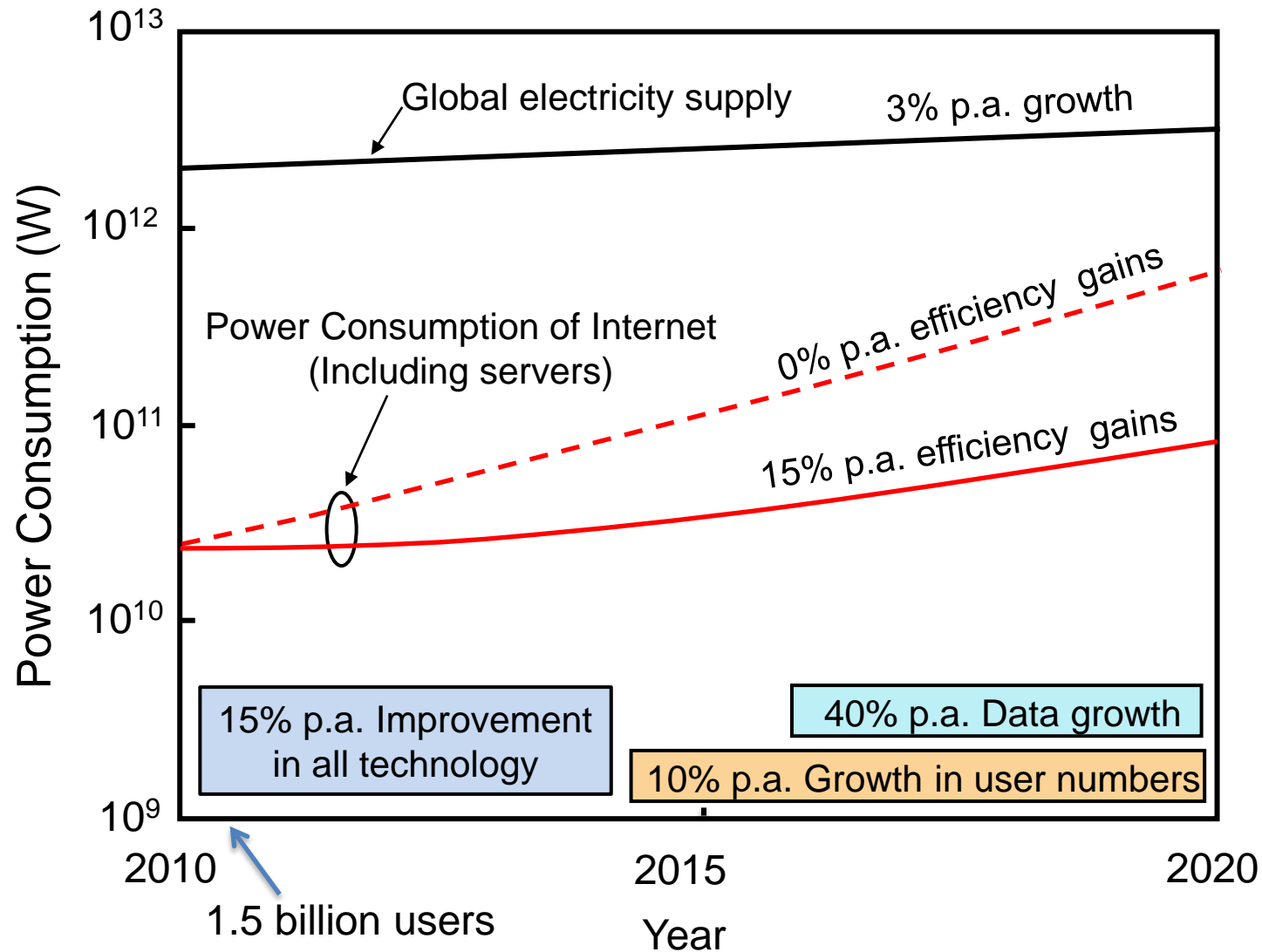


# Charting a Path to Sustainable and Scalable ICT Networks

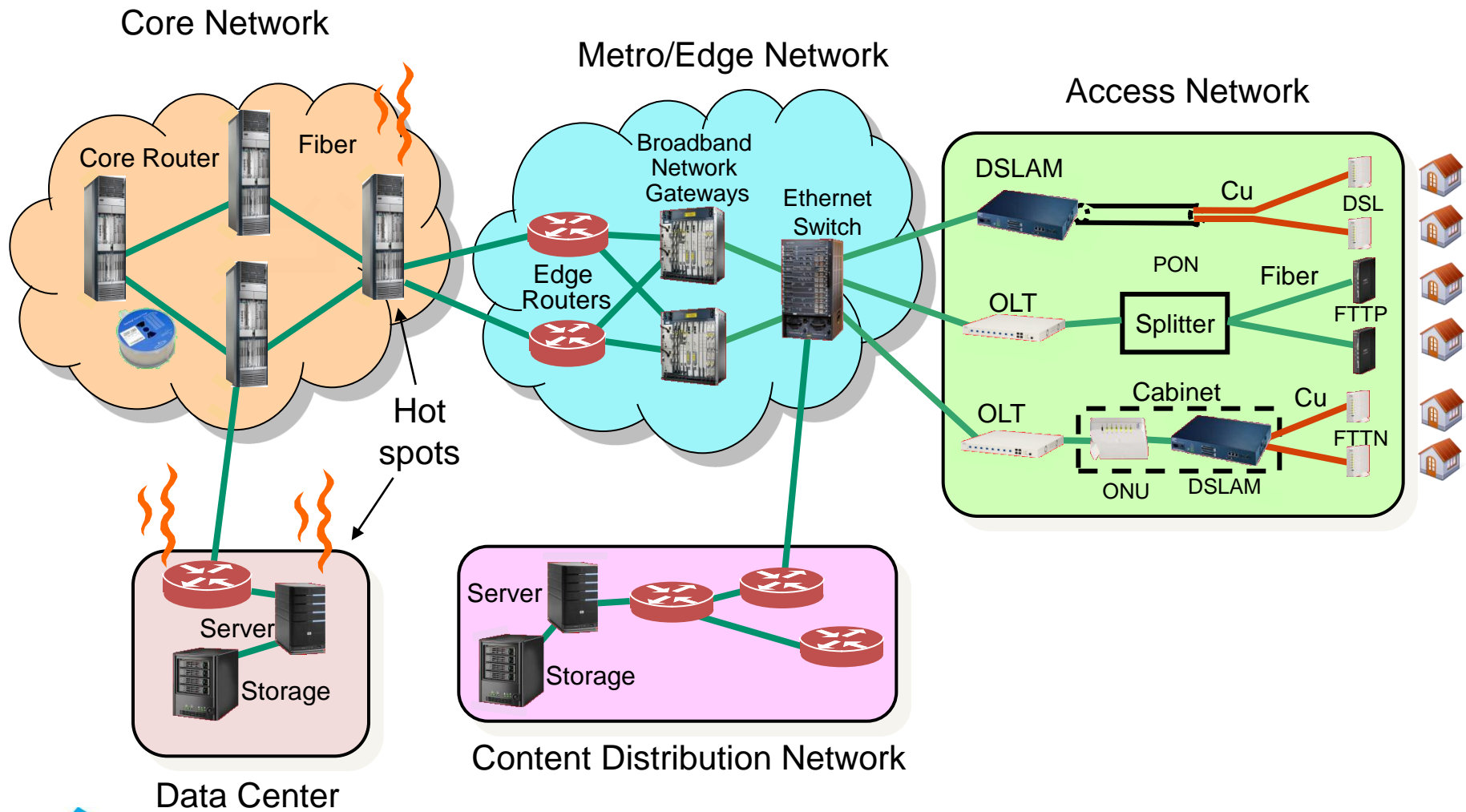
**Rod Tucker, Rob Ayre, Kerry Hinton**

Centre for Energy-Efficient Telecommunications  
University of Melbourne

# Power Consumption of the Global Internet

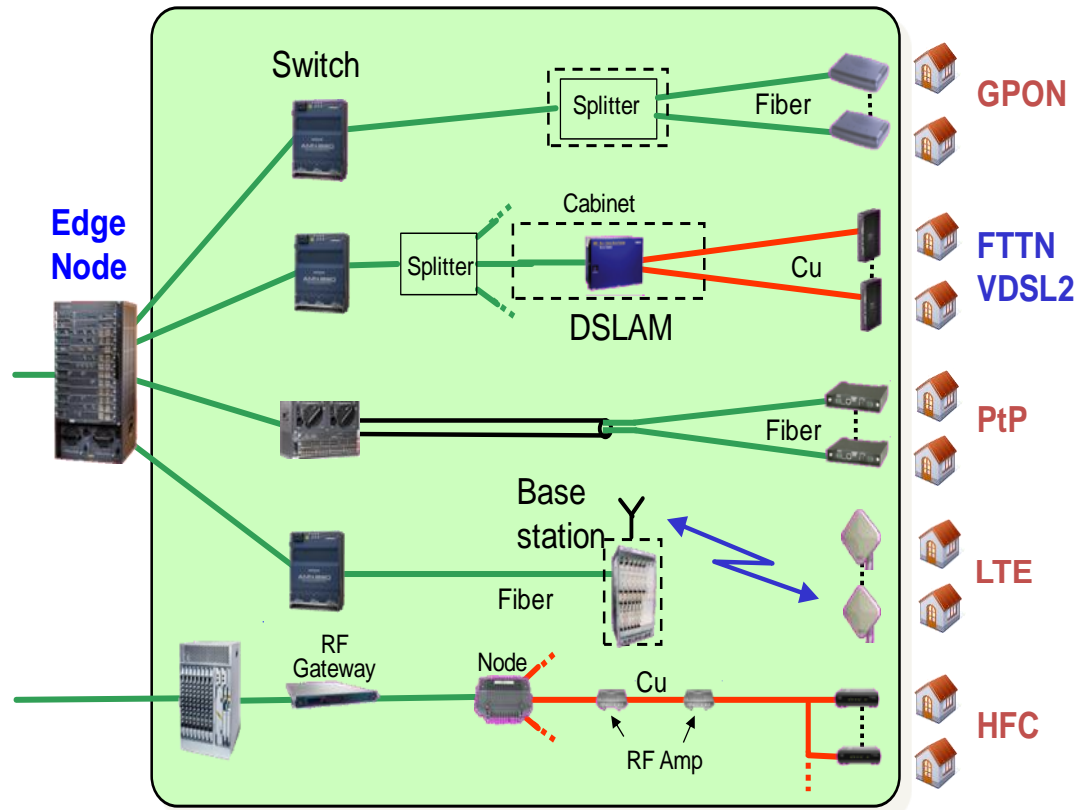


# Inside the Network

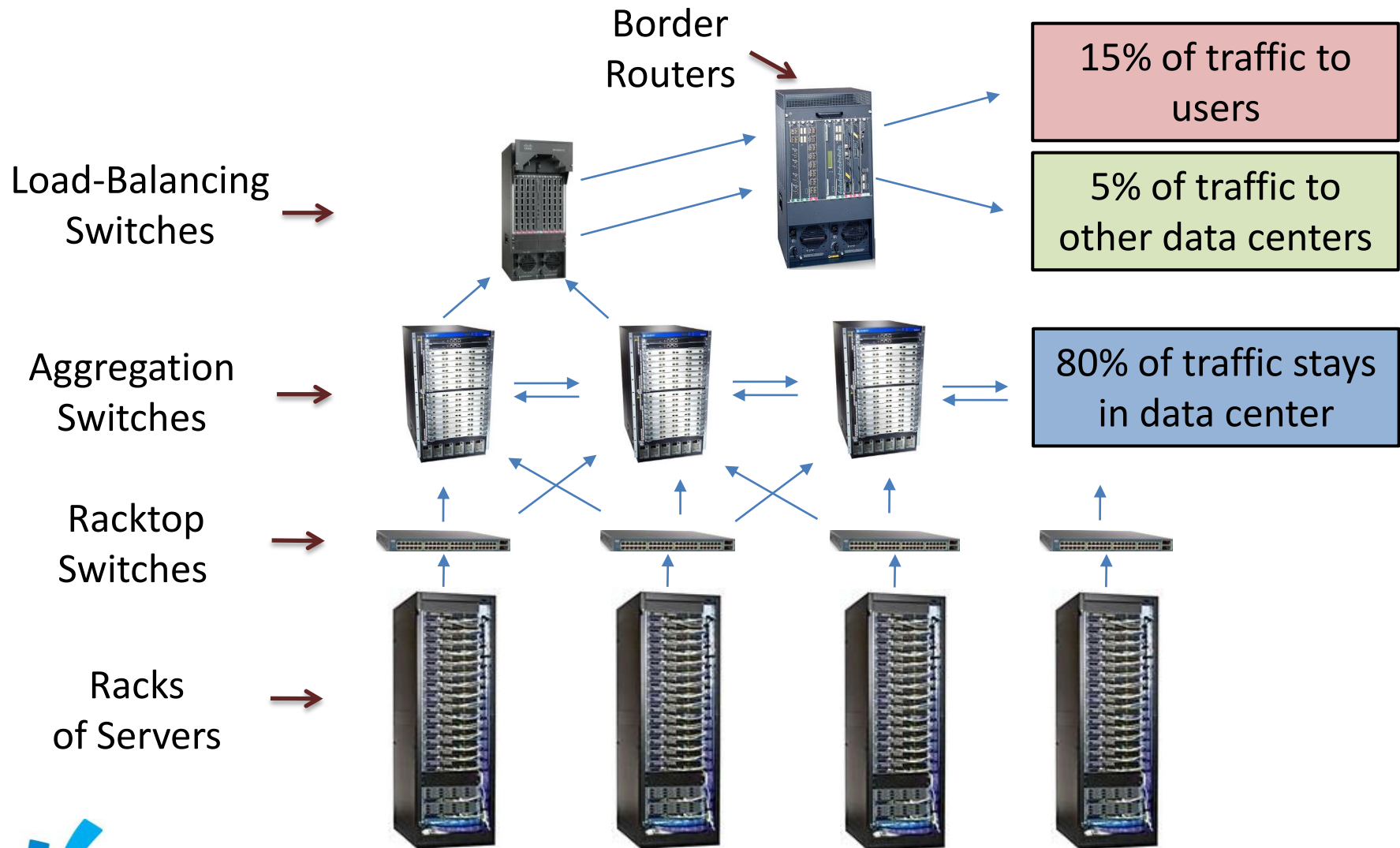


# Access Network

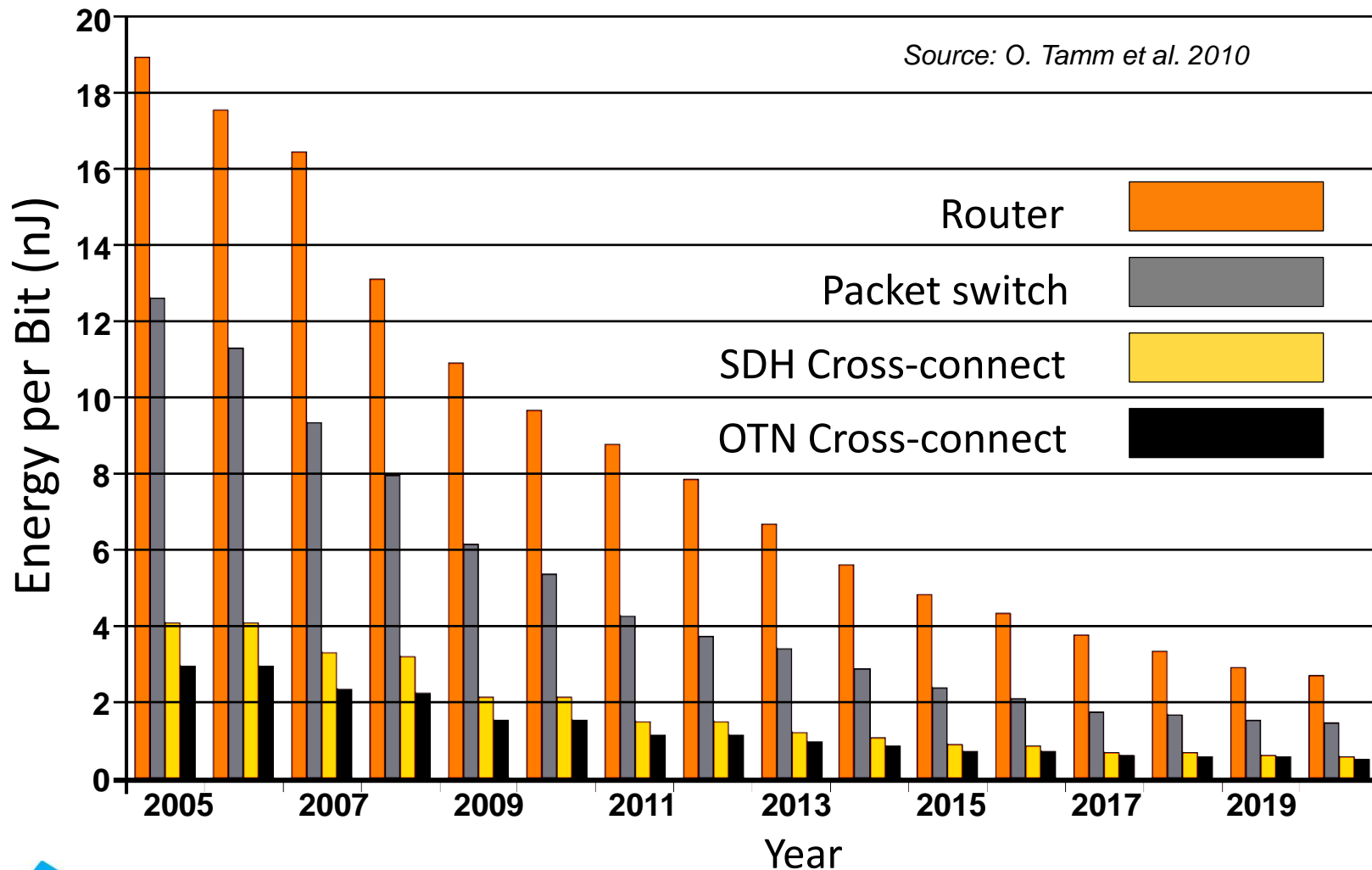
- Customer home terminal
  - ADSL modem, ONU, wireless/cable modem,..
- Access network field equipment
  - PON splitter, DSLAM, RF amps,..
- Central office equipment
  - OLT, gateway, switch, base station,..



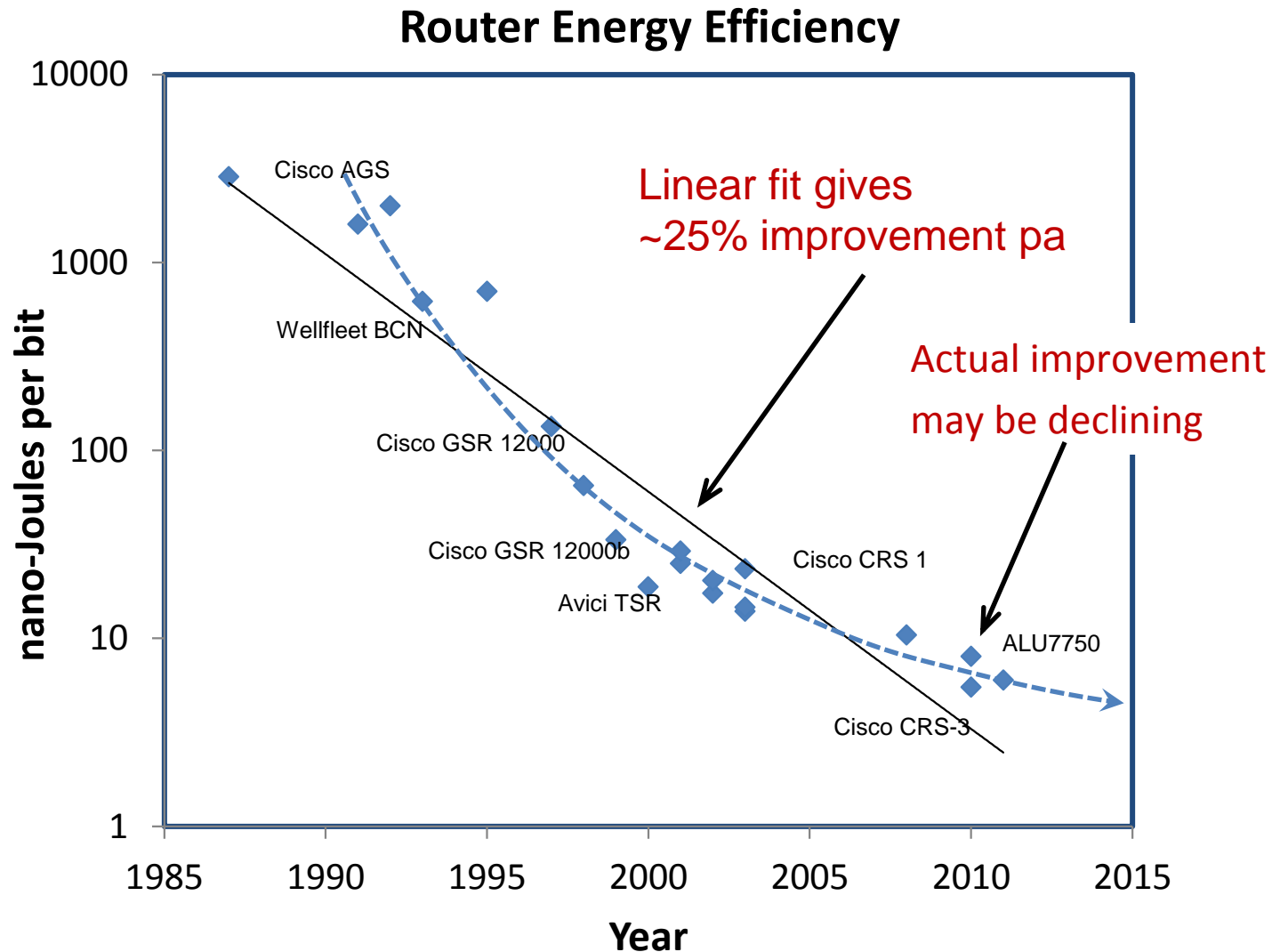
# Data Centers and Content Servers



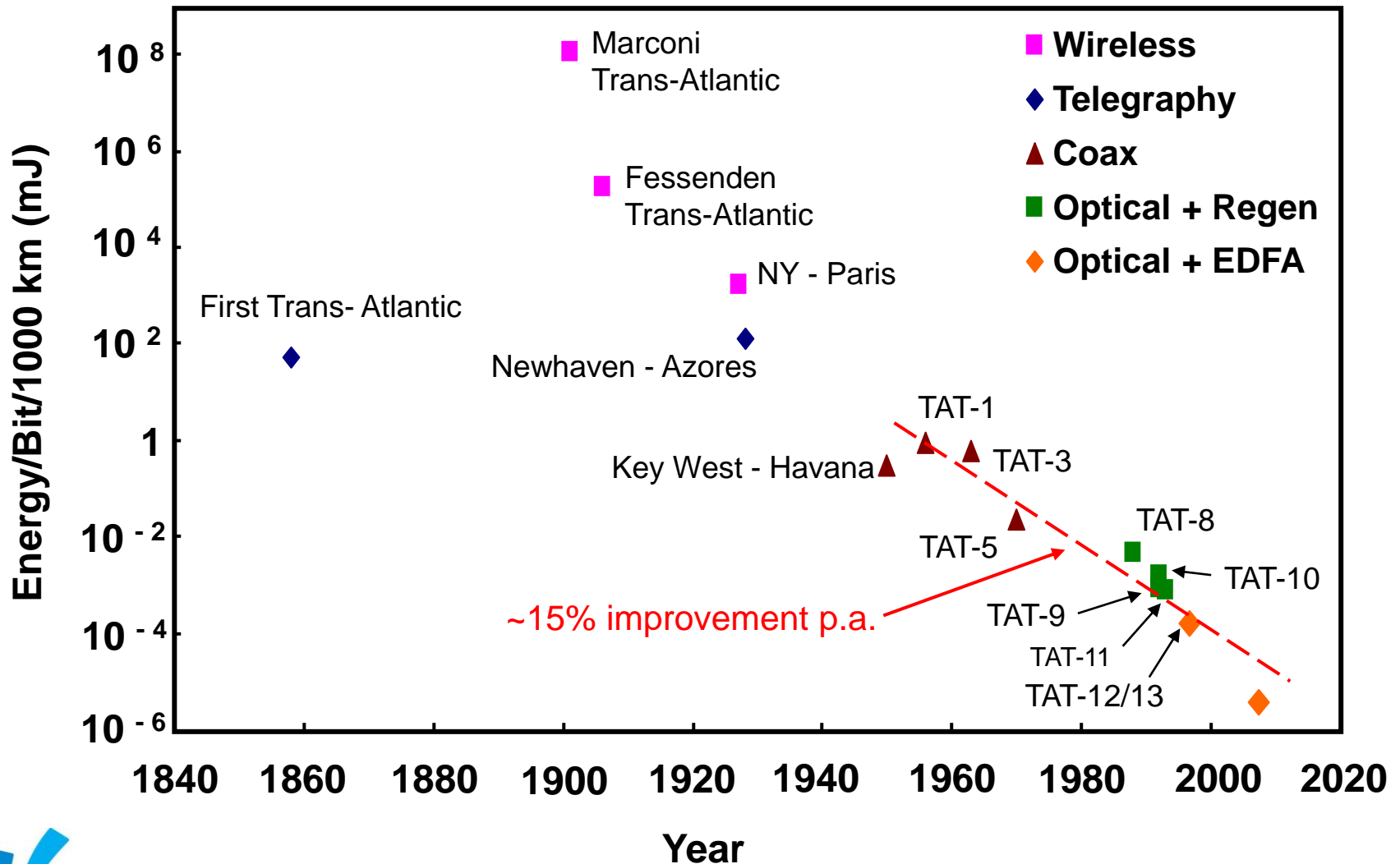
# Energy Efficiency of Key Equipment



# Router Energy Consumption Trends

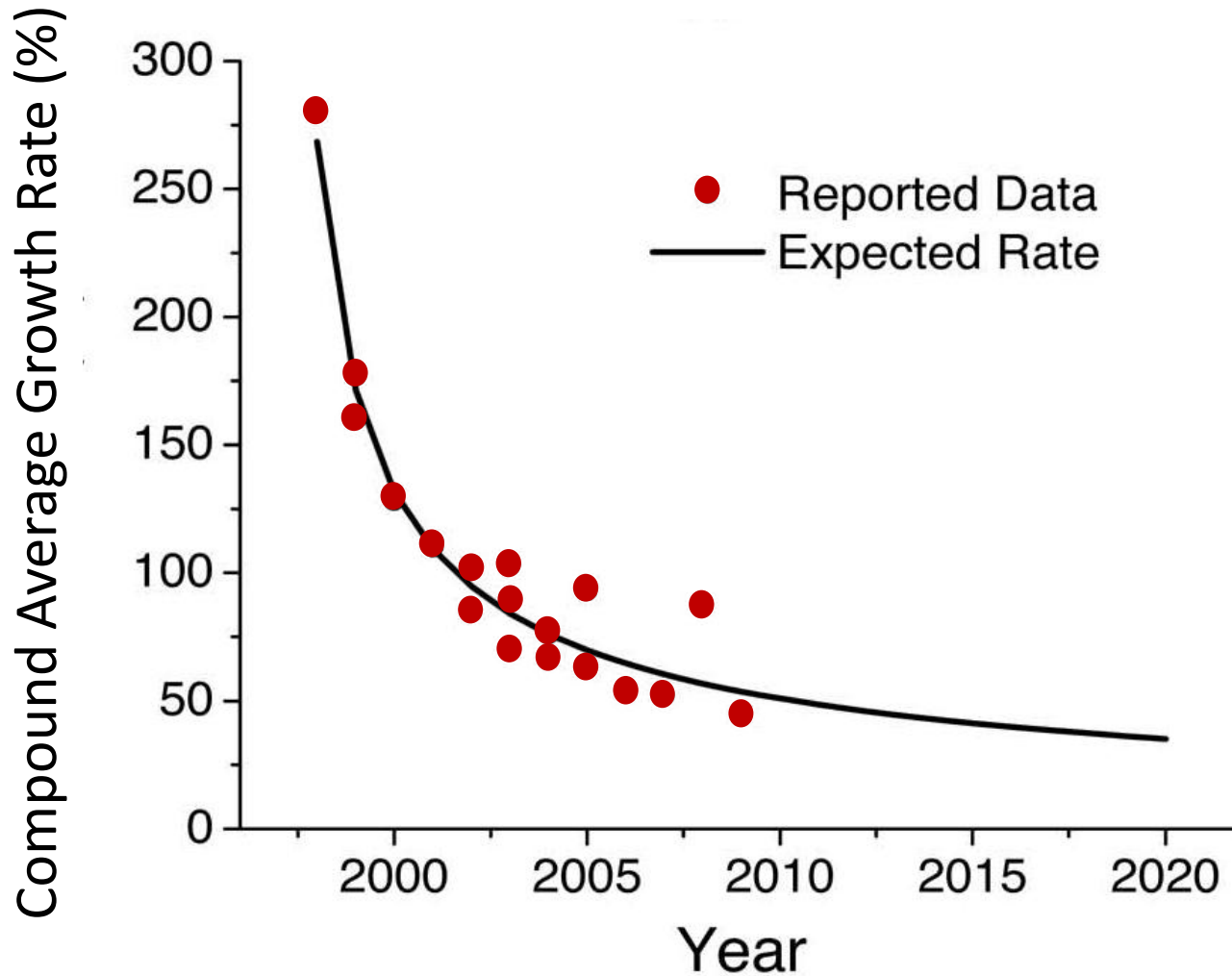


# Transport Energy Consumption Trends



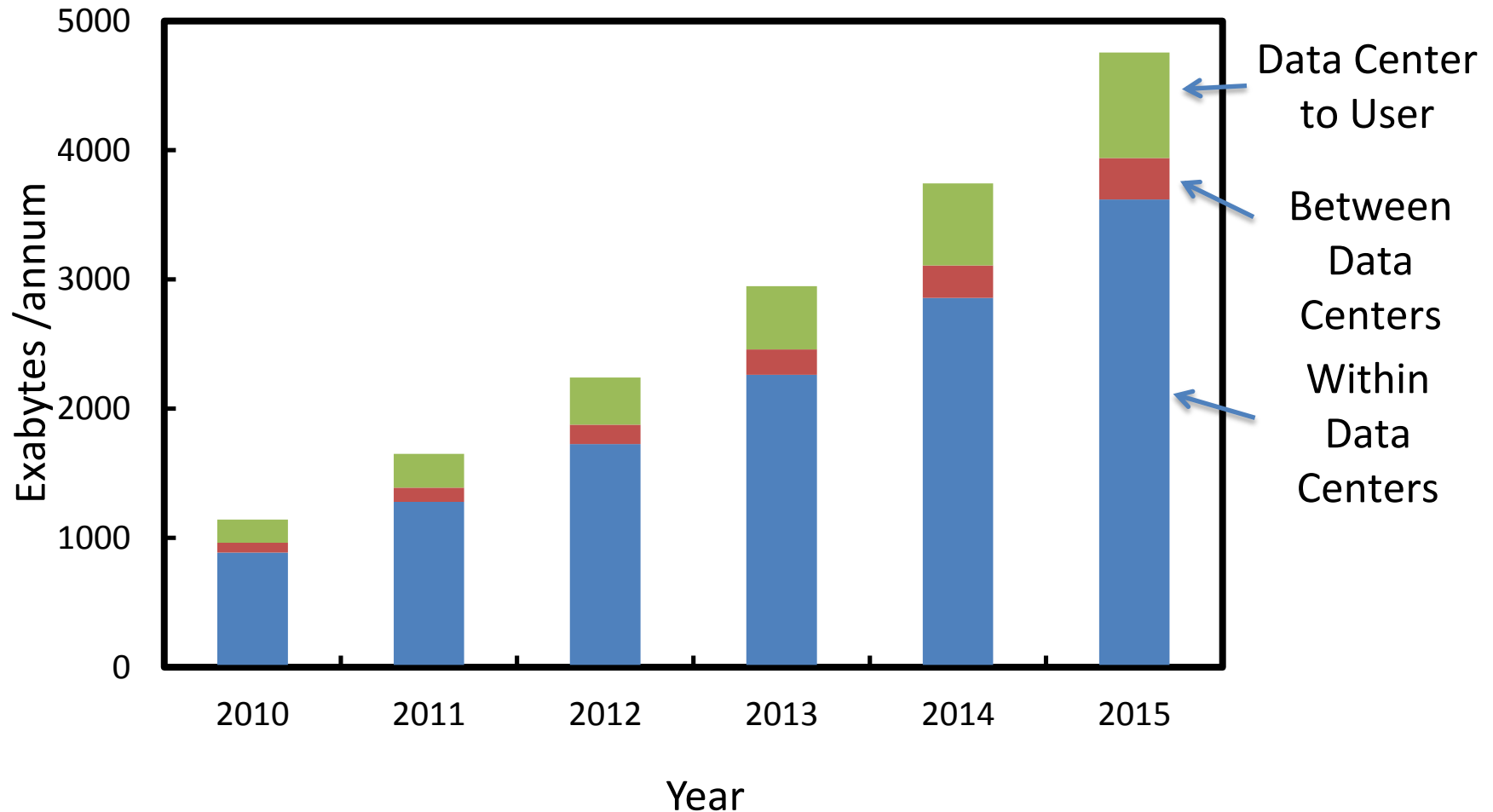
Source: Tucker 2011

# Internet Traffic Growth Trends



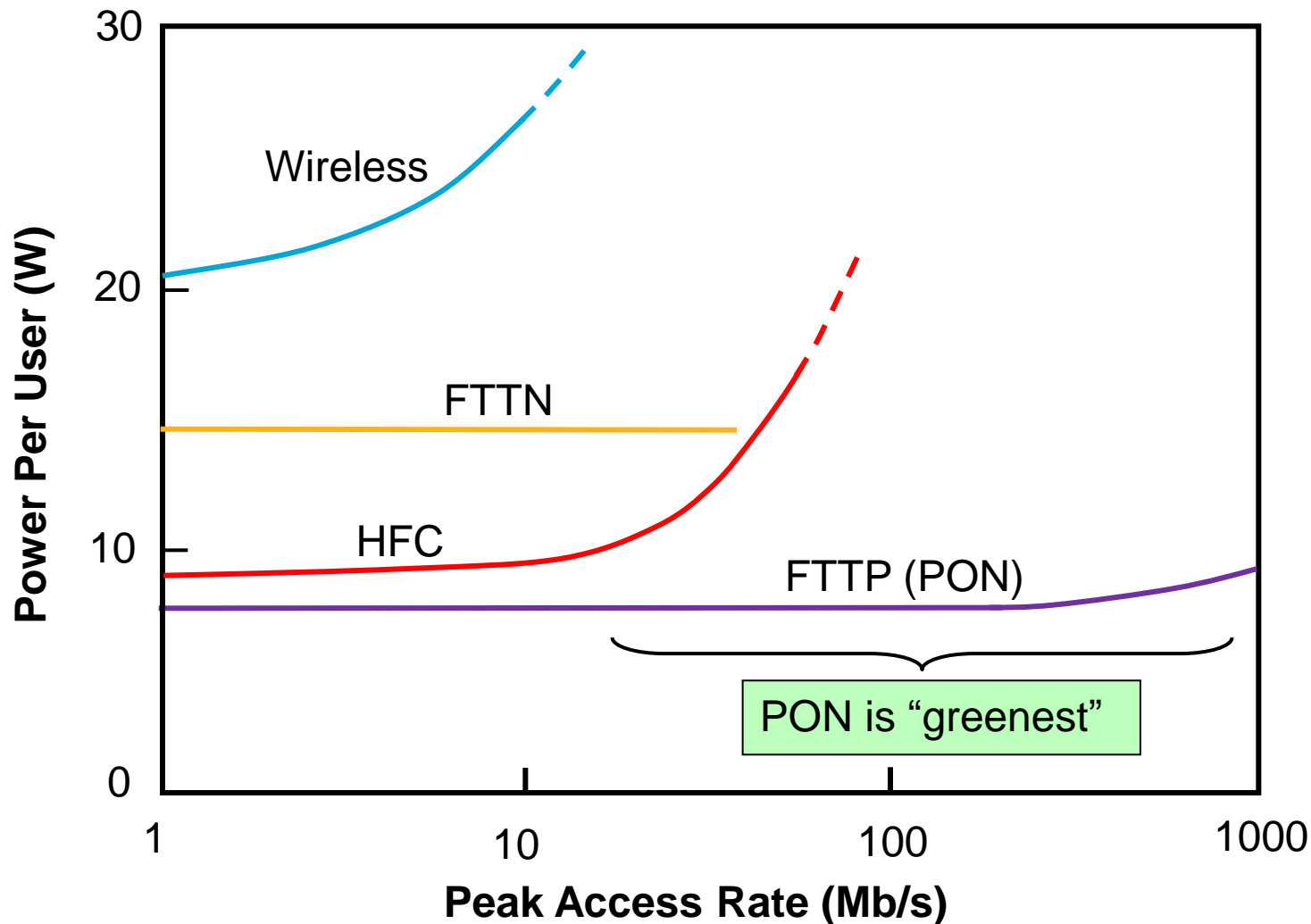
Source: Kilper et al., JSTQE 2011

# Cisco Projections of Data Centre Traffic

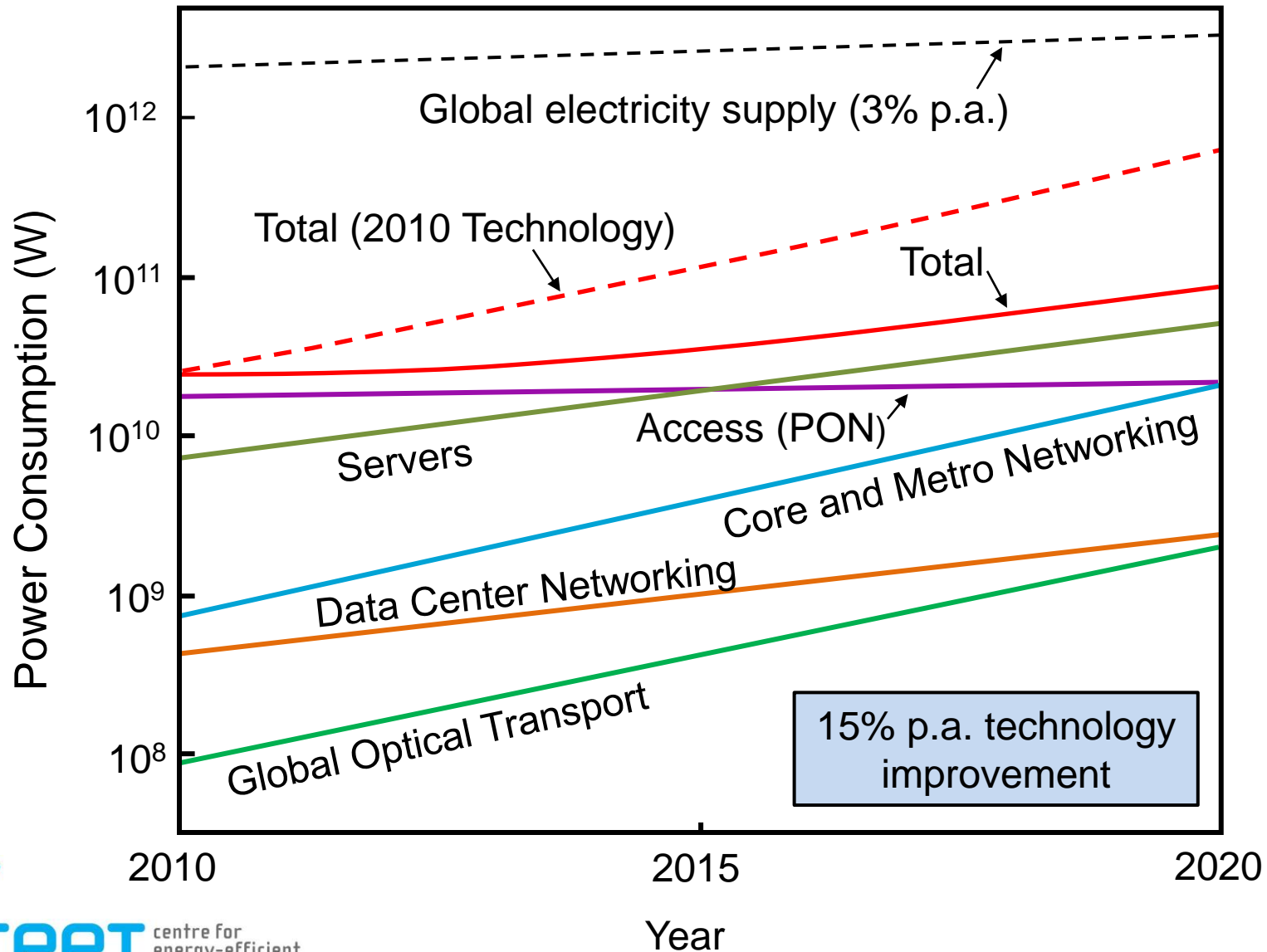


Source : Cisco Cloud Index 2011

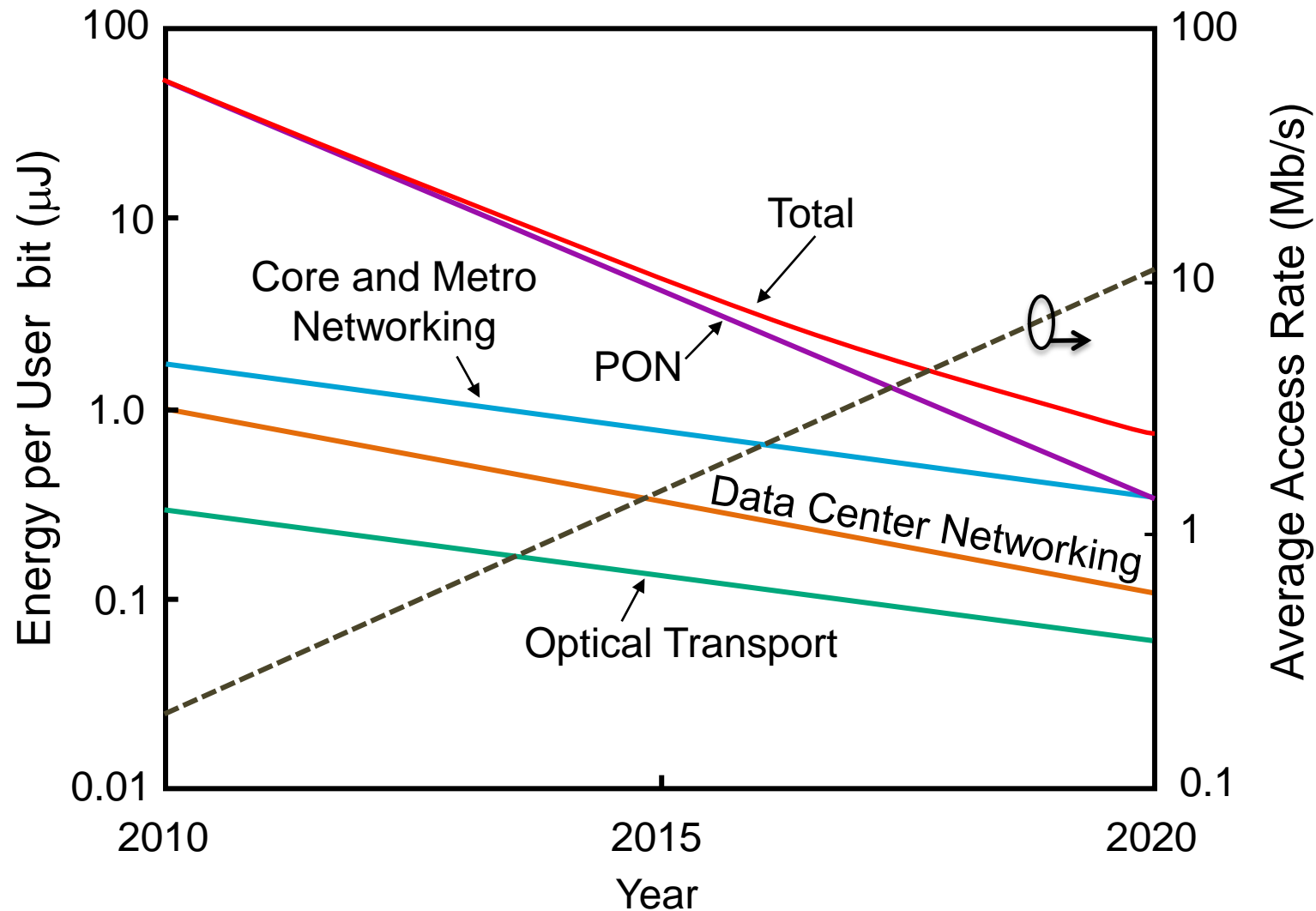
# Access Network Energy Consumption



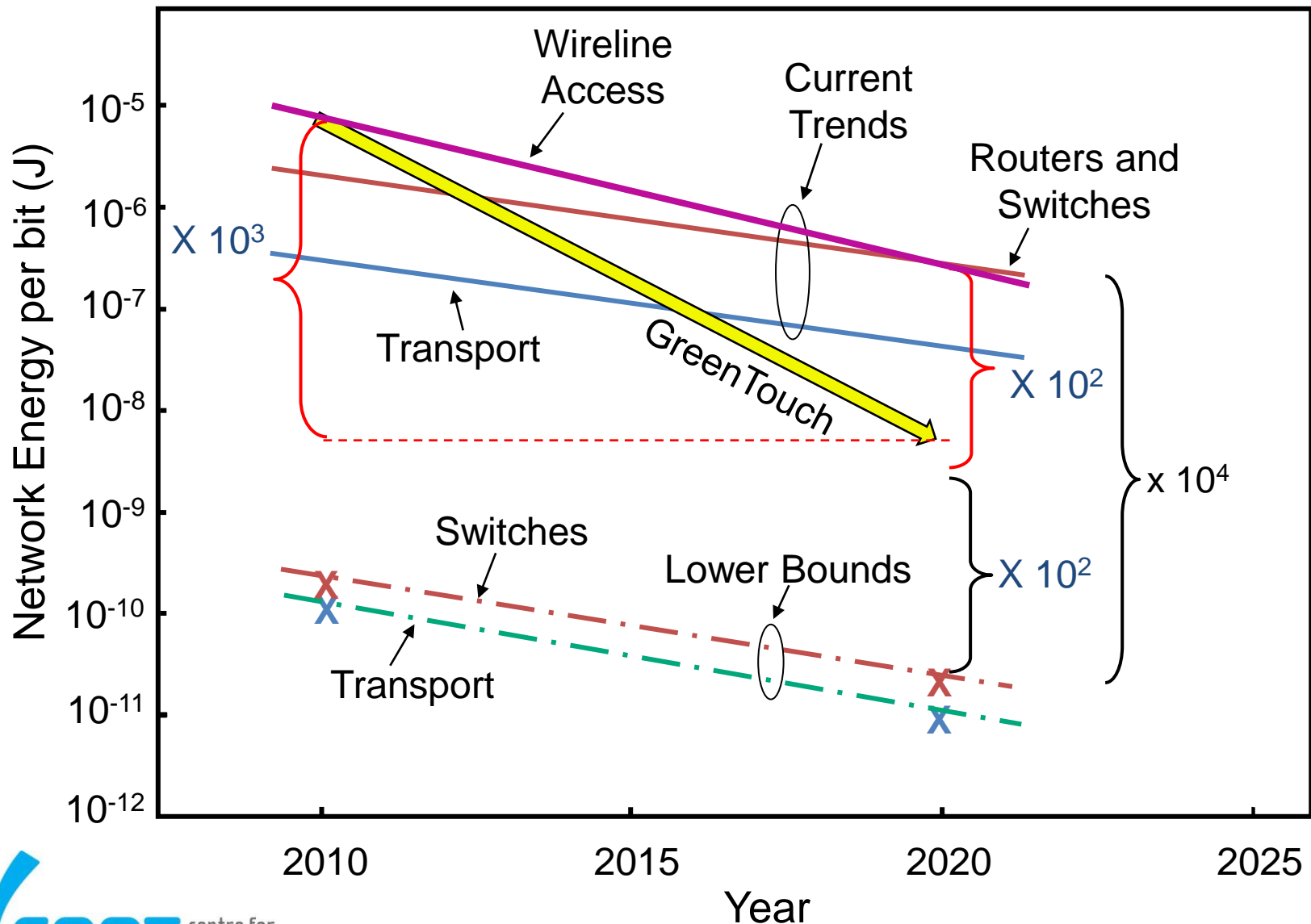
# Power Consumption of the Global Internet



# Network Energy per User Bit



# Gap Between Theory and Practice



# A Path to Sustainable ICT Networks

- Technologies
- Architectures
- Protocols

# A. Technologies

- Fundamental physical technologies for telecommunications:
  - Electronics: primarily CMOS
    - Used for signal and data processing and storage
  - Optics/photonics
    - Primarily used to transport data
- Interface between electronics & optics is evolving as these technologies develop
- Advances are needed in
  - Optical and electronic switch technologies
  - Optical and electronic interconnects at all levels
  - Low-power access technologies, especially wireless

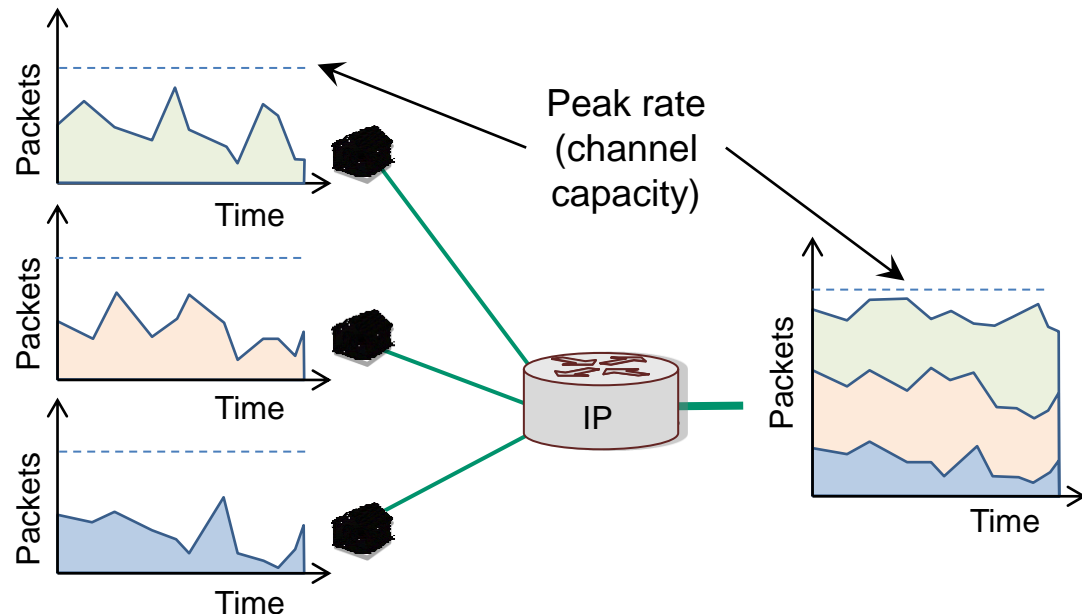
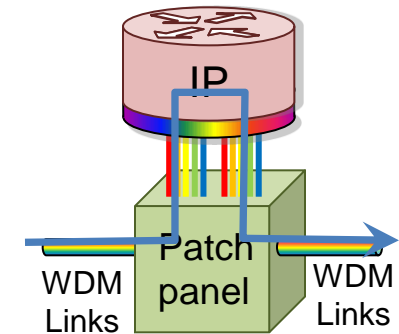
## B. Architectures

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

# Bypass options

## 1. No bypass:

- All traffic goes to IP layer for processing
  - All packets processed by IP router
  - $\sim 10$  nJ per bit
  - Allows aggregation of incoming traffic flows
  - Statistical multiplexing increases utilisation of paths

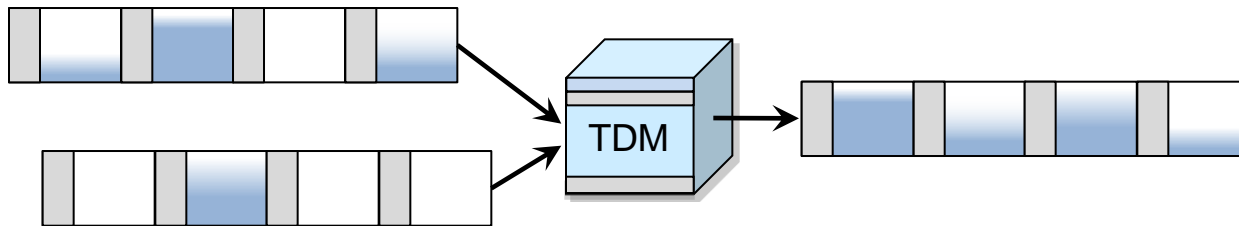


# Bypass options (cont'd)

## 2. Bypass

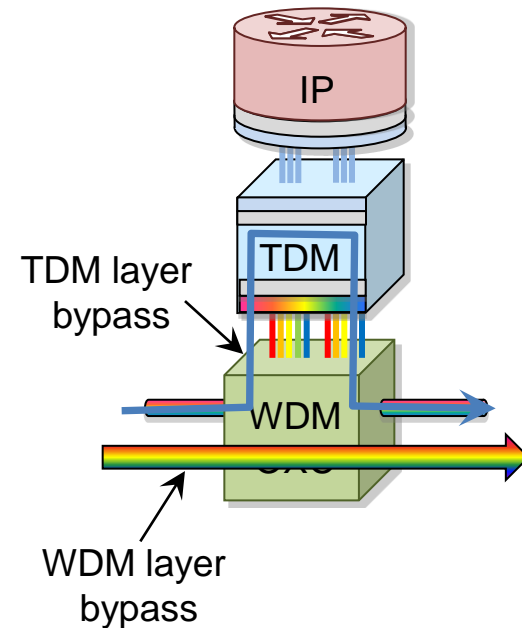
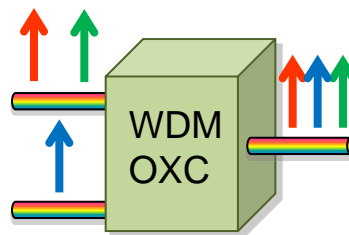
### – TDM layer (electronic cross connect, OTN)

- Some traffic streams processed at TDM level
- $\sim 1$  nJ per bit



### – WDM layer (optical cross connect)

- Some traffic switched at WDM layer
- $< 0.1$  nJ per bit
- Switching wavelengths



## C. Protocols

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

# Energy-efficient protocols

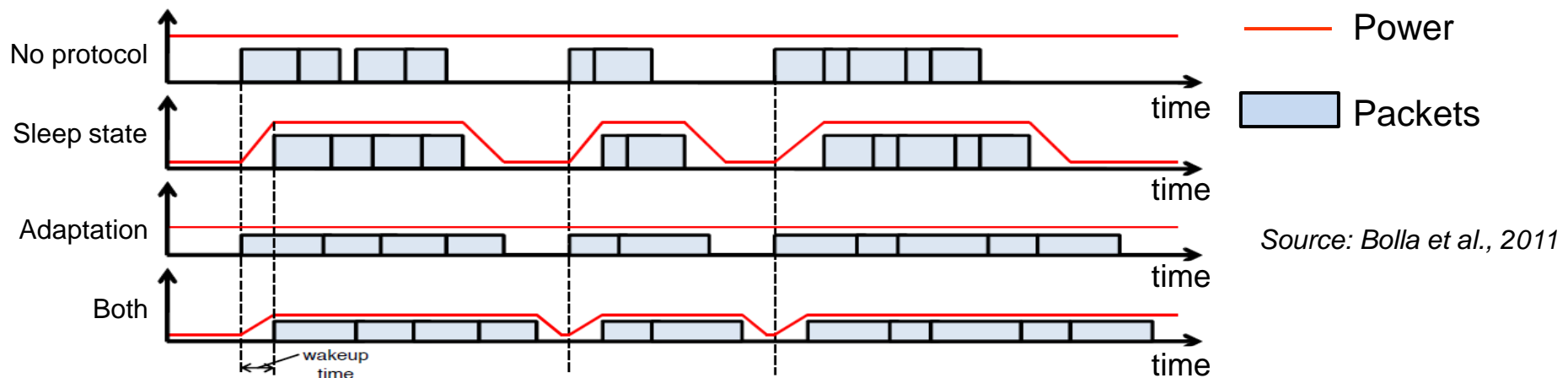
- Sleep & standby states
  - Network devices enter low power state when not in use
  - Can apply to systems and sub-systems
  - Need to ensure network presence is retained
    - Use Network Connection Proxy with sleep protocol
  - Need to account for state transition energy and time
  - May have multiple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

# Energy-efficient protocols

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

$$Power = C \cdot Voltage^2 \cdot frequency$$

- Slower speed to reduce power consumption
  - 100 Mbit/s uses 10-20 W less than 10 GE, 4 W less than 1 GE
  - Need to allow transition time between rates
- Dynamic rate adaptation and standby states can be combined



# Thank You