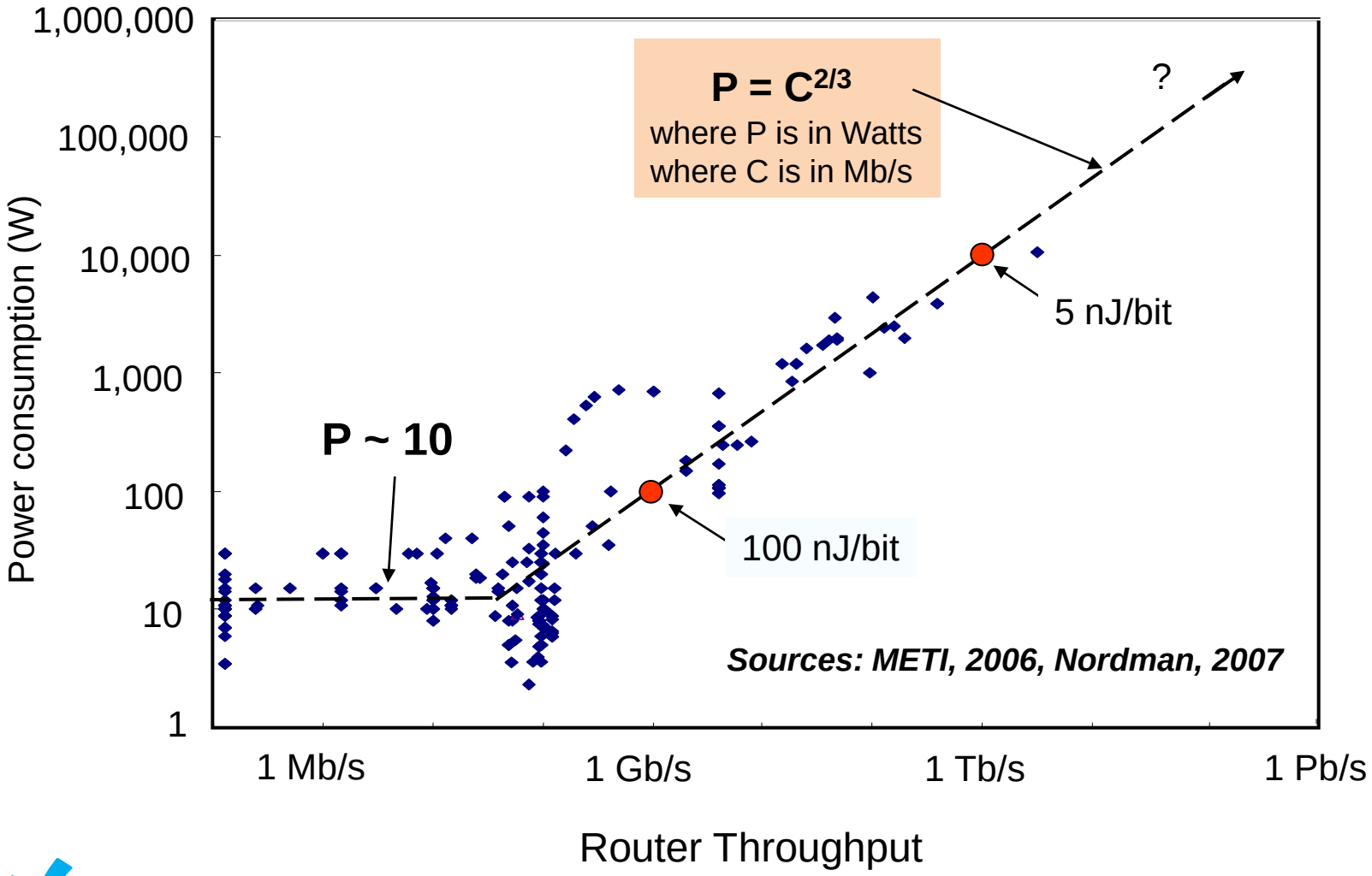
Data centers and content servers



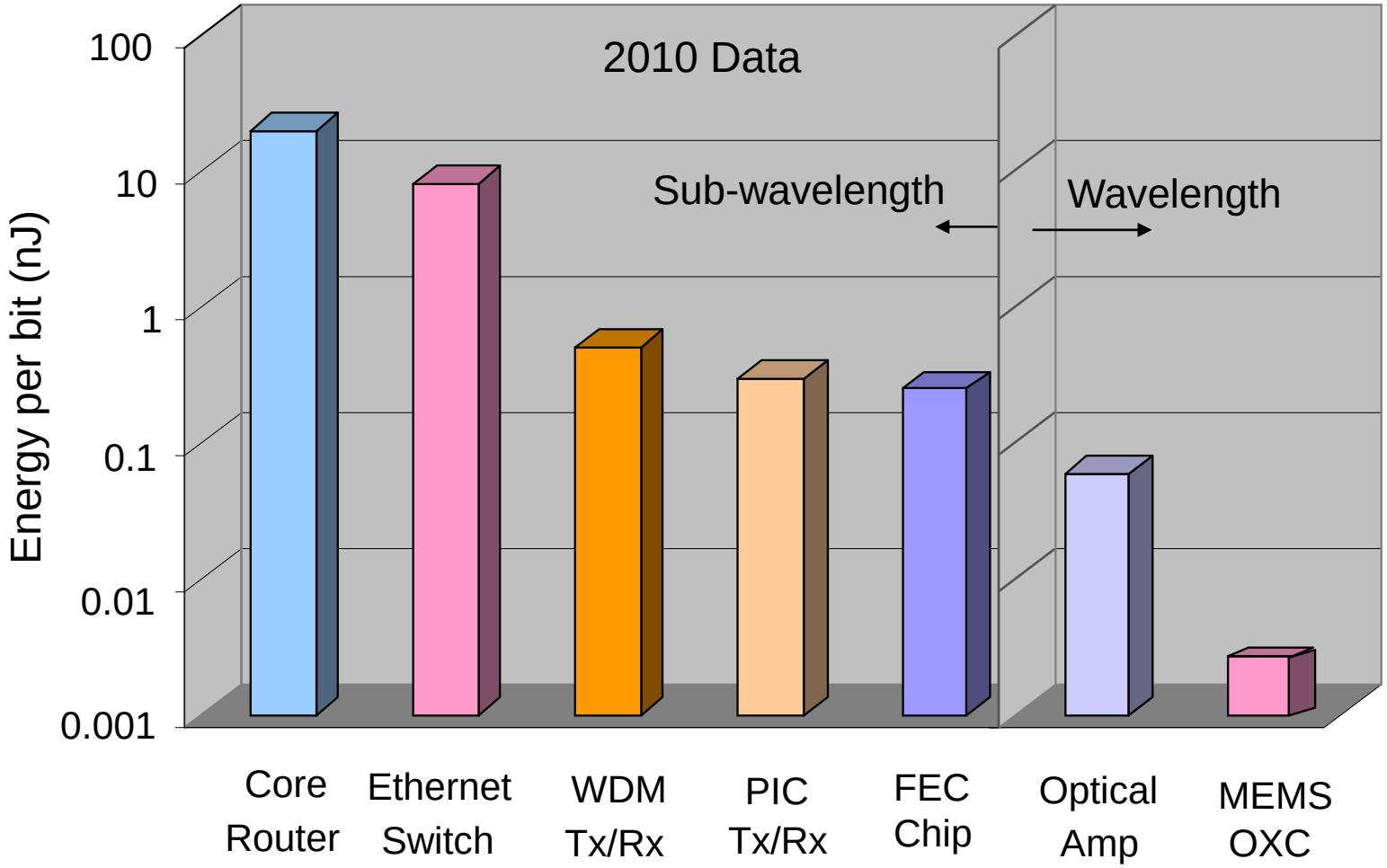
Power consumption of equipment

- 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

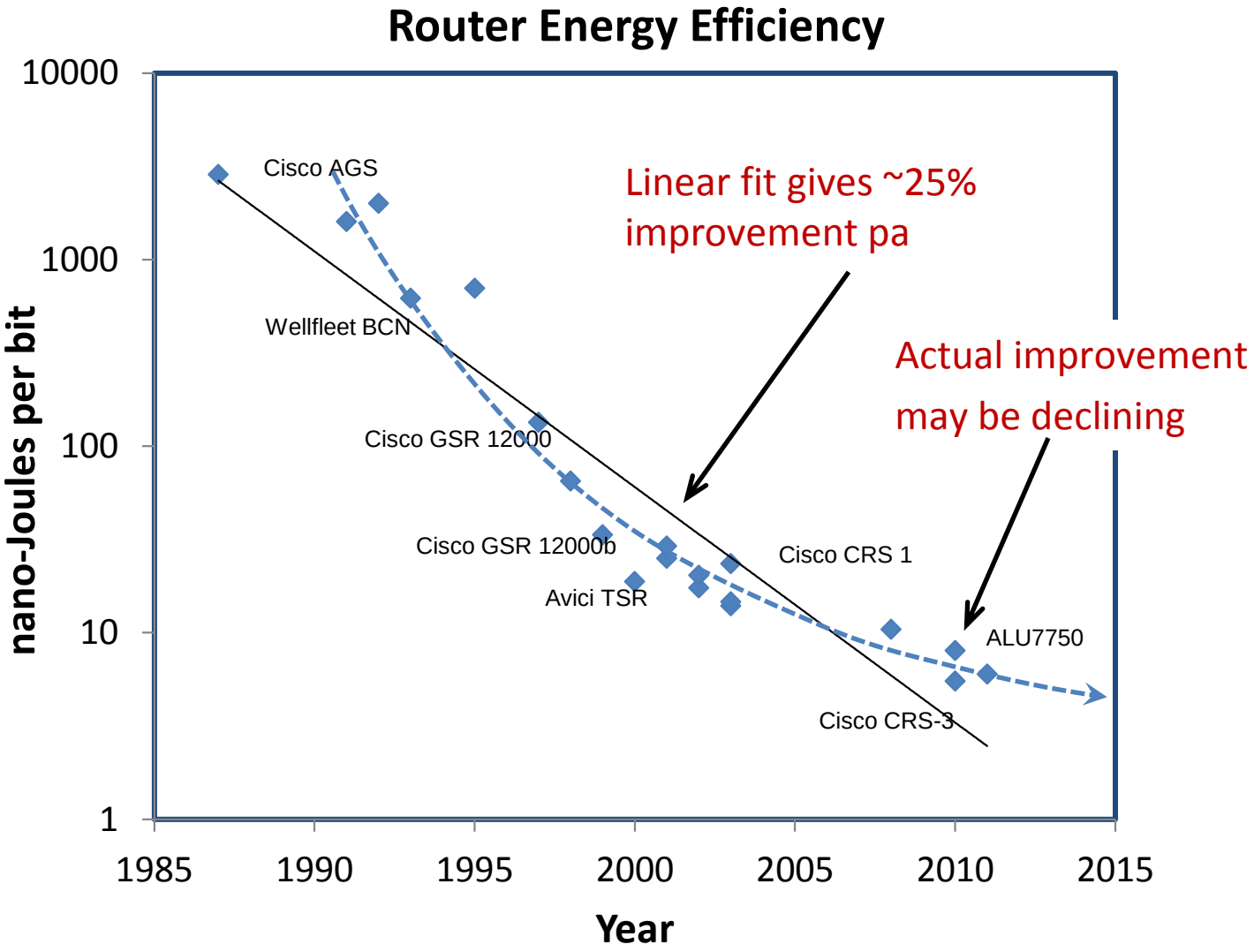


Energy efficiency of equipment



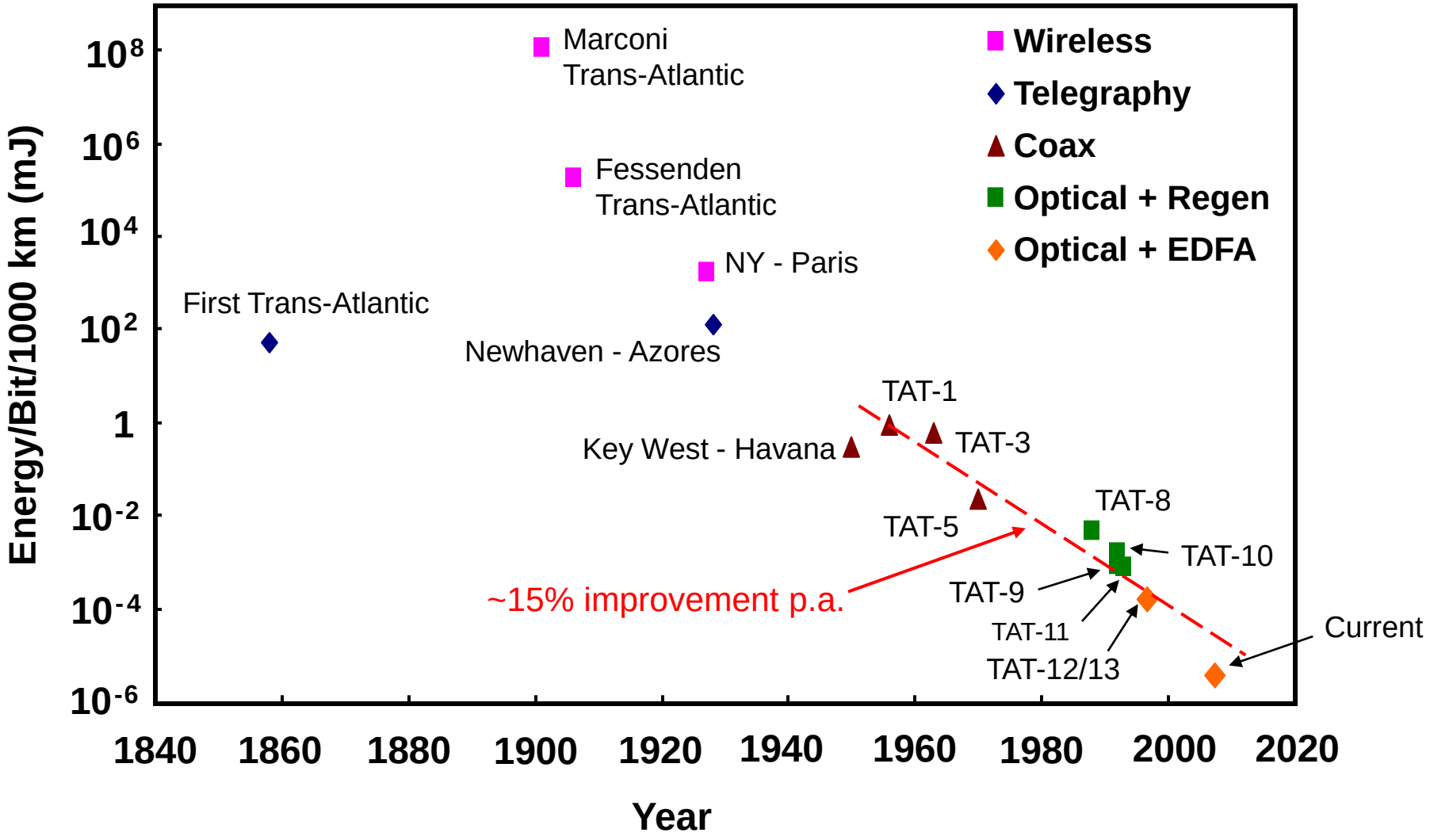
Tucker et al., 2010

Equipment Energy Consumption Trends



Nielsen, ECOC 2011

Trends in transport energy consumption

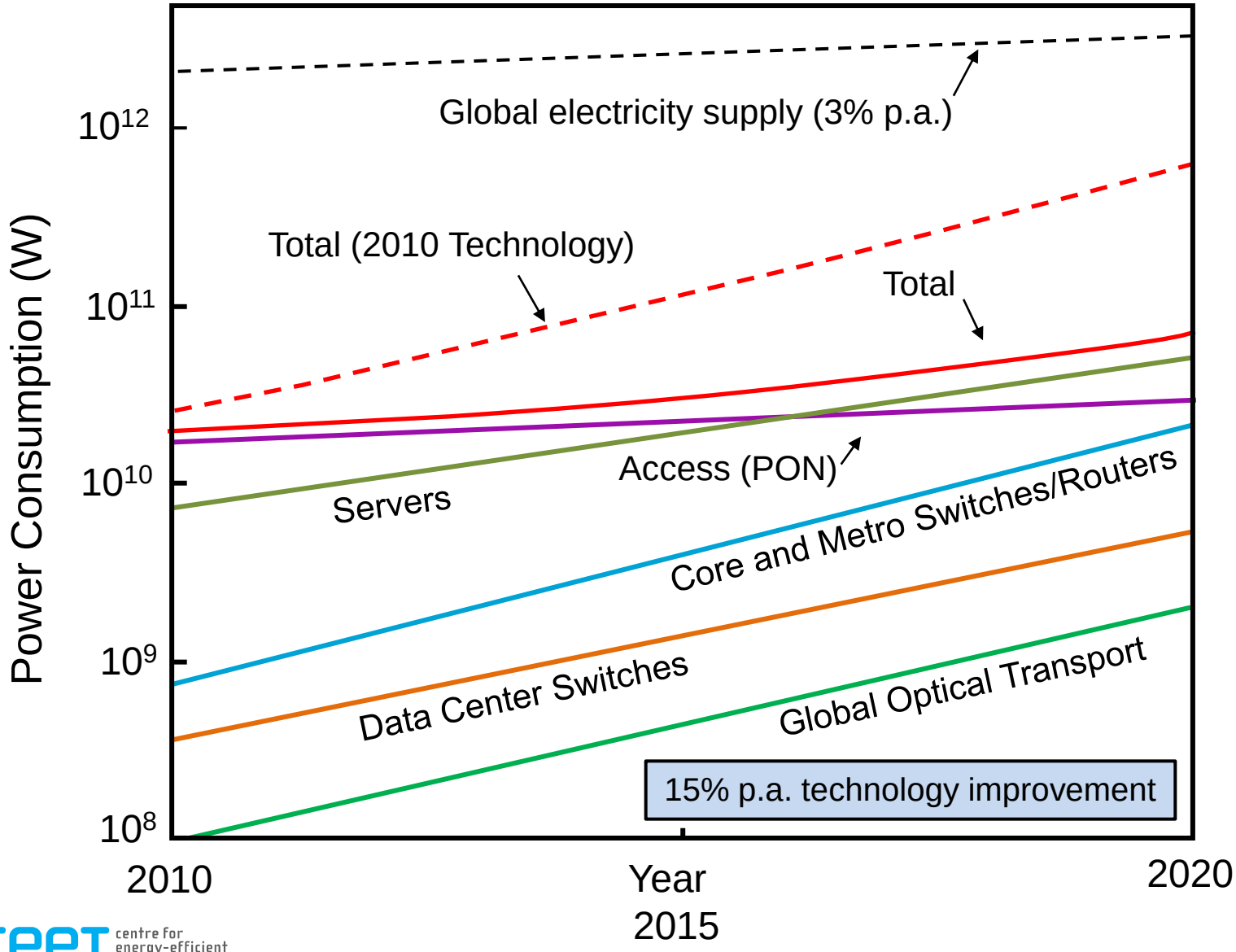


Tucker, JSTQE 2011

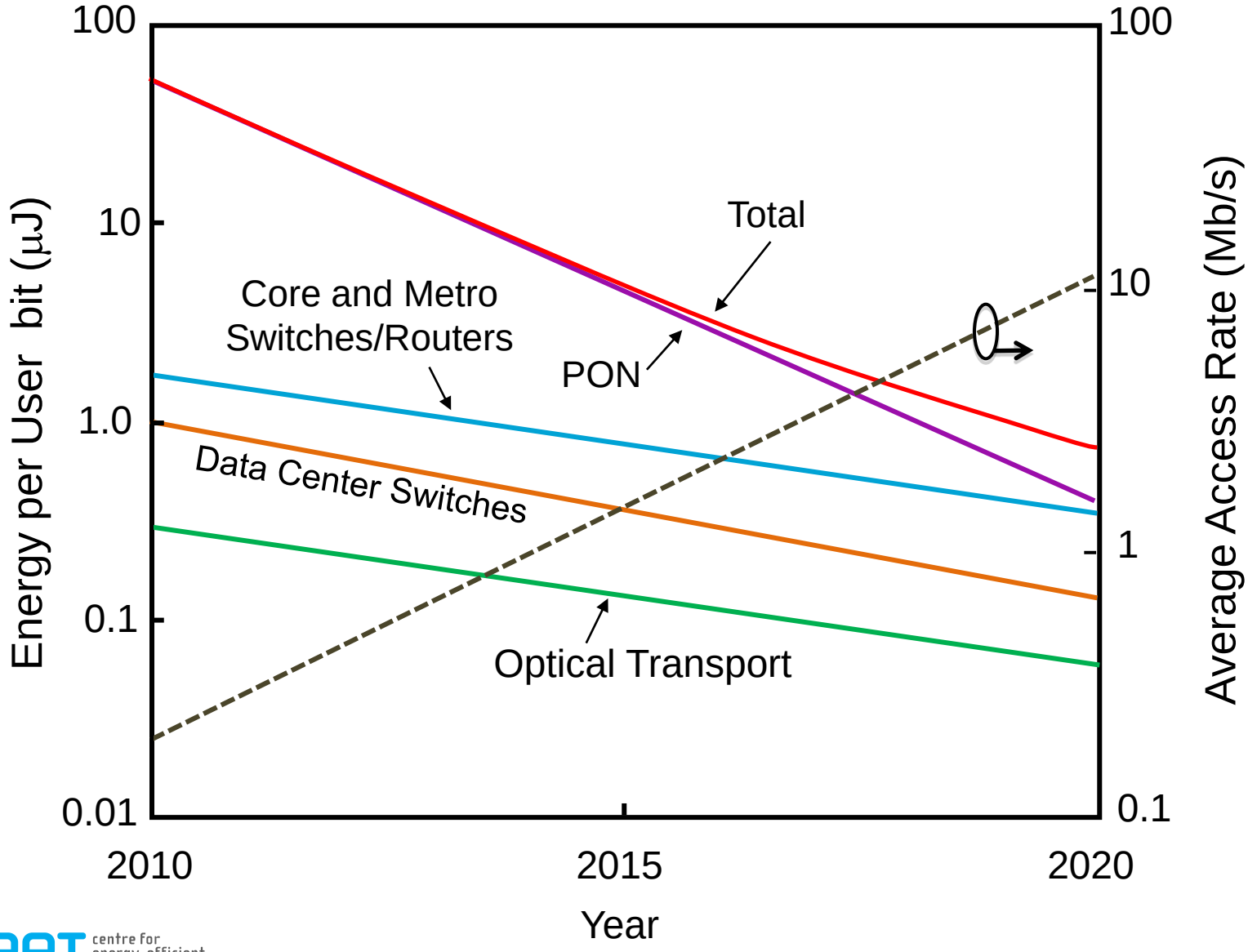
Putting it all together

- 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

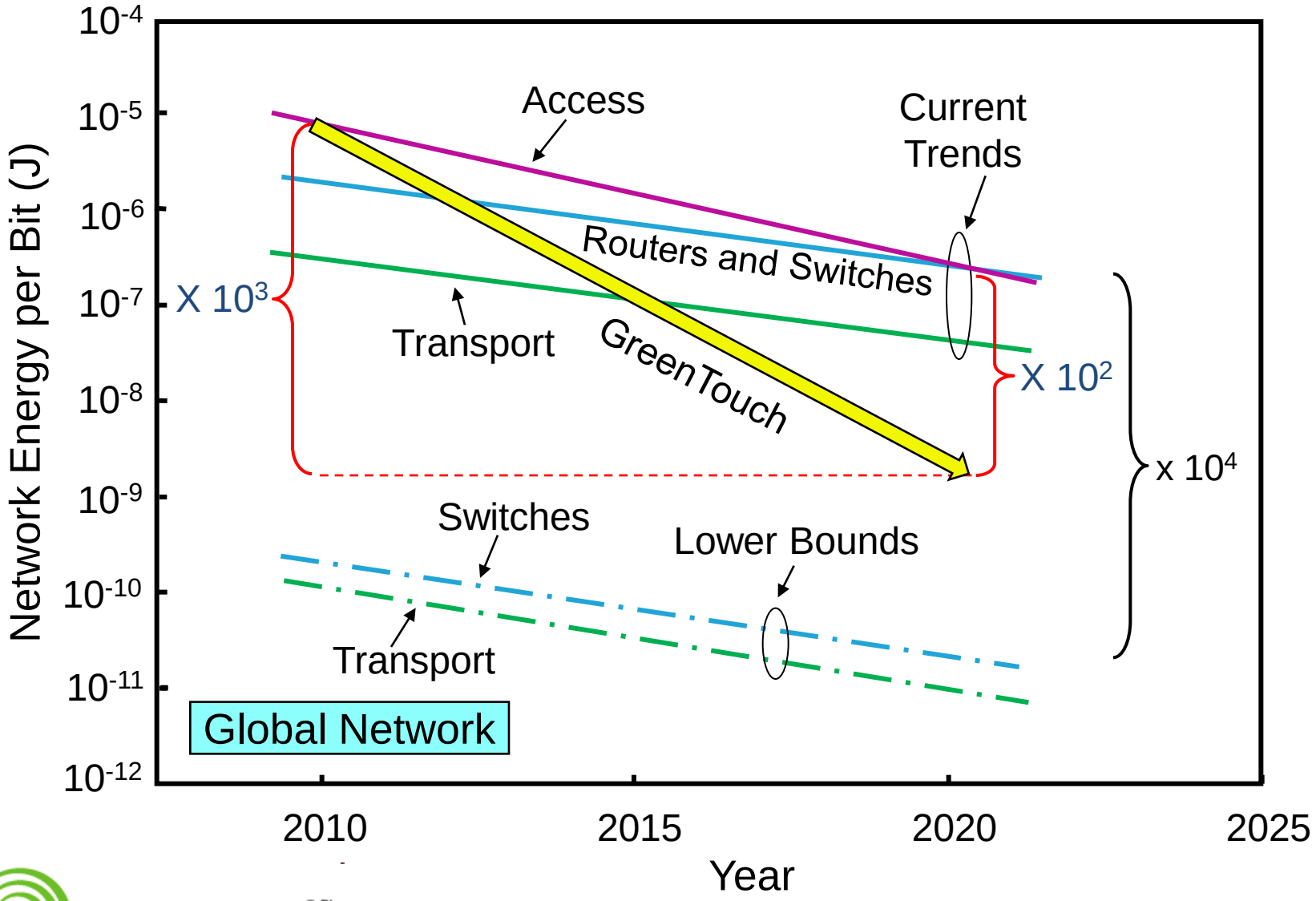
Power consumption of the global Internet



Network energy per user bit



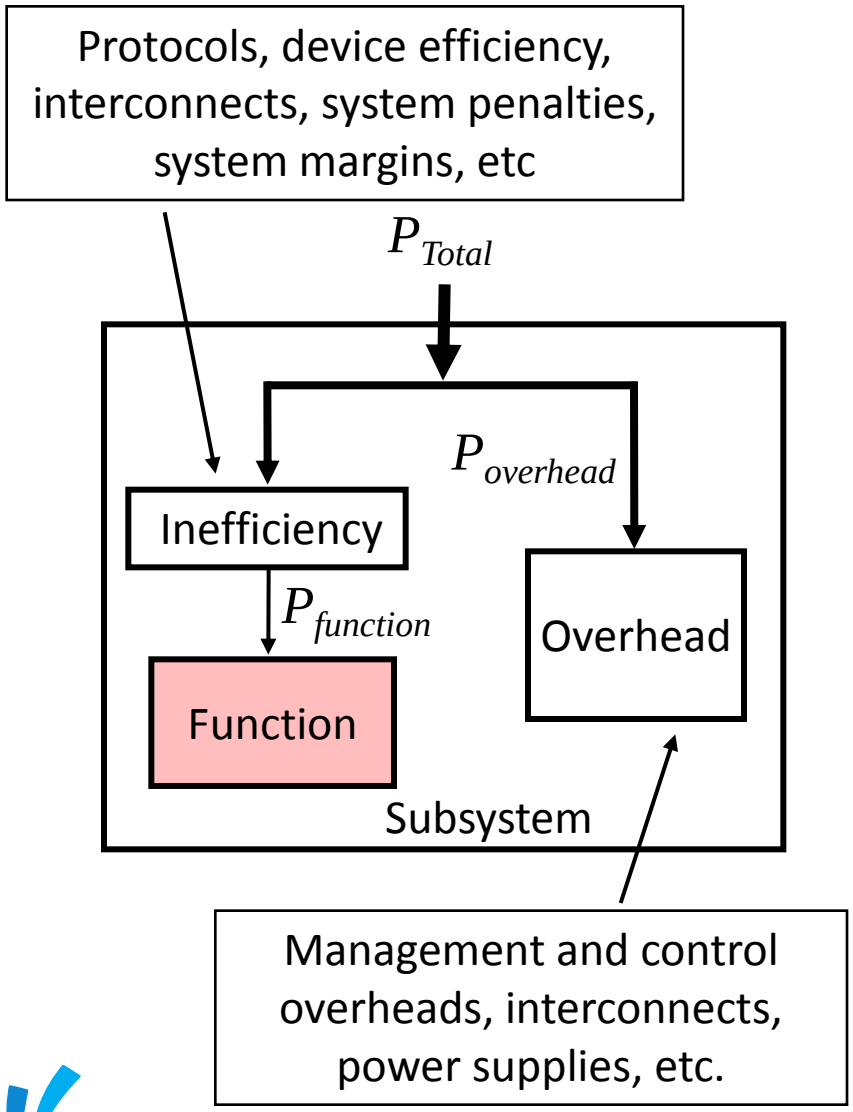
Gap between theory and practice

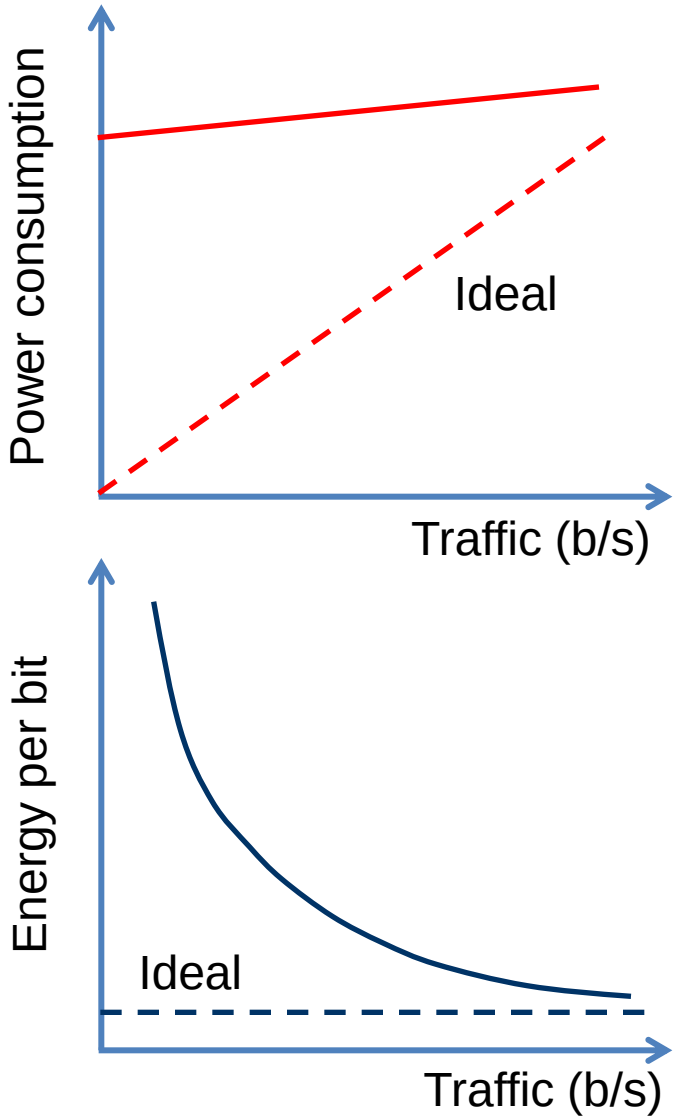


GreenTouch™

Tucker, JSTQE 2011

Gap between theory and practice





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

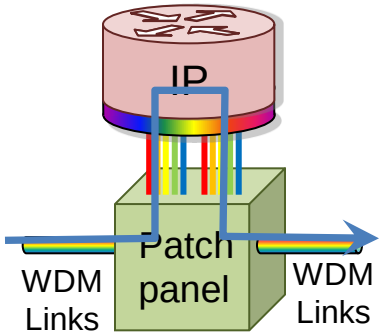
B. Architectures

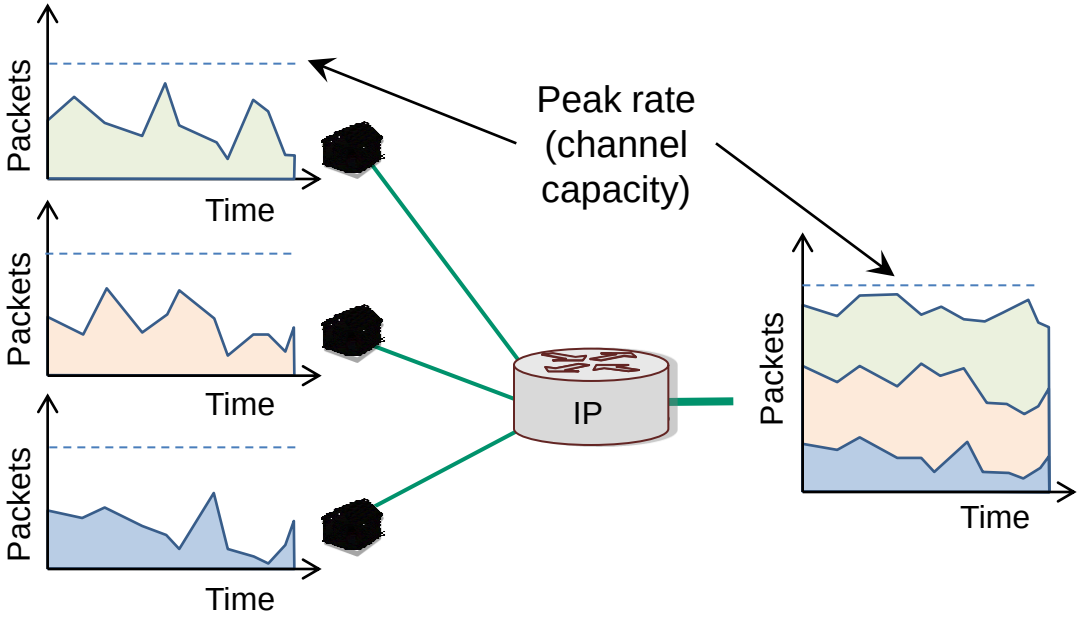
- Architectures that reduce the number of network hops
- Optical bypass
- Layer 2 rather than Layer 3 where possible
- Dedicated content-delivery networks

Bypass options

Without bypass:

- All traffic goes to IP layer for processing
- ~10 nJ per bit
- Allows aggregation of incoming traffic flow
- Statistical multiplexing increases utilisation of paths

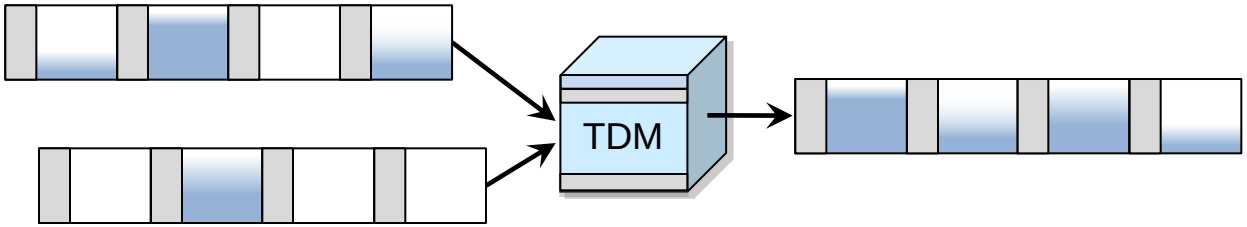


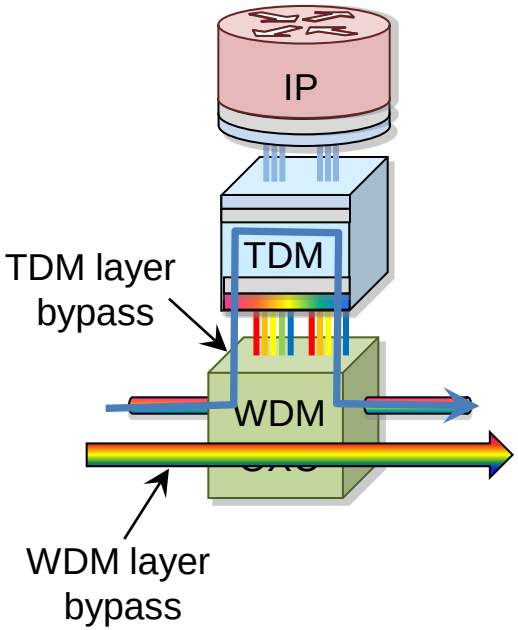


Bypass options (cont'd)

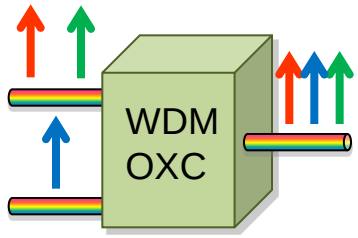
With bypass:

- 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

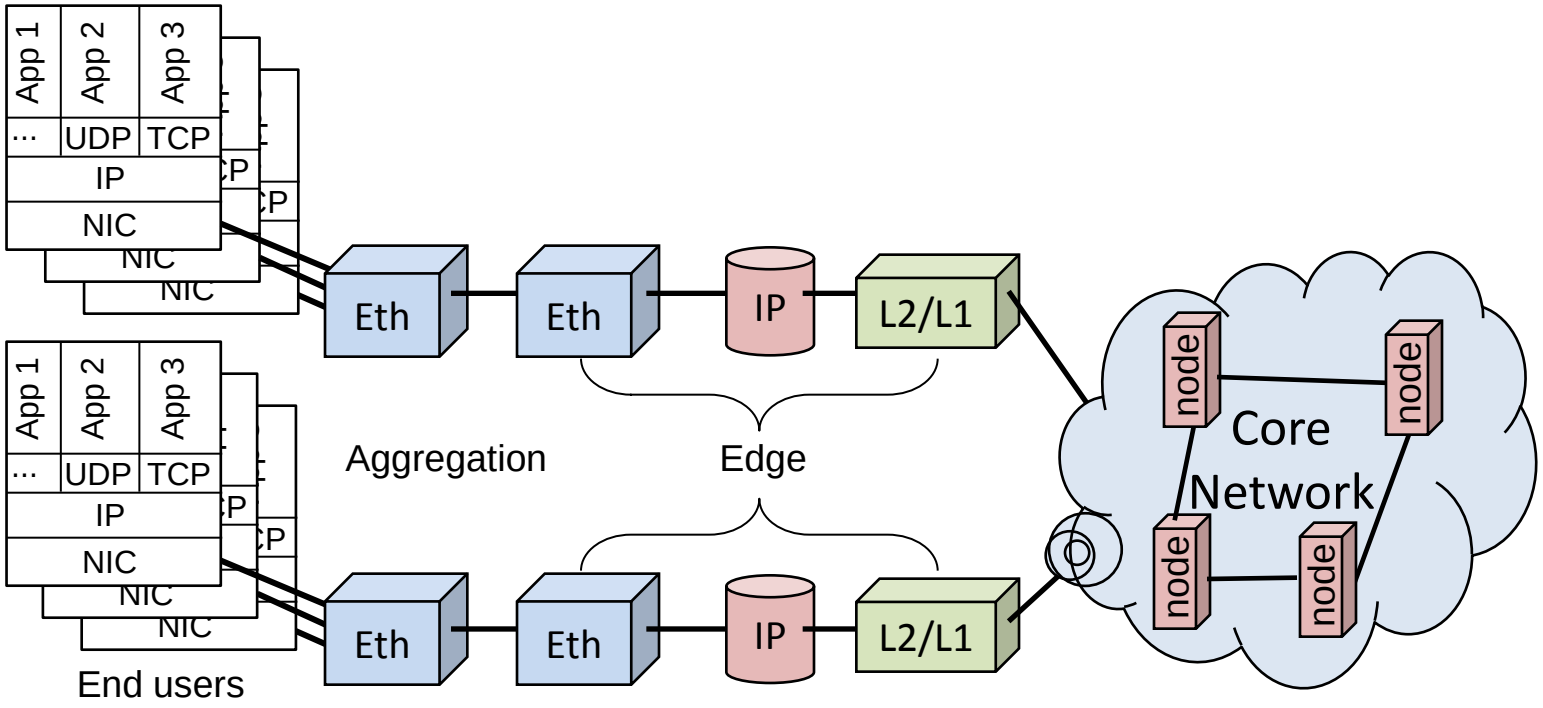


C. Protocols

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

Service transactions & protocols

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

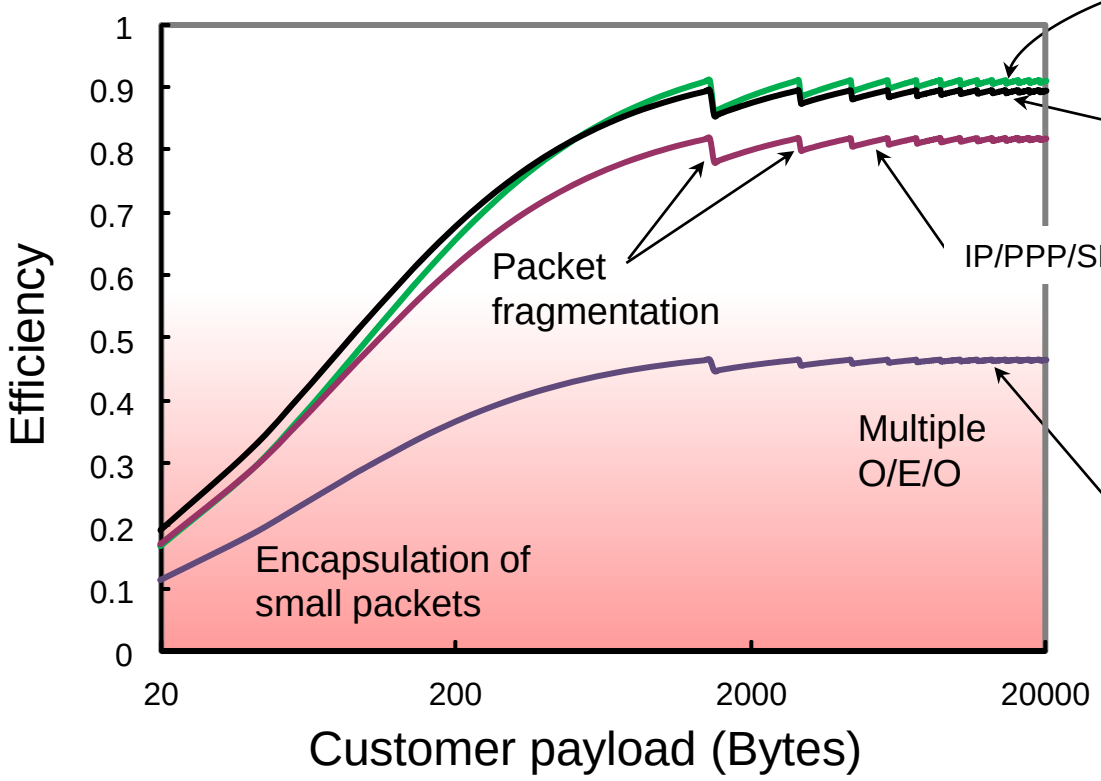


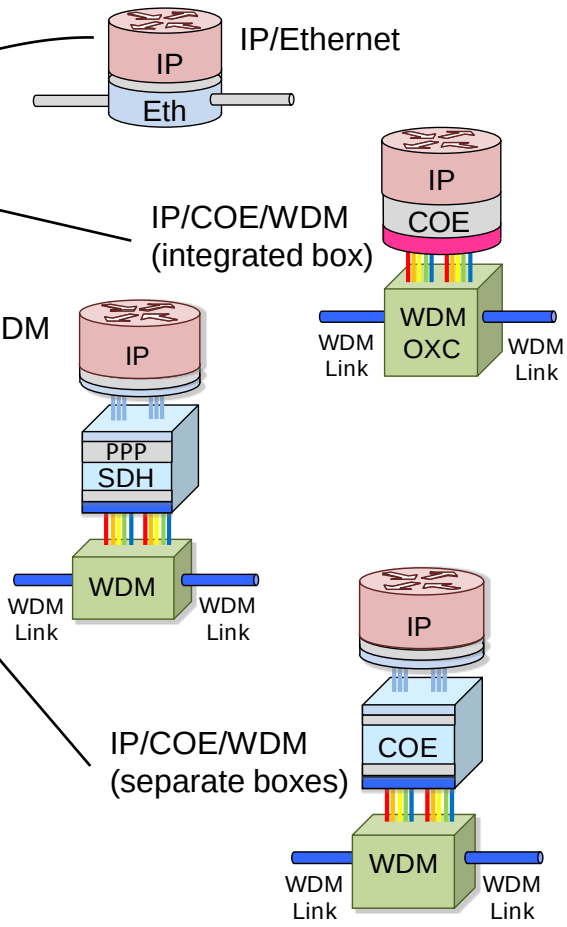
Source: Zhong et al., OFC 2012

Efficiency of multi-layer protocol suite

Combining boxes for multi-layer protocol suites can improve efficiency

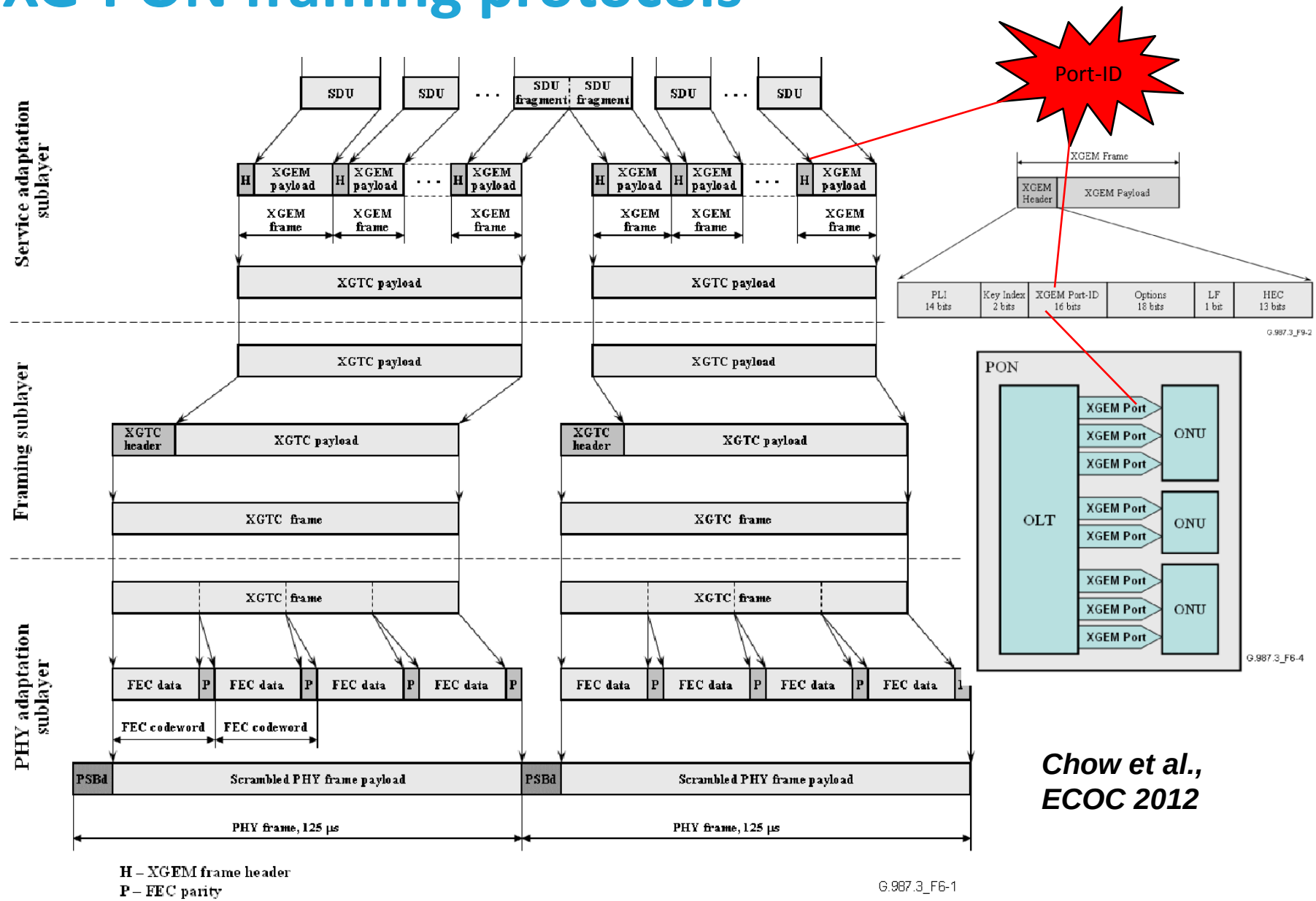
$$Efficiency = \frac{Customer\ payload \quad IP\ layer\ energy}{Total\ multi\text{-}protocol\ suite\ packet\ energy}$$





Source: Zhong et al., OFC 2012

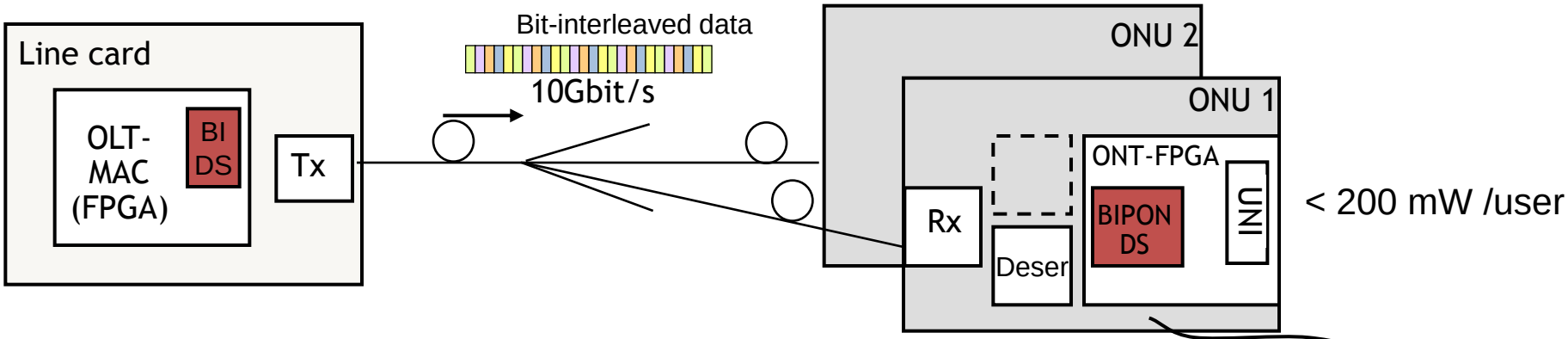
XG-PON framing protocols



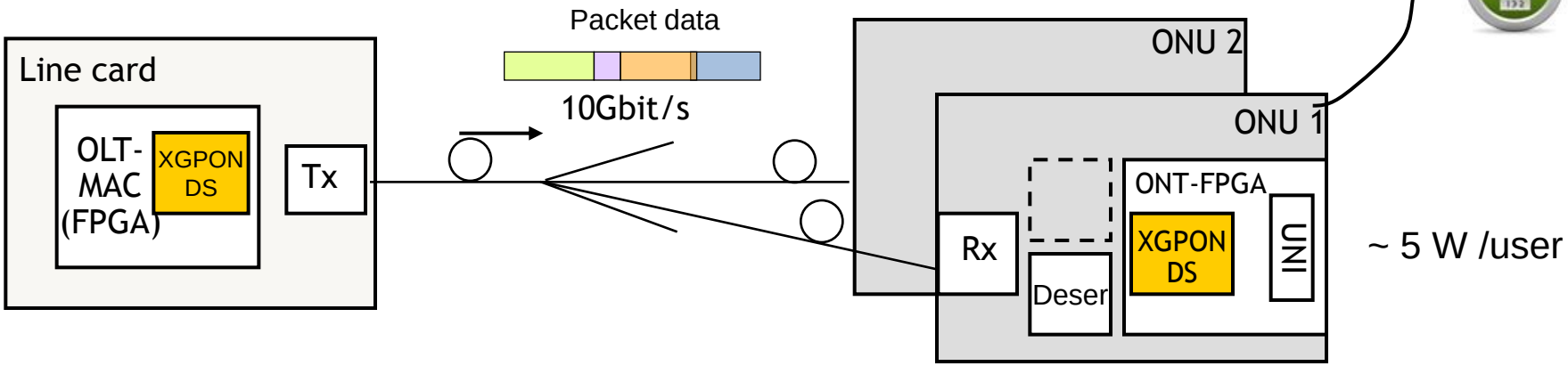
Chow et al., ECOC 2012

Solution: BiPON

Bit-Interleaved PON



Conventional PON



Delta

Bell Labs

INTEC design

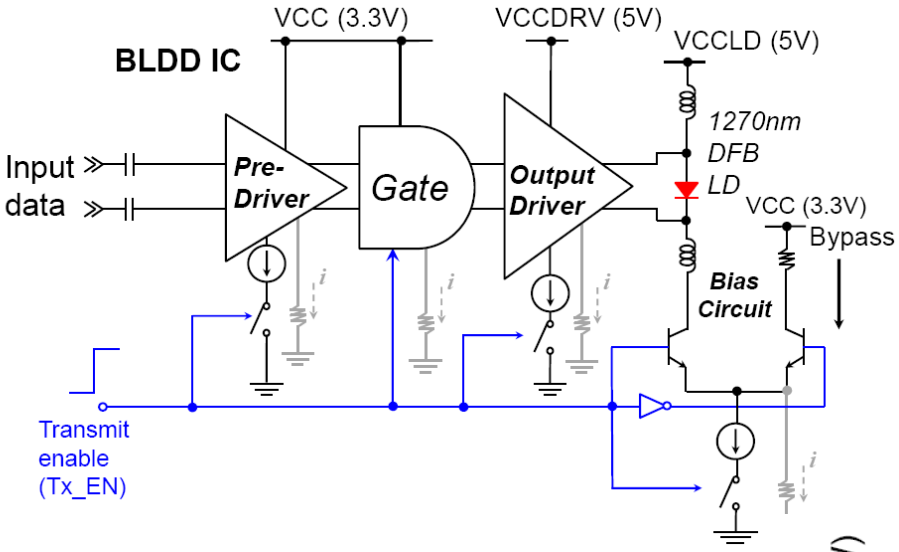
orange

Chow et al., ECOC 2012

Energy-efficient protocols

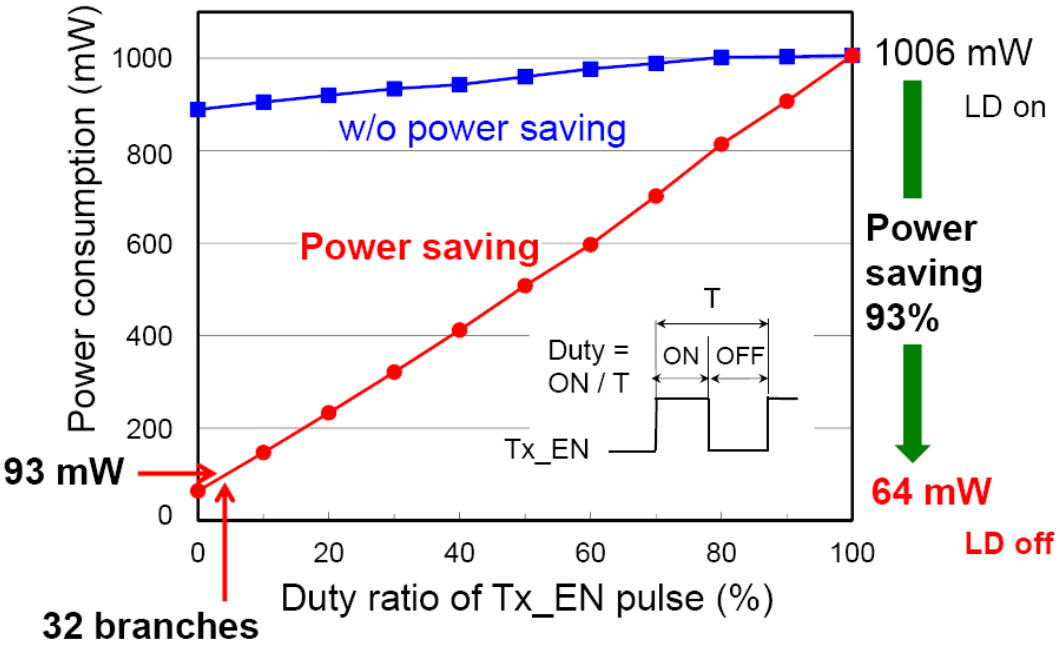
- Sleep & standby states
  - Network devices enter low power state when not in use
  - Can apply to systems and sub-systems
  - Need to ensure network presence is retained
    - Use Network Connection Proxy with sleep protocol
  - Need to account for state transition energy and time
  - May have multiple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



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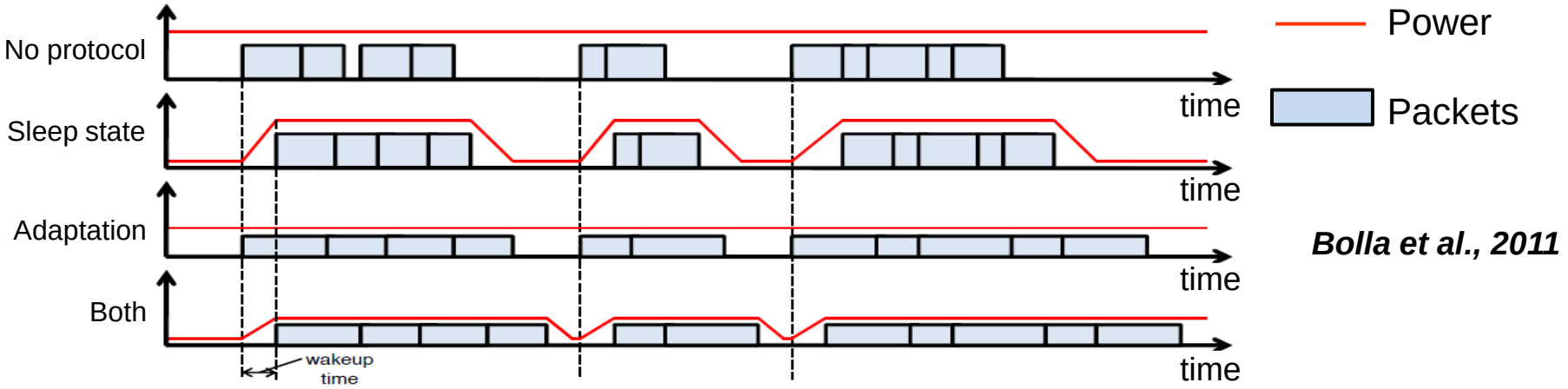
Energy-efficient protocols

- Dynamic rate adaptation
  - Modify capacity of network devices in response to traffic demands
  - Change clock frequency, processor voltage

$$Power = C \times Voltage^2 \times Frequency$$

  - Slower speed to reduce power consumption
  - Need to allow transition time between rates

- Dynamic rate adaptation and standby states can be combined



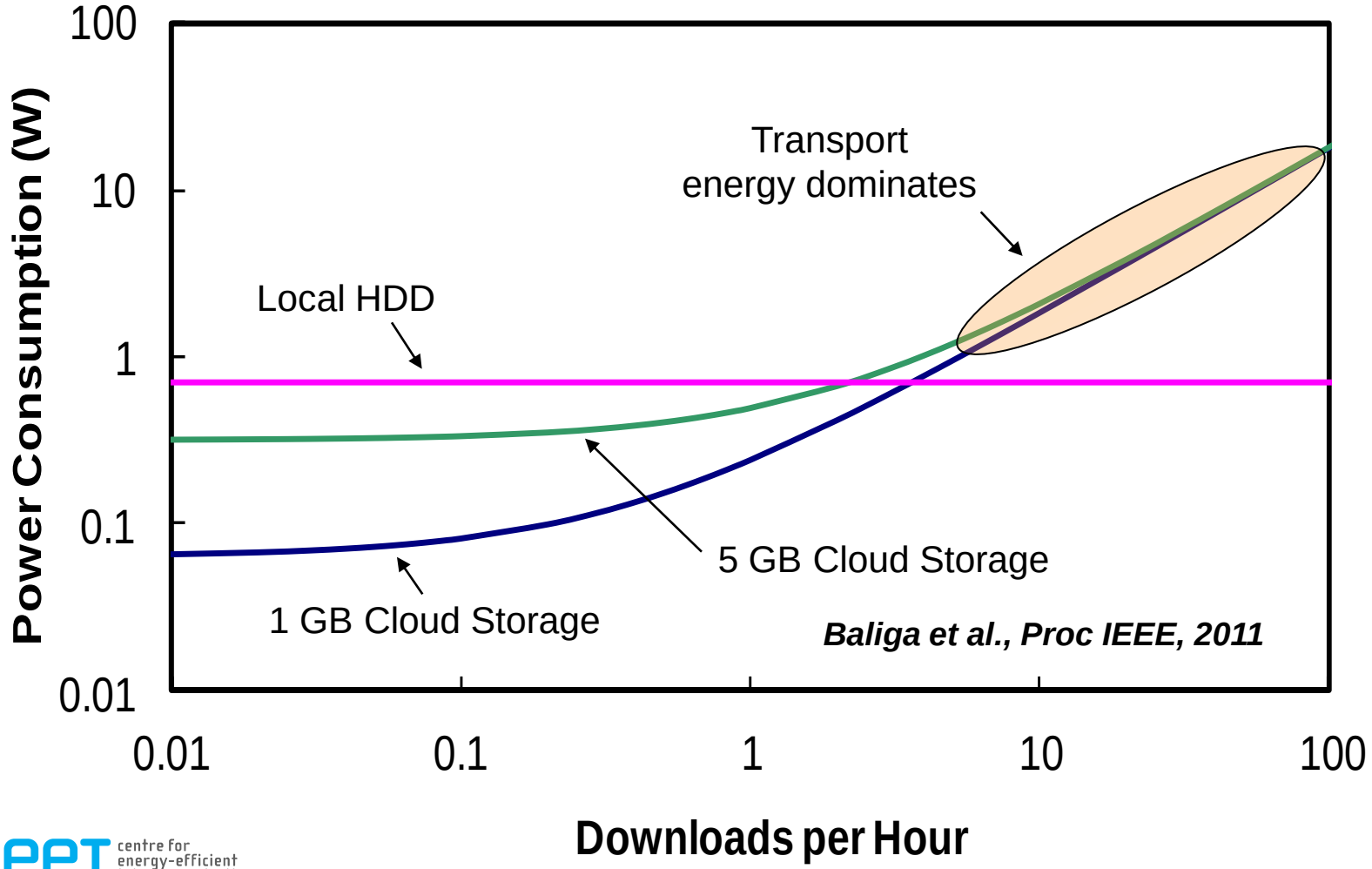
Bolla et al., 2011

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)

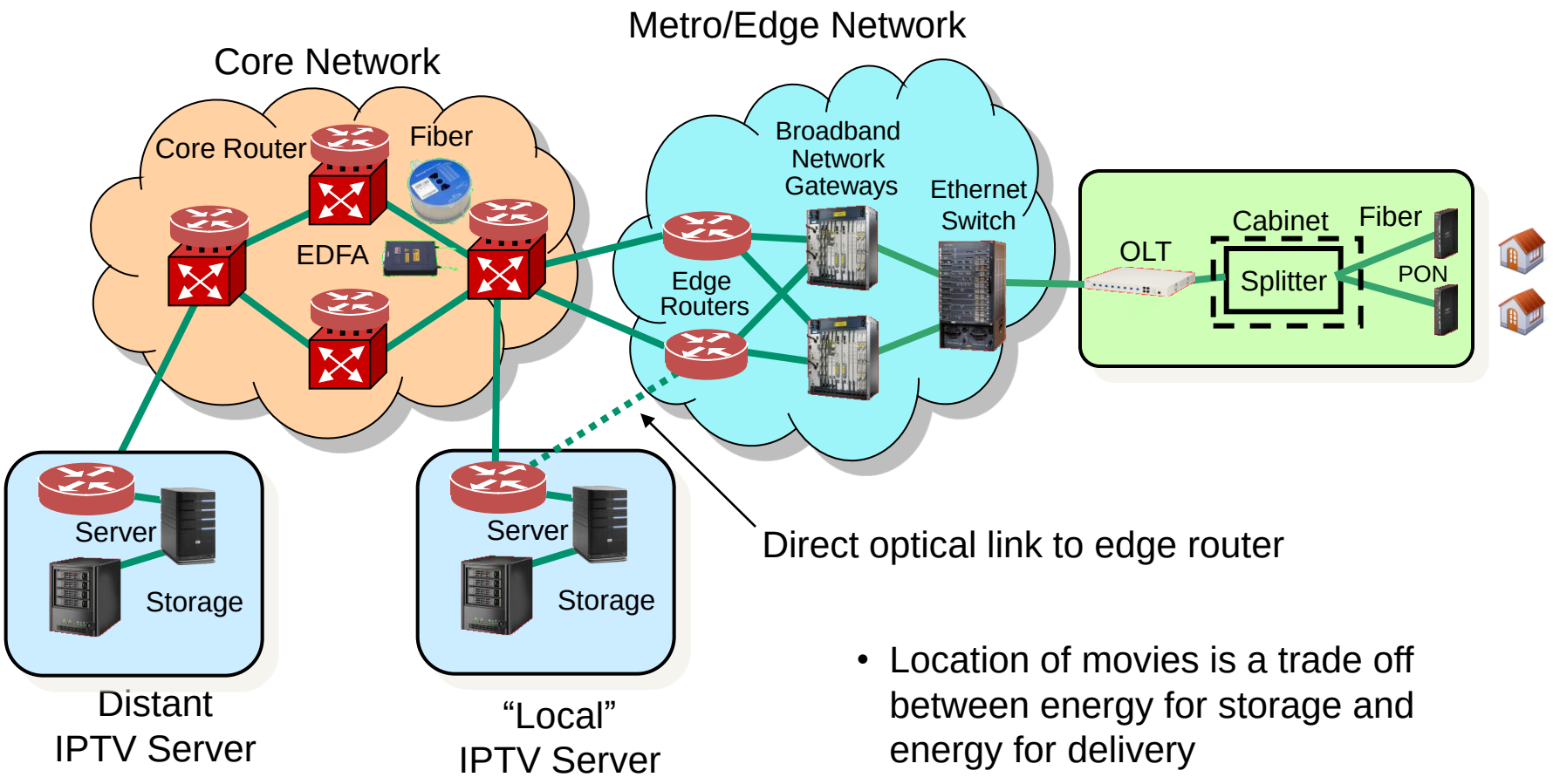
Storage of application & data “in the cloud” compared with storing on a local disk.
50 MBytes per download. Modern laptop-style HDD 20% read/write and 80% idle.



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



- 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

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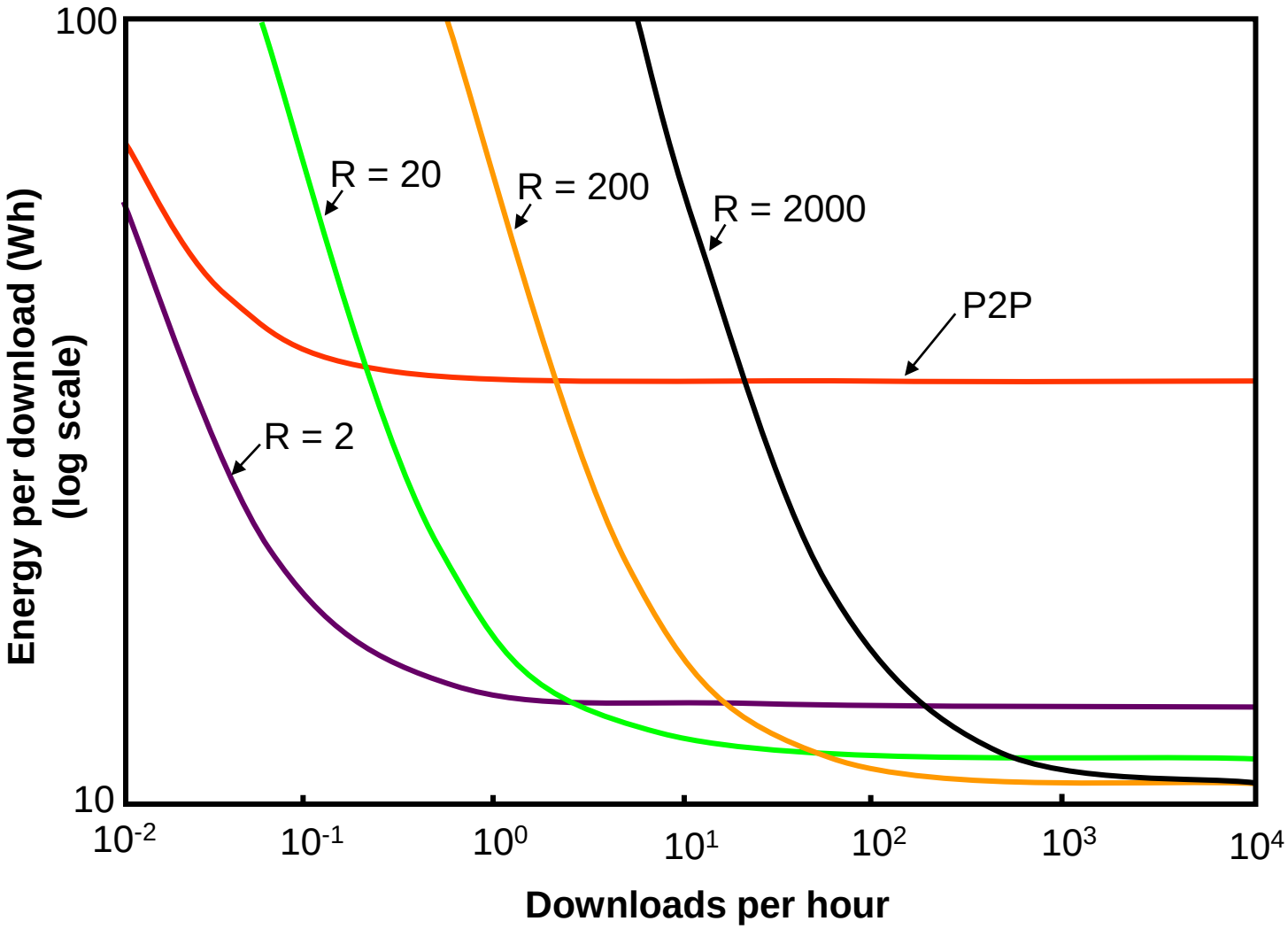
IPTV over the public Internet



Baliga et al., OFC, 2009

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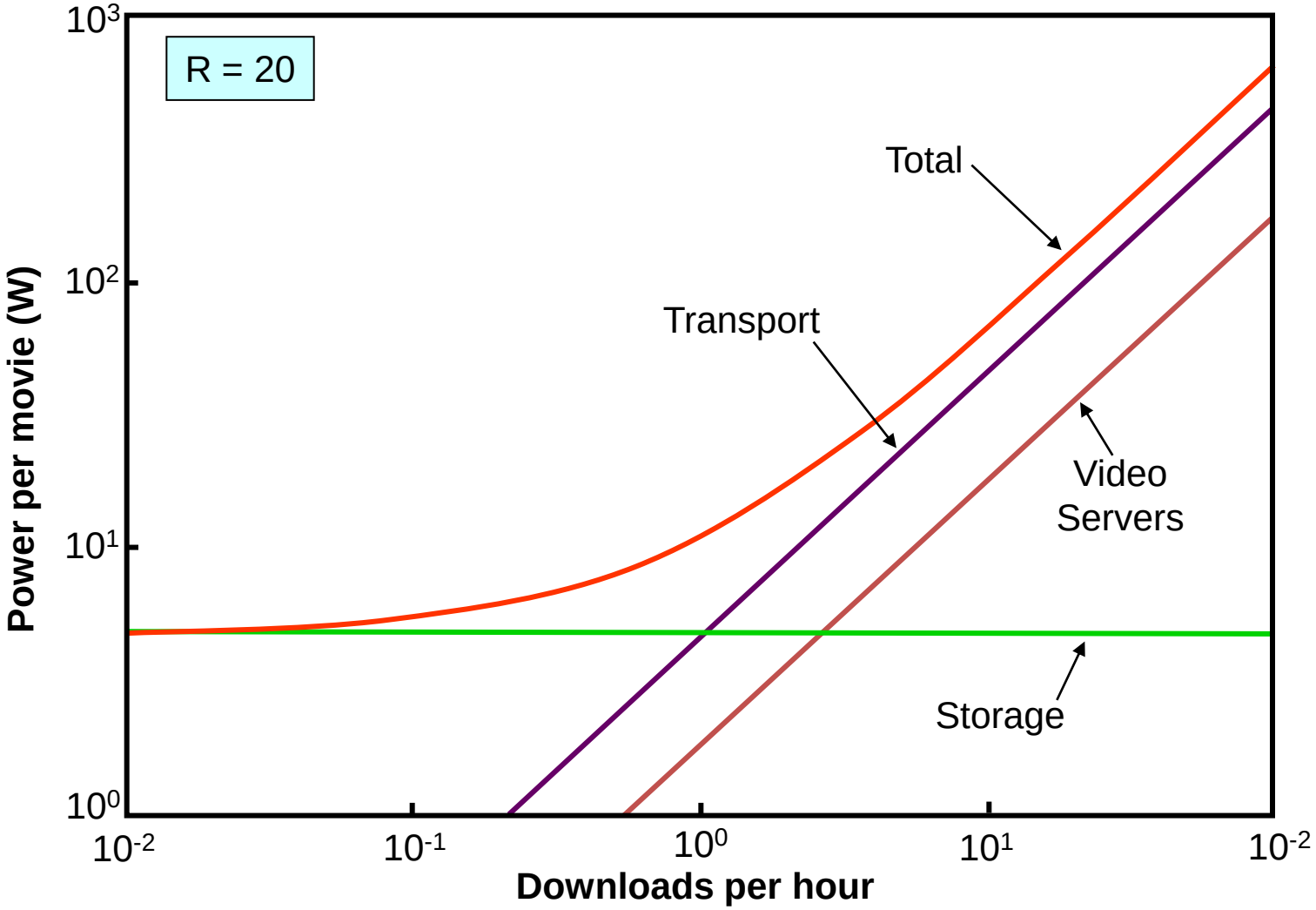

Baliga et al., OFC, 2009

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