Energetic Efficiency (EE) over Wired Networks

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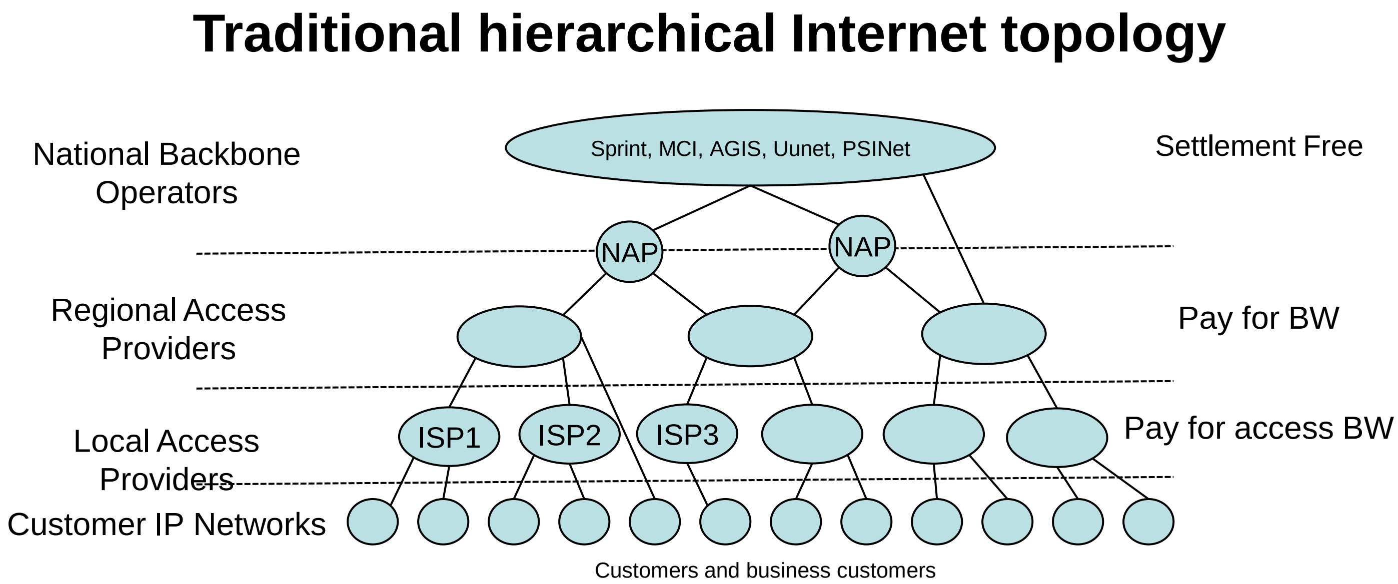
Disclaimer

- The contents of this presentation include figures and results from several Internet sources.
- Author has tried to include all the corresponding references, included at the end of this presentation
- With all, the major part of the presented technologies and solutions are actually over researching and the lecturer recommends to complete the information for each option directly over the source to obtain concrete details.
- If you are not referenced yet, I’m sorry and I’ll include your name in next versions of this document.

Agenda

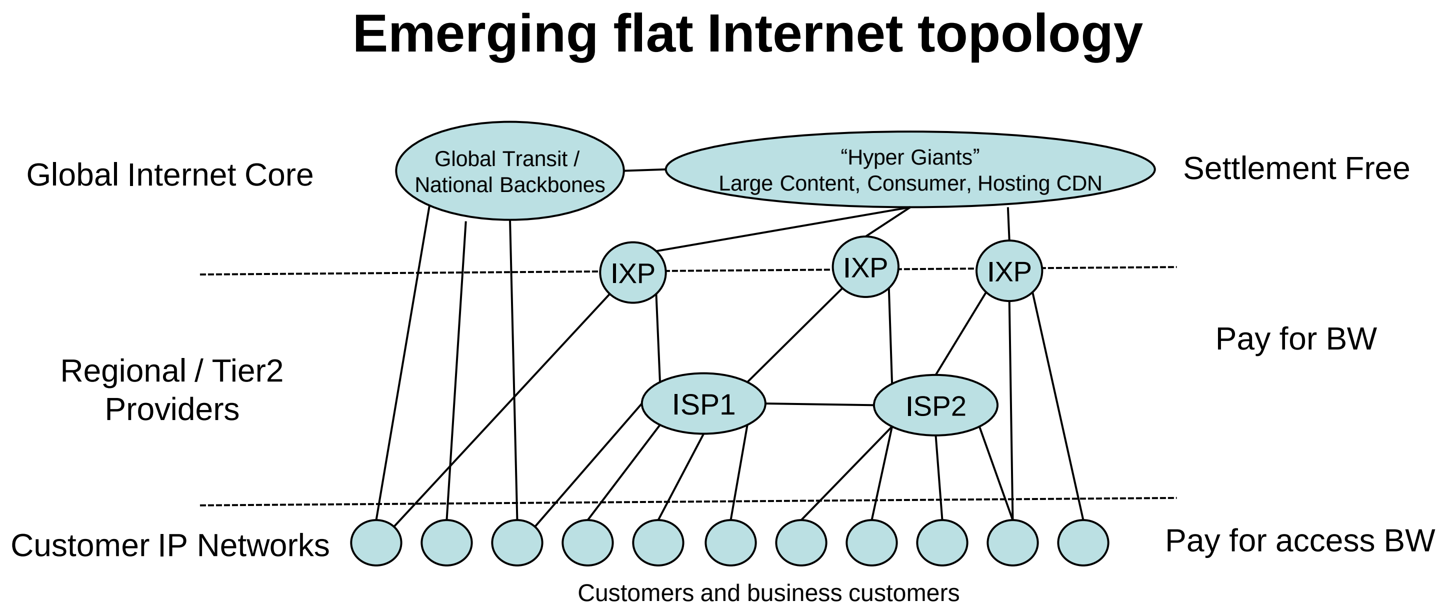
1. Power consumption over the access
2. Power consumption over the backbone
3. Why Energy Efficiency over networks
4. EE over the practice: some proposals
5. Main keywords:
   1. EE techniques
   2. Circuit switching
   3. Slow down
   4. Turn off hardware
   5. EE applications/protocols

Internet: the origin



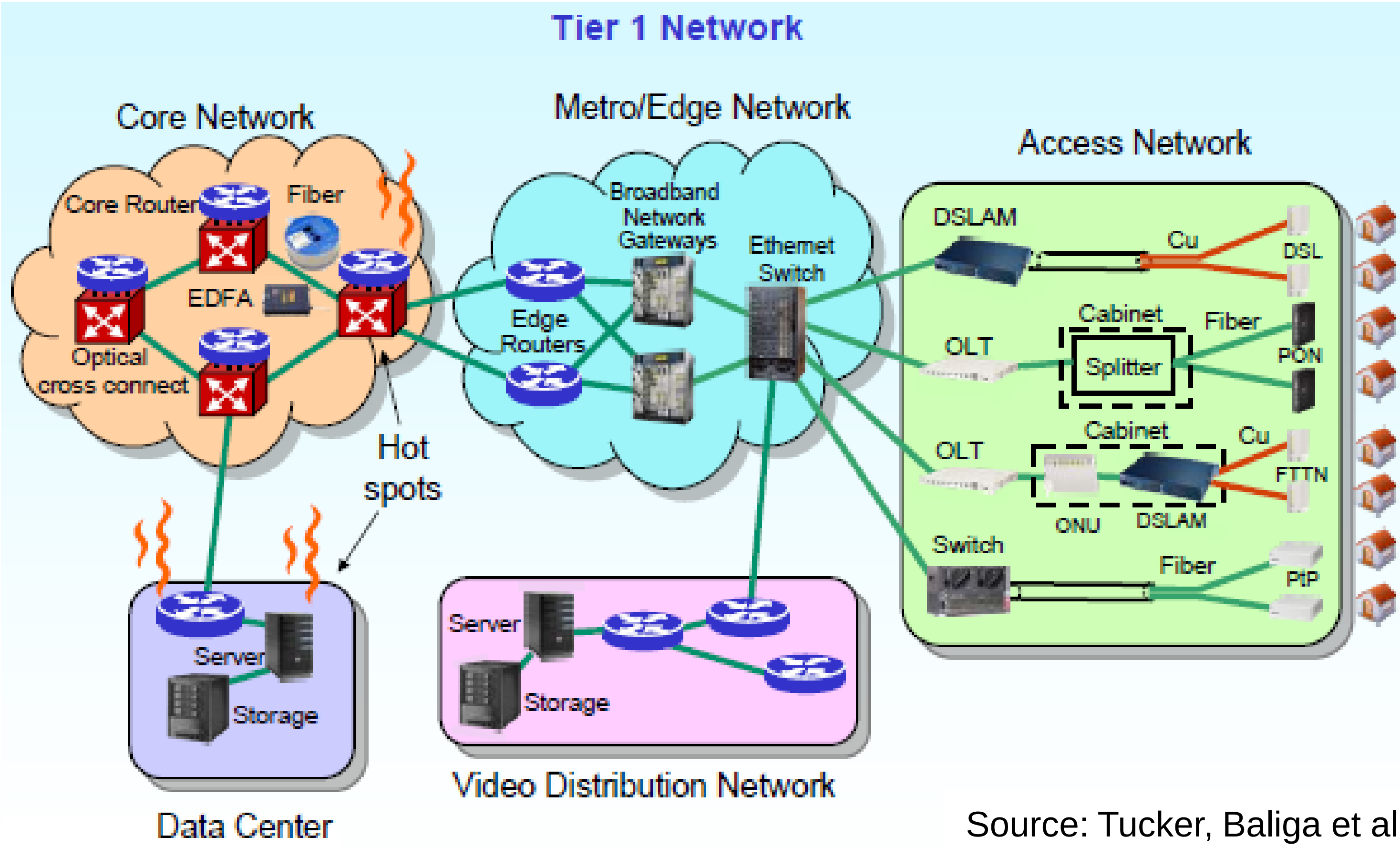
- Most traffic flowing between the core tier-1 provider

Internet: actually



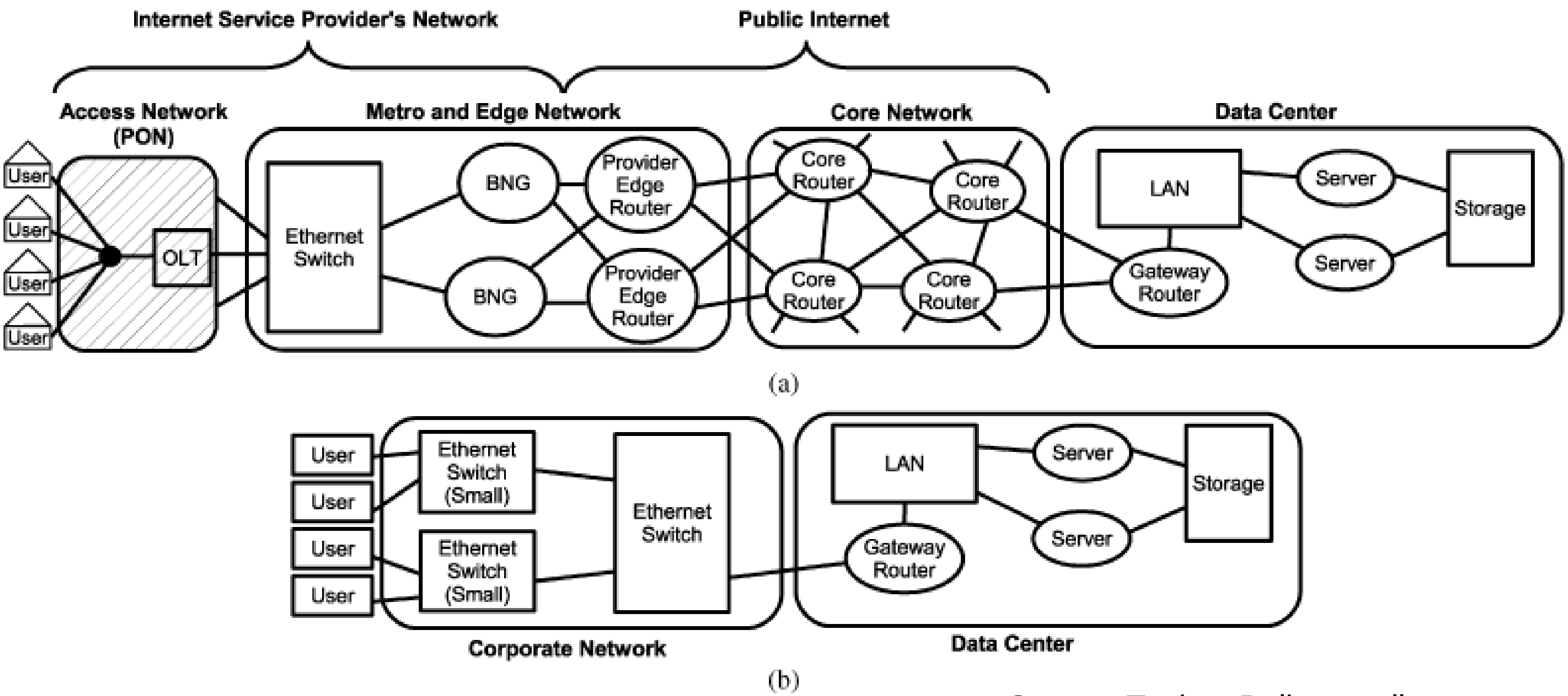
- Most traffic flowing directly between content providers and customer IP networks
- Part flows to the global Internet through Internet Exchange Points (IXP)

Internet: the practical view



Source: Tucker, Baliga et all

And …cloud computing???



a) **Public cloud**
b) **Private cloud**

Source: Tucker, Baliga et all

EE: What is the objective?

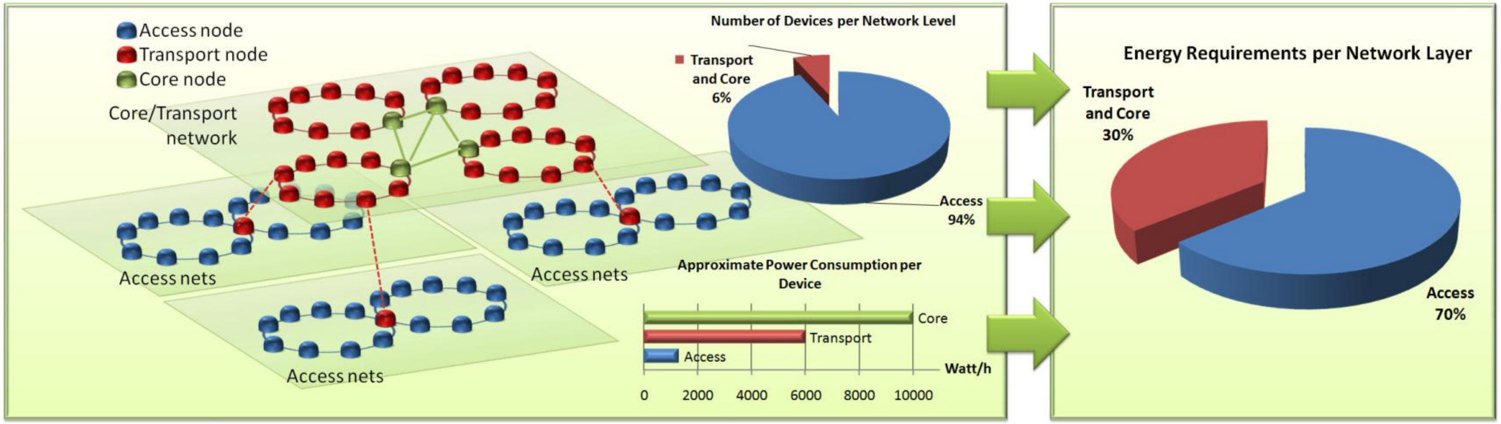
Communication from the Commission - Energy efficiency: delivering the 20% target /* COM/2008/0772 final */

- The optimization of energy consumption is a crucial topic
- European Commission promoted the ambitious

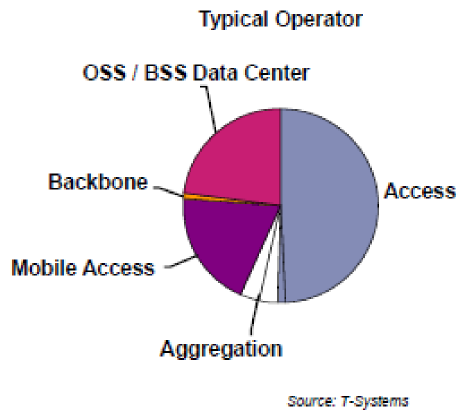
"20-20-20"

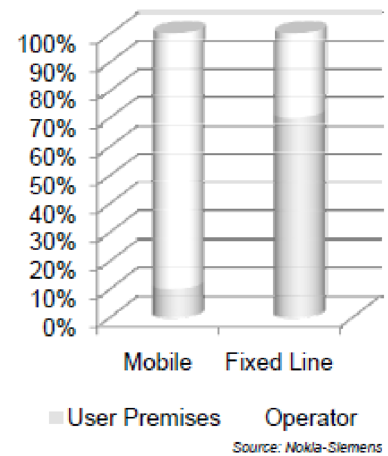
  - 20% cut in emissions of greenhouse gases by 2020 (compared with 1990 levels); a
  - 20% increase in the share of renewable sources in the energy mix
  - 20% cut in energy consumption.
- Transport networks are into the hurricane eye

Which transport networks?

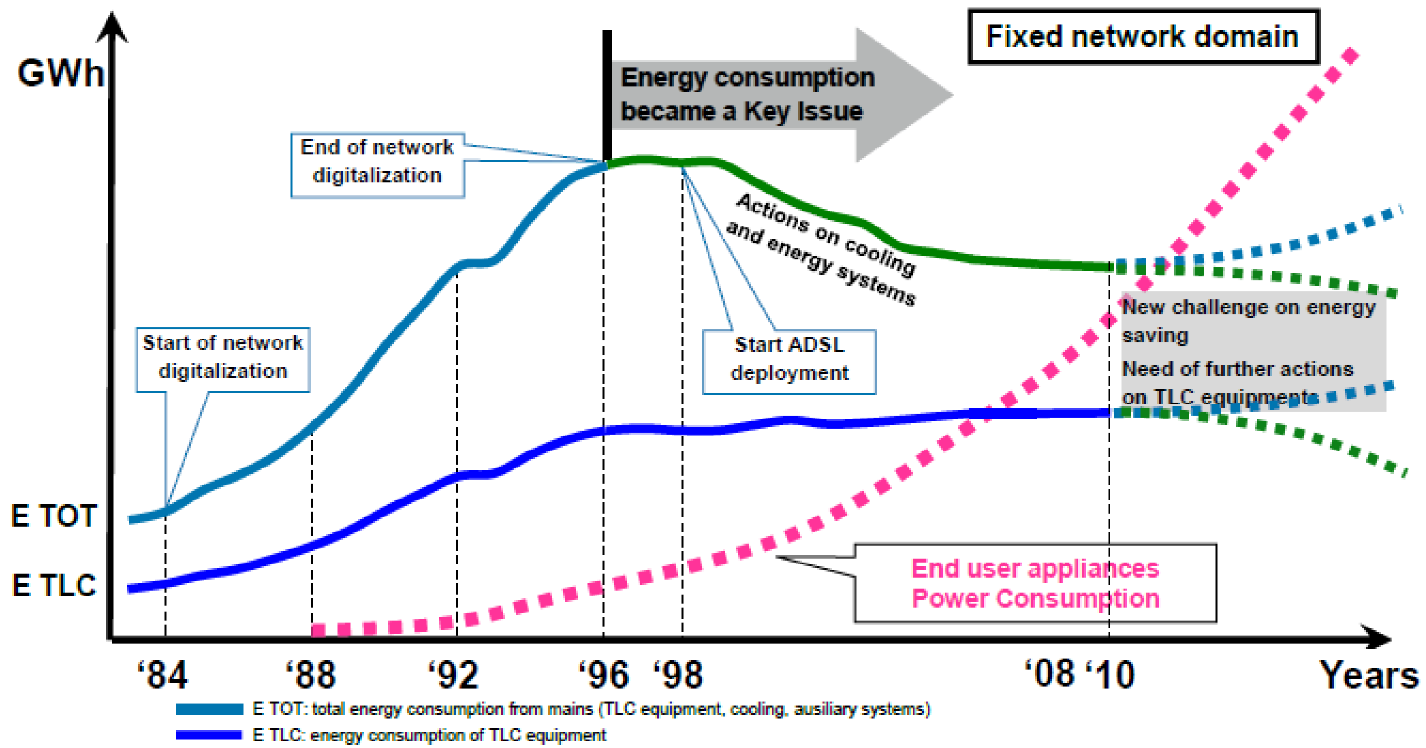


Source Bolla et all



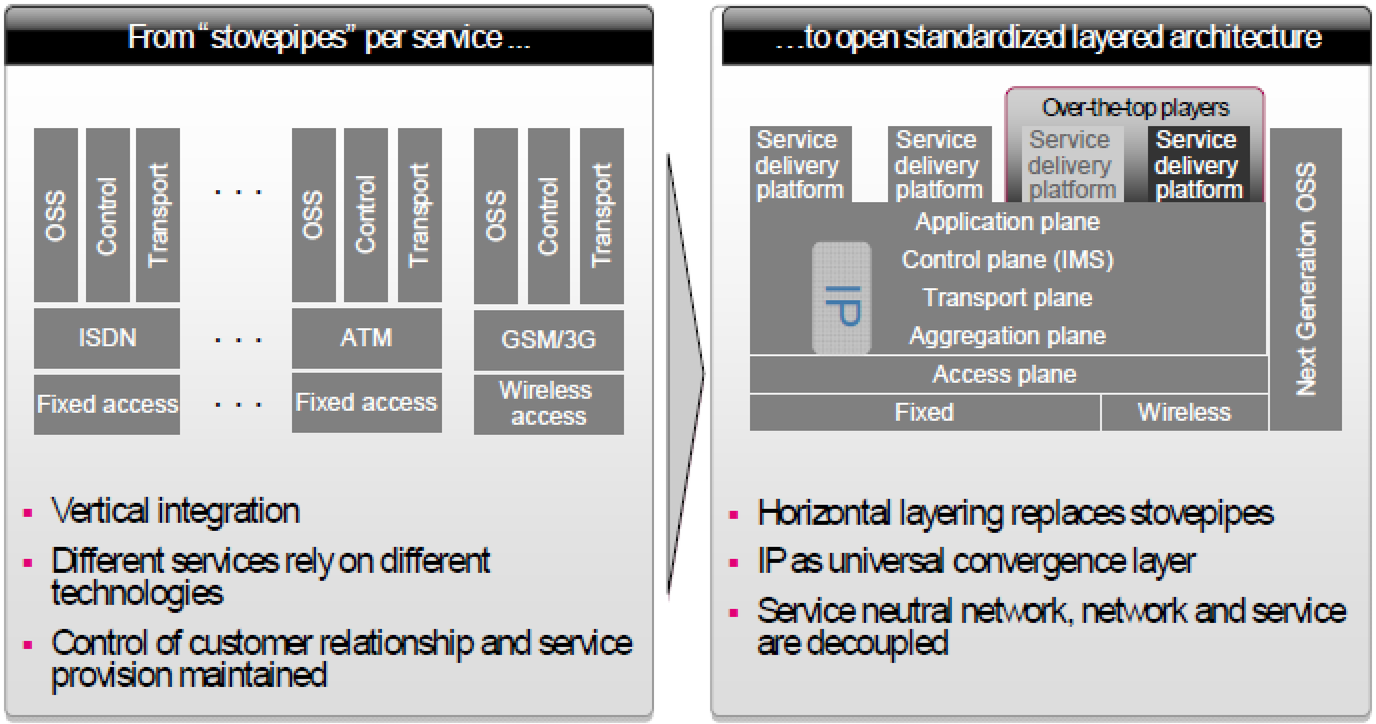


Is it possible???



Source: TELIT

NGN is an explanation too



Source STRONGEST Project

It's the time of the (ICT) networks

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

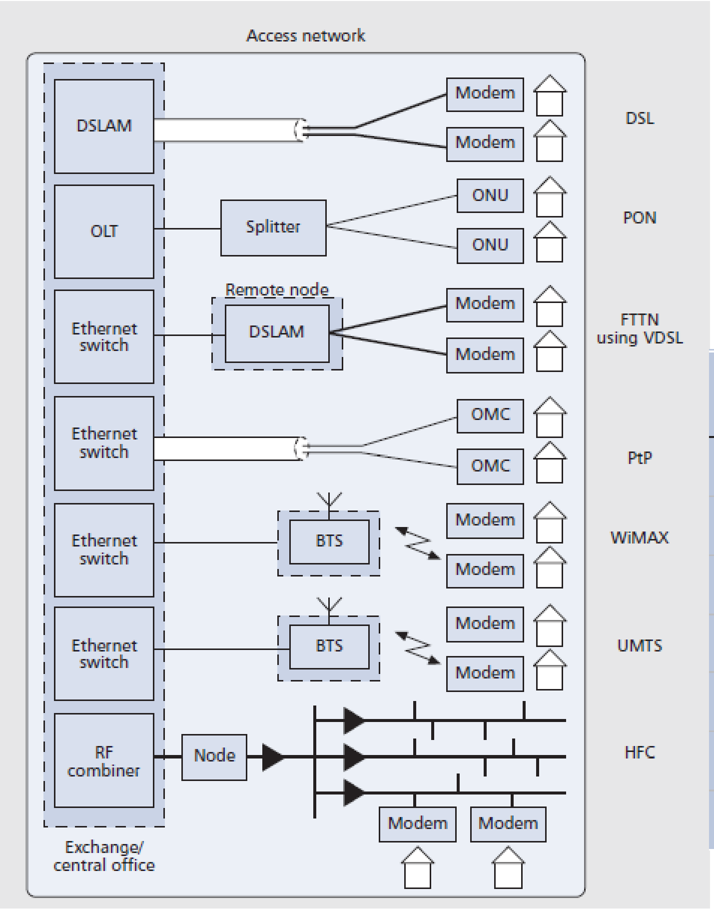
Draft Version 3
Issue 15 – 17 July 2008

"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

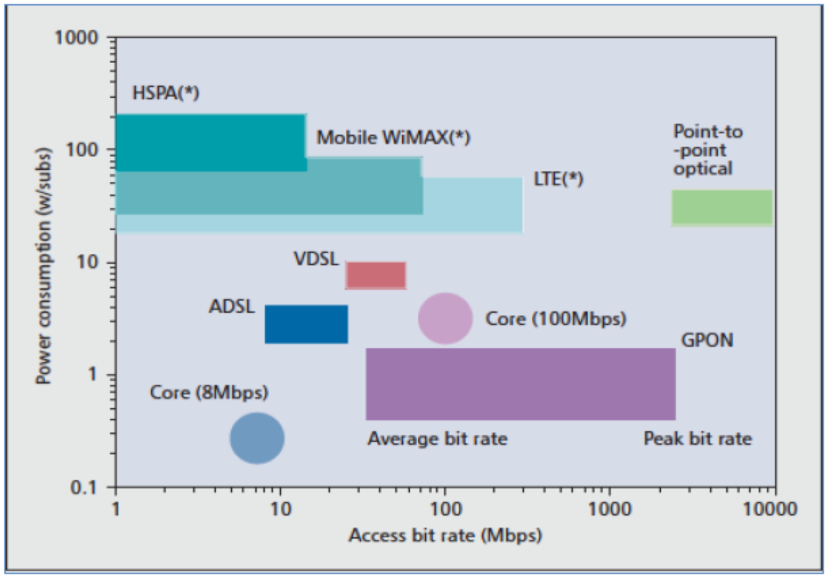
The reality of the access



- Coexistence of several access worlds
- Limits depending of technology

	P_{TU} (kW)	N_{TU}	P_{RN} (W)	N_{RN}	P_{CPE} (W)	Technology limit	Per-user capacity
ADSL	1.7	1008	N/A	N/A	5	15 Mb/s	2 Mb/s
HFC	0.62	480	571	120	6.5	100 Mb/s	0.3 Mb/s
PON	1.34	1024	0	32	5	2.4 Gb/s	16 Mb/s
FTTN	0.47	1792	47	16	10	50 Mb/s	2 Mb/s
PtP	0.47	110	N/A	N/A	4	1 Gb/s	55 Mb/s
WiMAX	0.47	24400	1330	420	5	22 Mb/s	0.25 Mb/s
UMTS	0.47	15300	1500	264	2	20 Mb/s	0.25 Mb/s

Access: What are the limits?



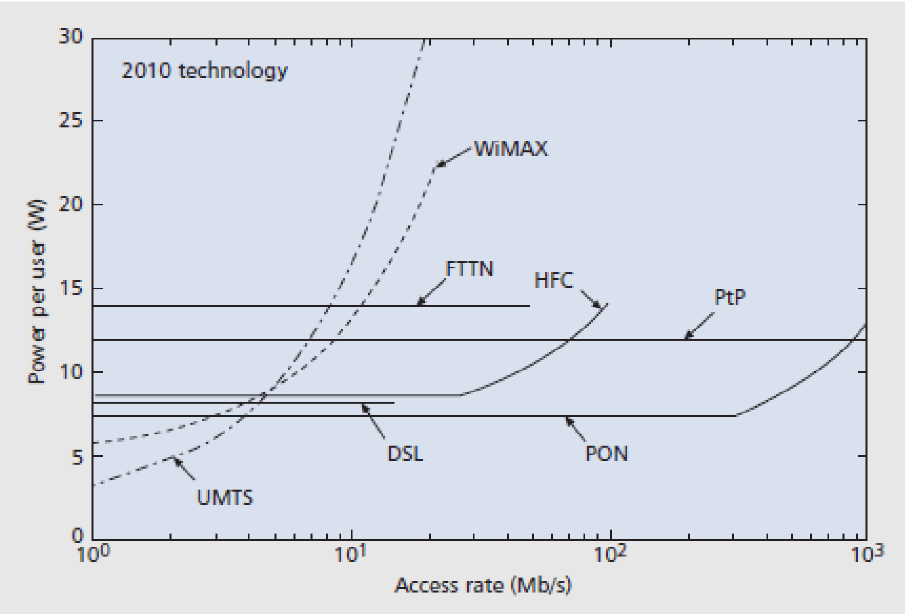
Technology	Range (km)	Bit rate (Mb/s)	Users/node	Minimal user density ($subs/km^2$)	Power/subs (with PUE) (W/subs)
ADSL ADSL2+	5.5 1.5	8[1] 24[1]	384–768	4–8 50–100	2–4
VDSL VDSL2+	1.0 0.3 0.3	26[1] 55[1] 100	16–192	5–60 50–700 50–700	6–10
GPON (32) GPON (64)	20 10	2488/32 2488/64	(4–72) * 32 (4–72) * 64	0.1–2 0.8–14	0.4–1.6
Mobile WiMAX HSPA LTE	0.340 (3 Mb/s) 0.240 (3 Mb/s) 0.470 (3 Mb/s)	1–70 1–14 1–300	272[2] 225[2] 180[2]	N/A N/A N/A	27[3] 68[3] 18[3]

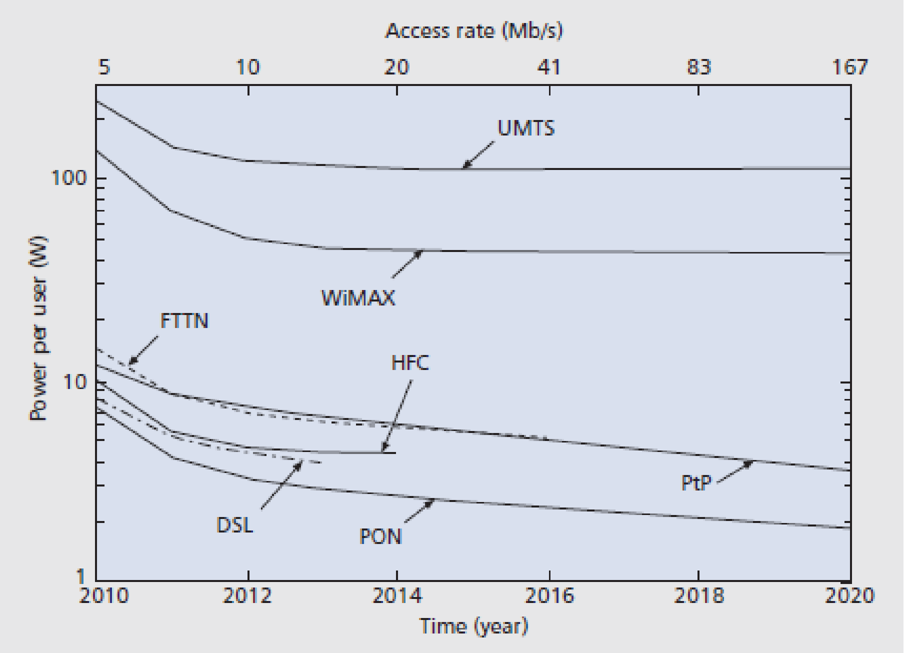
[1] Downstream [2] Simultaneous Active Users [3] Modelled for 300 subscribers per km^2

Source ECOnet Project
(low **E**nergy **CO**nsumption **NET**works)
https://www.econet-project.eu/

Source: “Power consumption in telecommunication networks: overview and reduction strategies”, IEEE Communications Magazine, June 2011

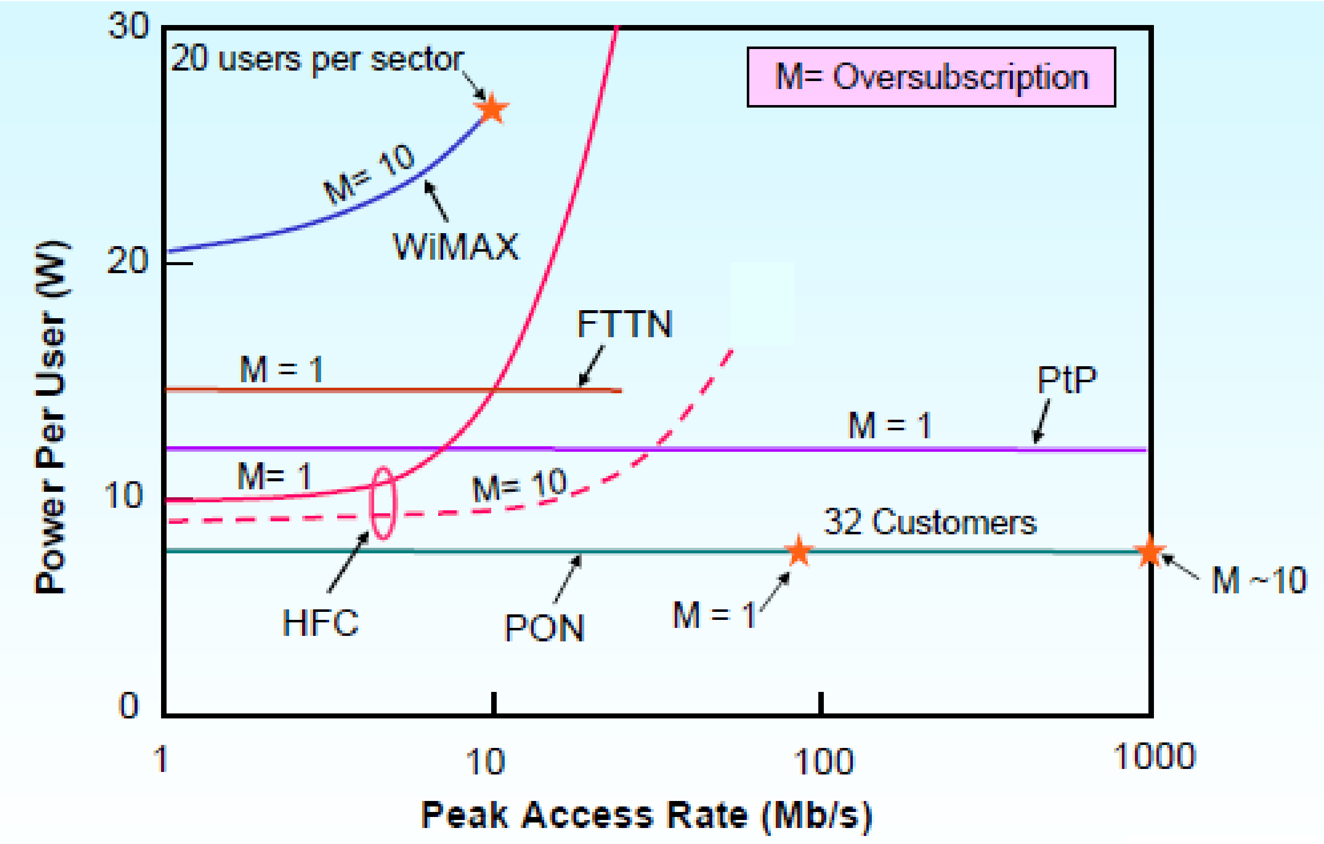
Access: How many and When?





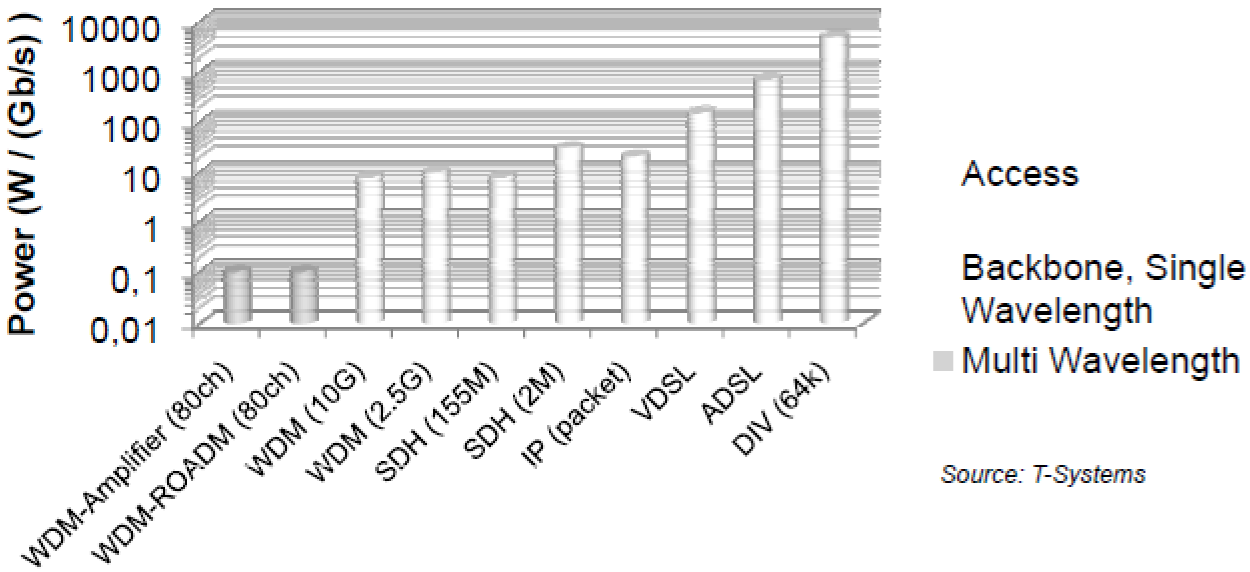
- *Power as a function of access rate with an oversubscription rate of 20.*
- *Expected power consumption of latest*
- *Base access rate in 2010 = 5 Mb/s.*

Access: and the winner is…



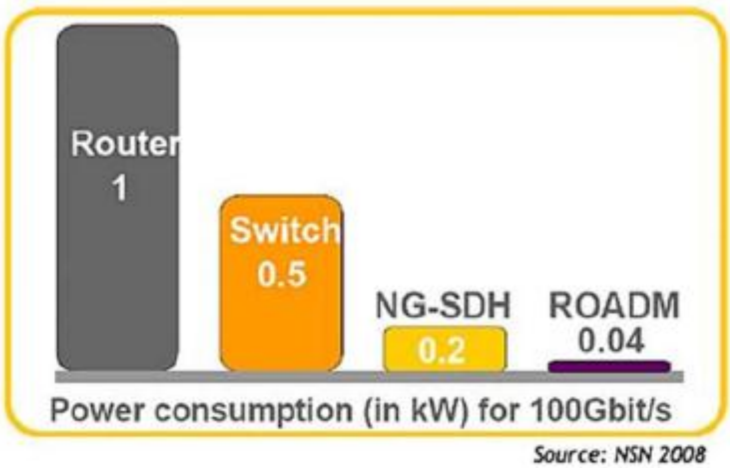
PON FTTH is "greenest"

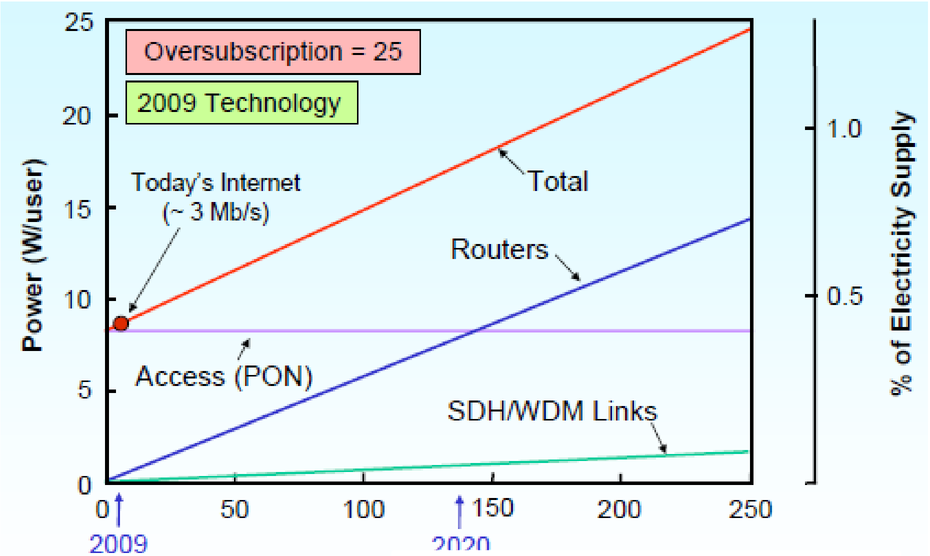
Comparing with the rest



- Optical technologies are most eficient
- Backbone equipment more efficient than access equipment

And the backbone?

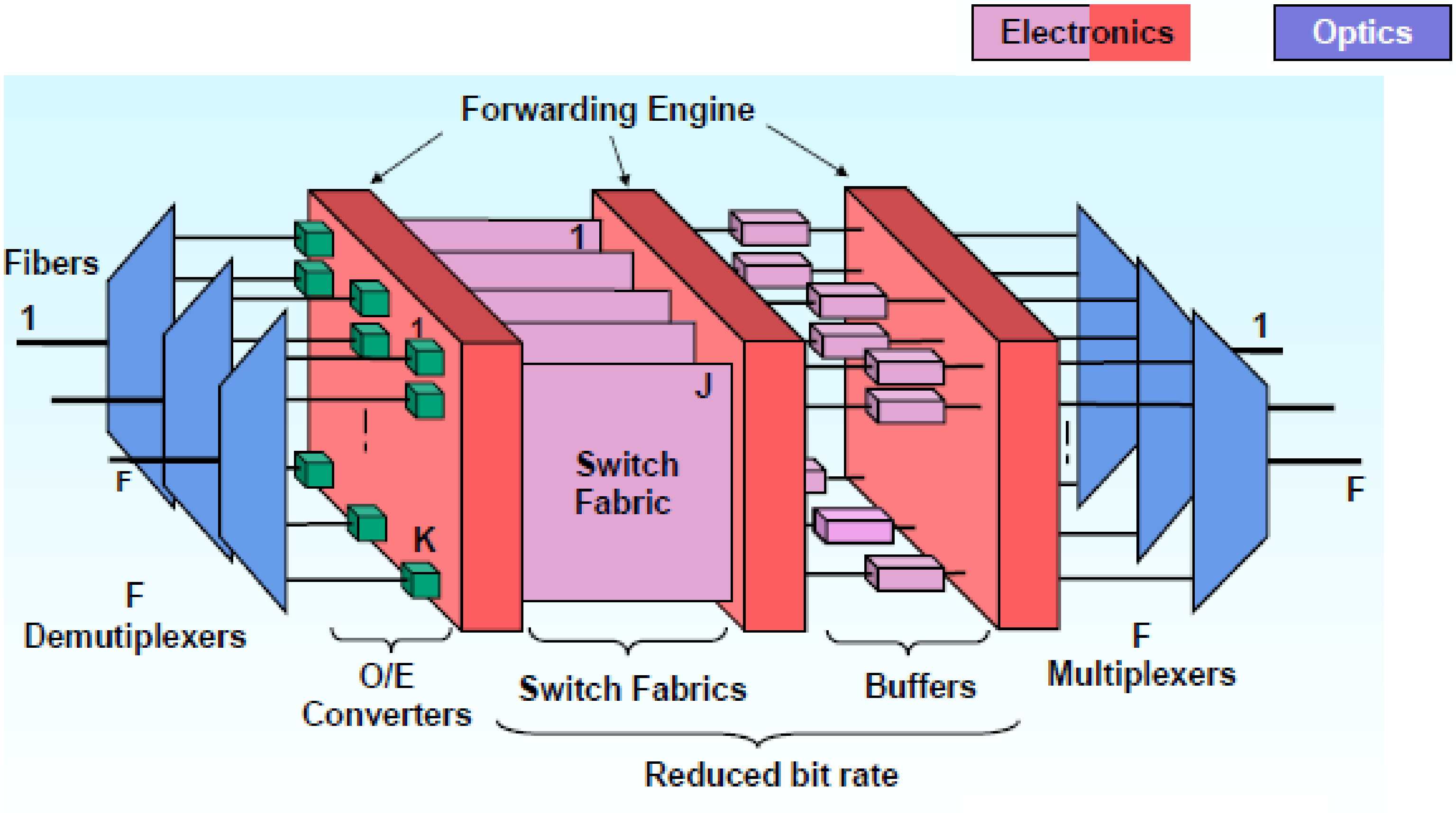




Source: Tucker, Baliga et all

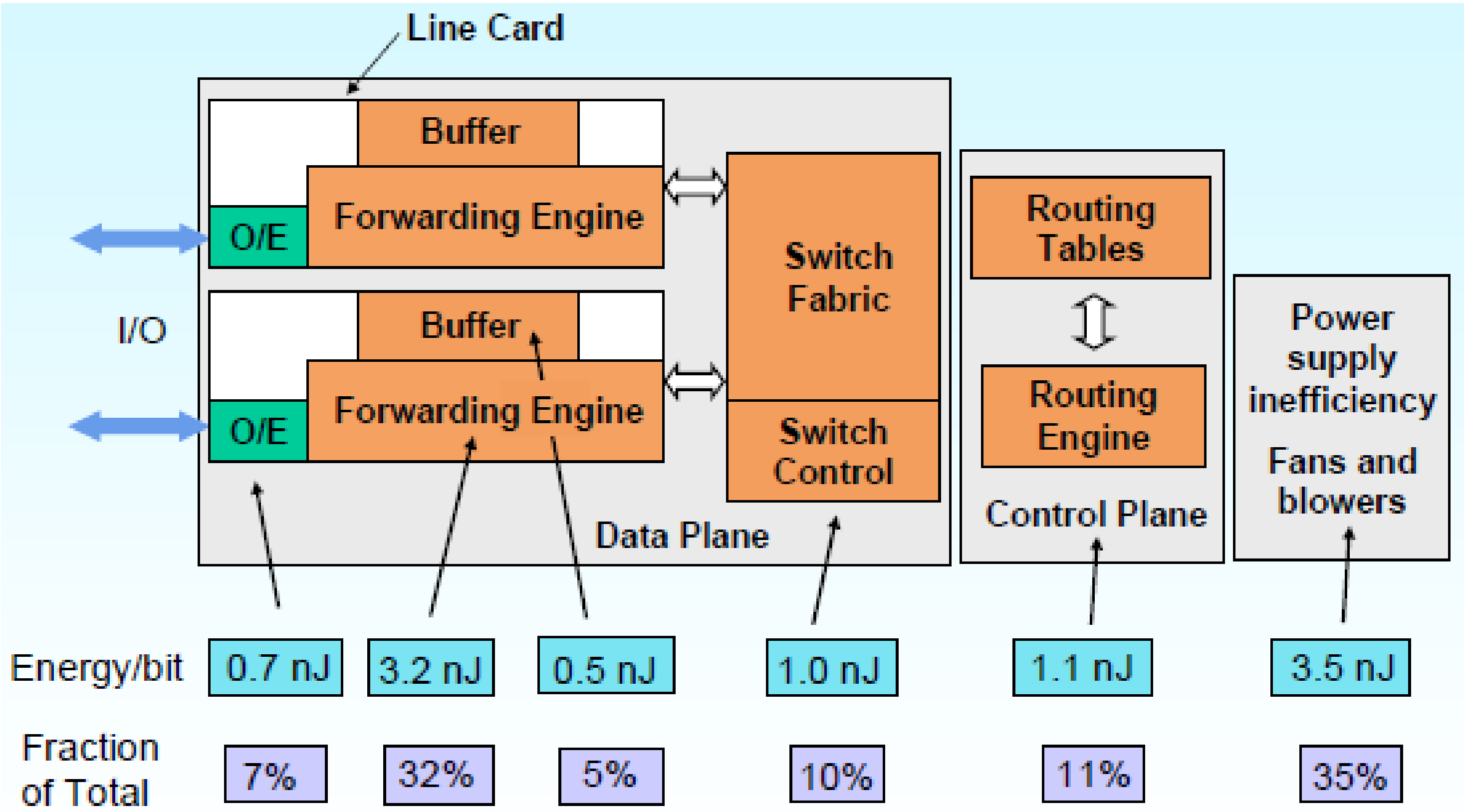
- Backbone equipments evolved too
- But, what is the problem?
  - **comsumption proportional to the bandwidth**

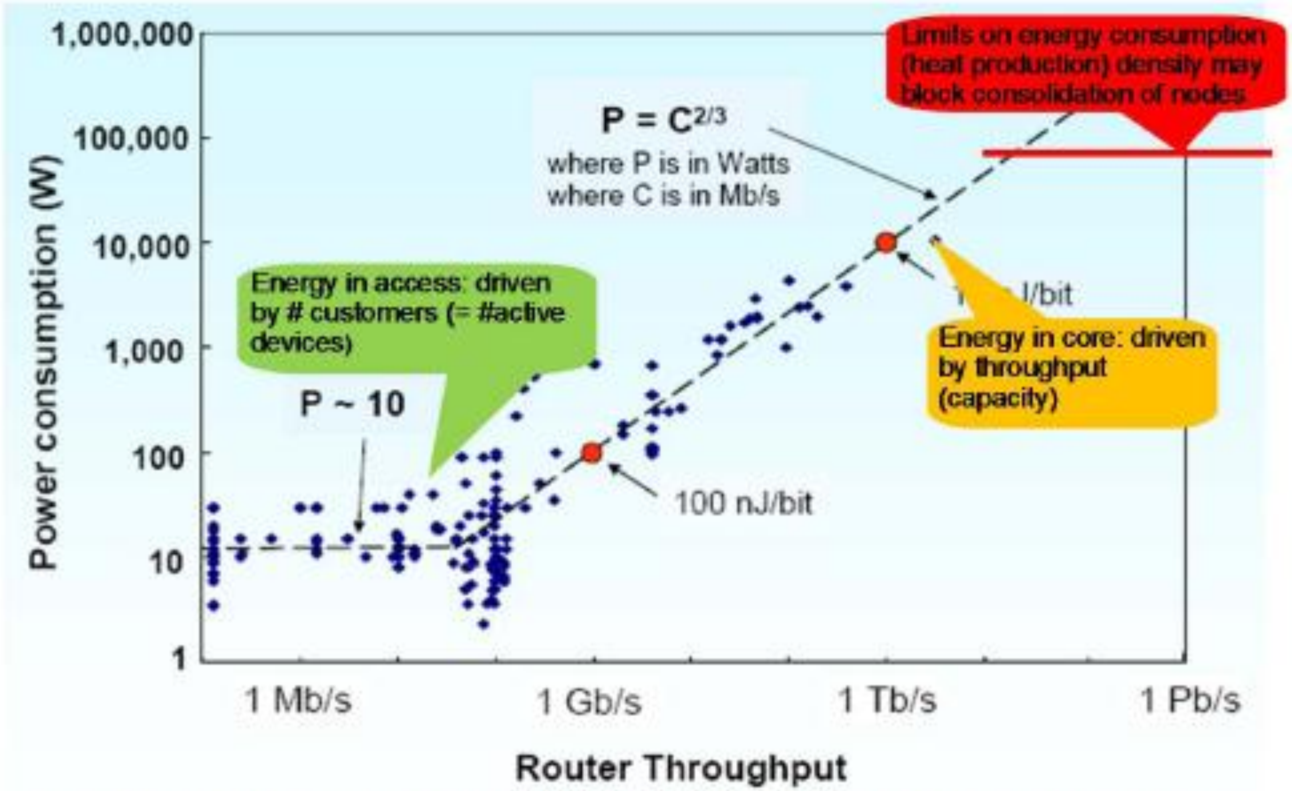
Inside a router



Source: Tucker et al

EE in routers: who is who?



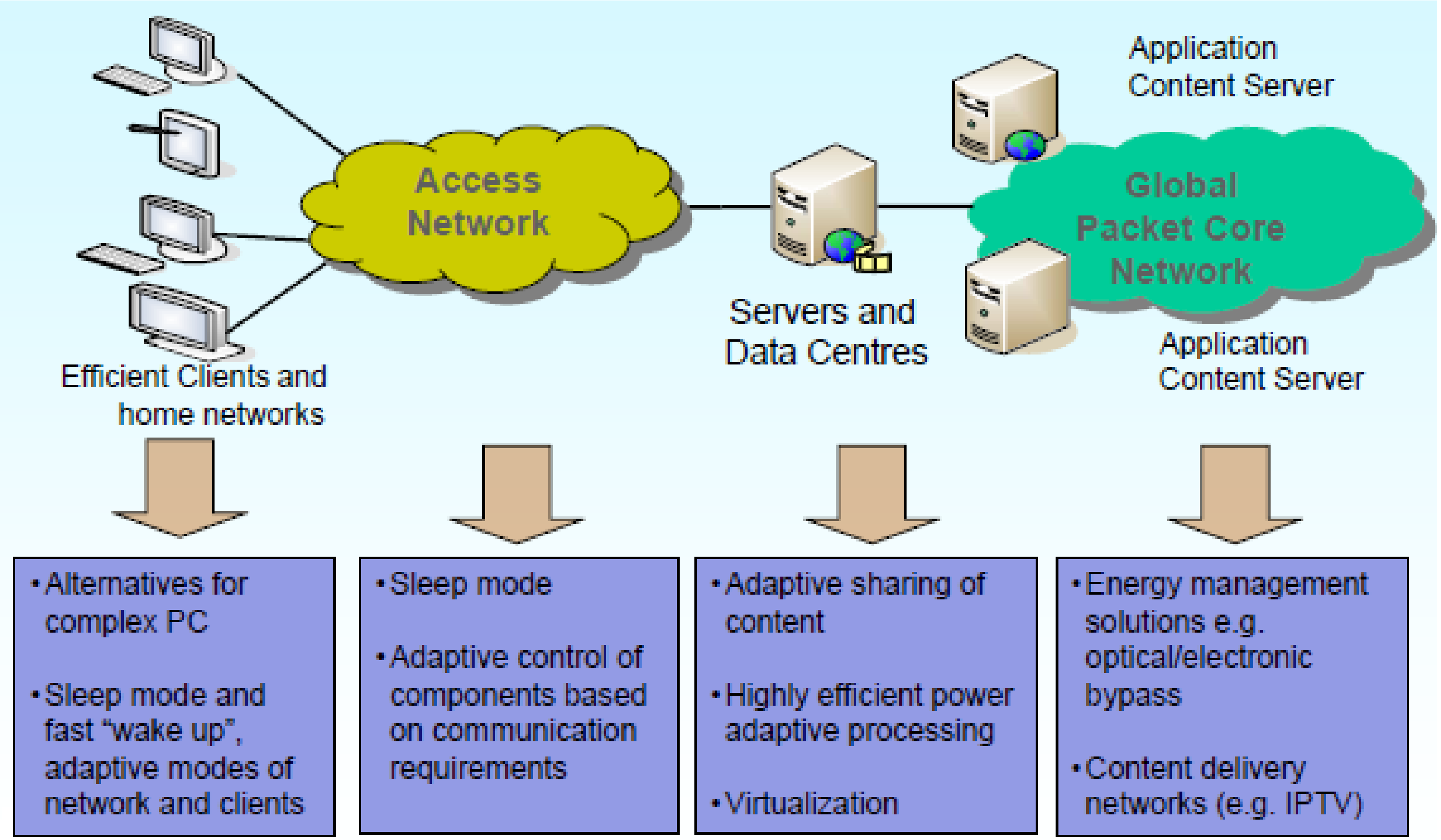


(From: M. Pickavet et al. "Energy footprint of ICT", METI, 2006, Nordman, 2007)

Why does the network need EE ?

- Currently:
  - Access is dominating overall energy consumption
- In future…near future!!!
  - Core will become increasingly important
  - Feasibility limits may be reached (growing traffic volumes & more node consolidation)
- Innovation needed:
  - To keep this under control
  - To stay well below these limits
  - Even avoid further growth of energy

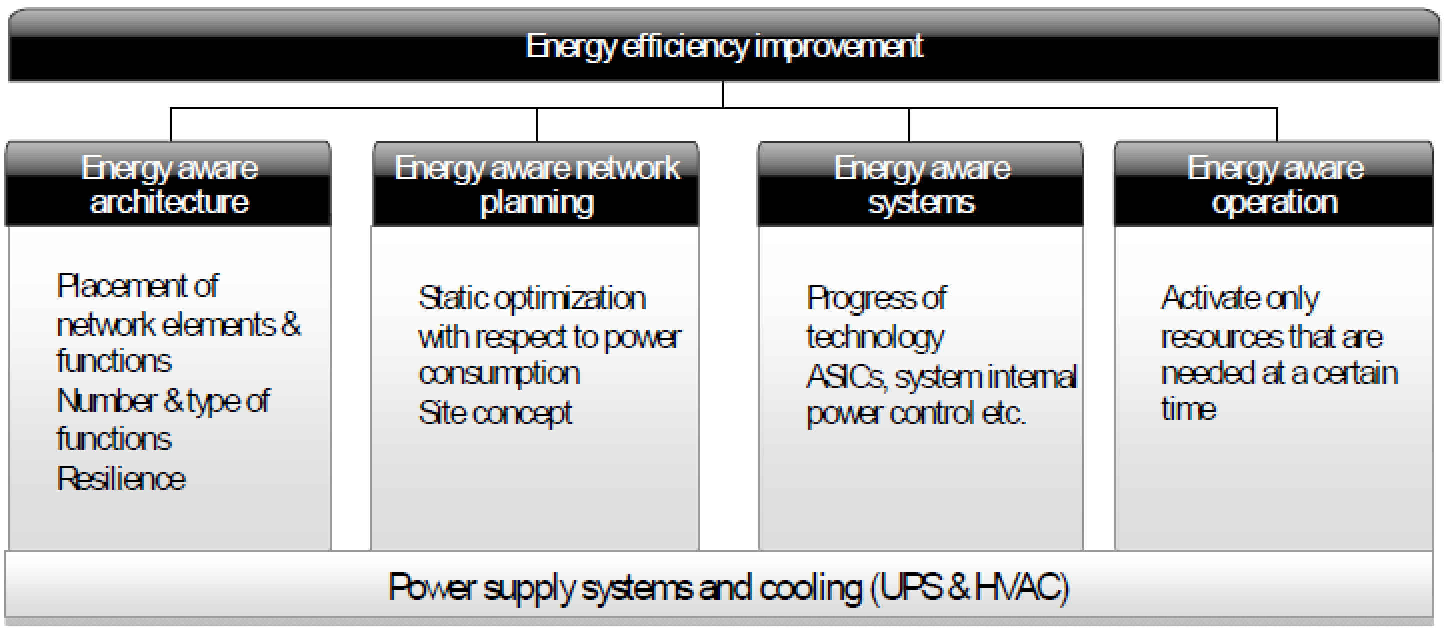
EE: some suggestions



Practical EE: a formal approach

STRONGEST

Scalable, Tunable and Resilient Optical Networks Guaranteeing Extremely-high Speed Transport



Source: STRONGEST project
http://www.ict-strongest.eu/

The "Strongest" Keywords

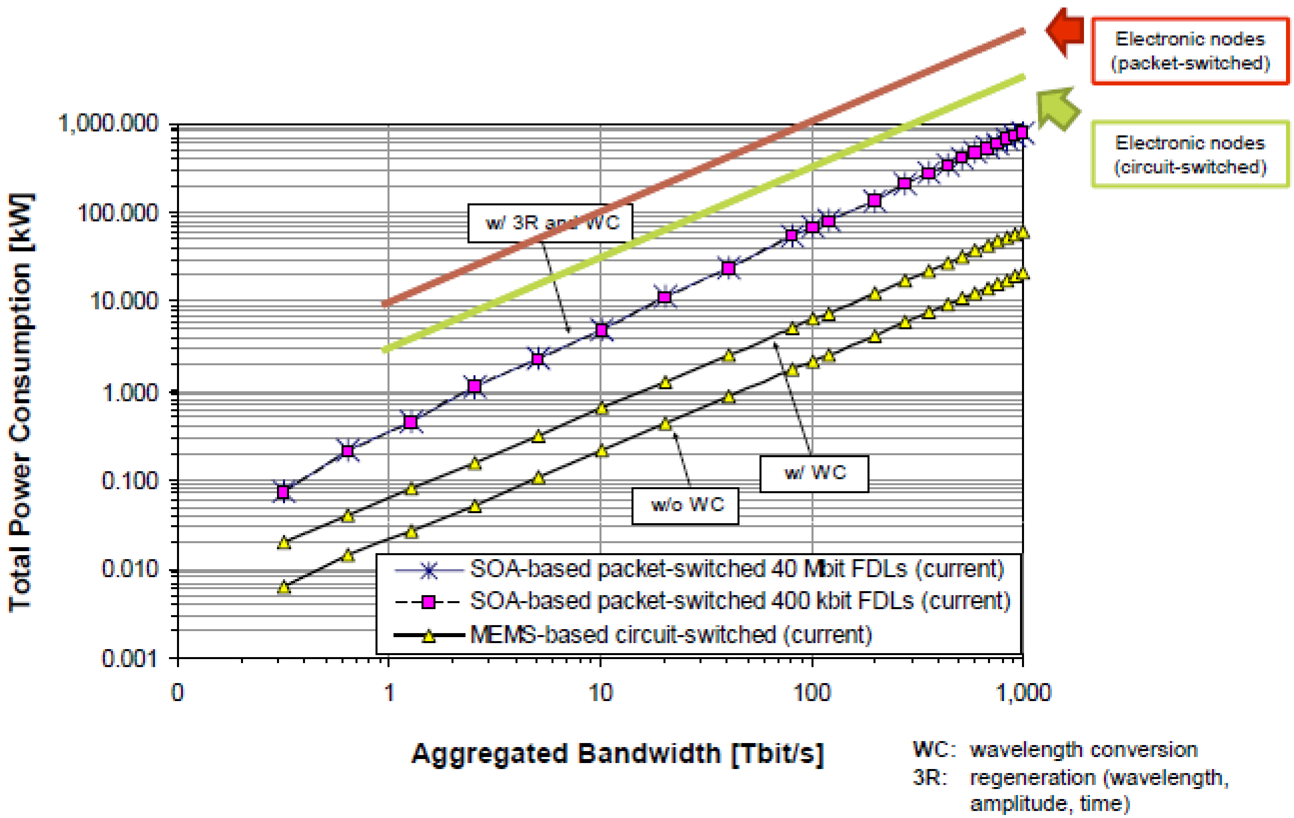
- A. Improved inherent energy-efficiencies as offered by electronics technologies
  - (1) More efficient CMOS technologies
  - (2) High temperature operation of ICs
- B. More sophisticated management and exploitation of network resources
  - (3) Source coding & caching
  - (4) Multi-layer traffic engineering (MLTE),
  - (5) Powering down, sleep/idle modes and burst-mode operation.
- C. The inherent energy efficiencies as offered by optics technology solutions
  - (6) Optical bypass
  - (7) Coherent detection
  - (8) Polarisation multiplexing.
- D. More environmentally sustainable approaches to network design such as
  - (9) Micro-power generation
  - (10) Increased reliability and robustness of network equipment.

EE: some solutions

- Techniques for improving energy efficiency in communication networks:

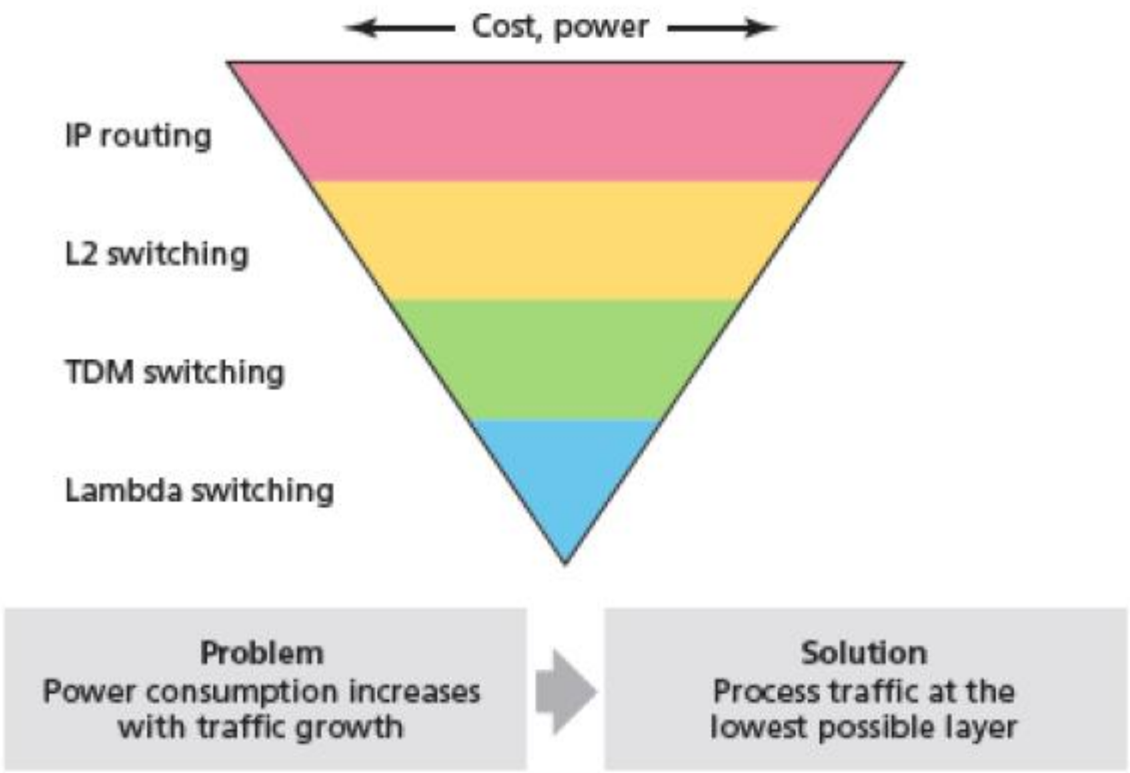
1. EE technics
2. Circuit switching less work/buffering
3. Slow down
4. Turn off hardware

EE Technics



Source Aleksic

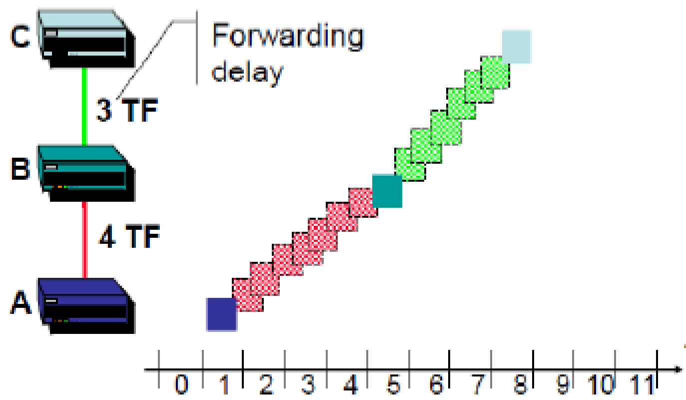
Routing vs. switching



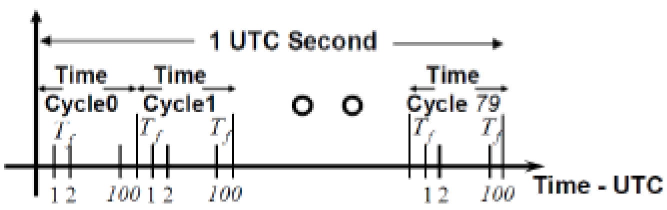
Source: ECOnet

Circuit Switching

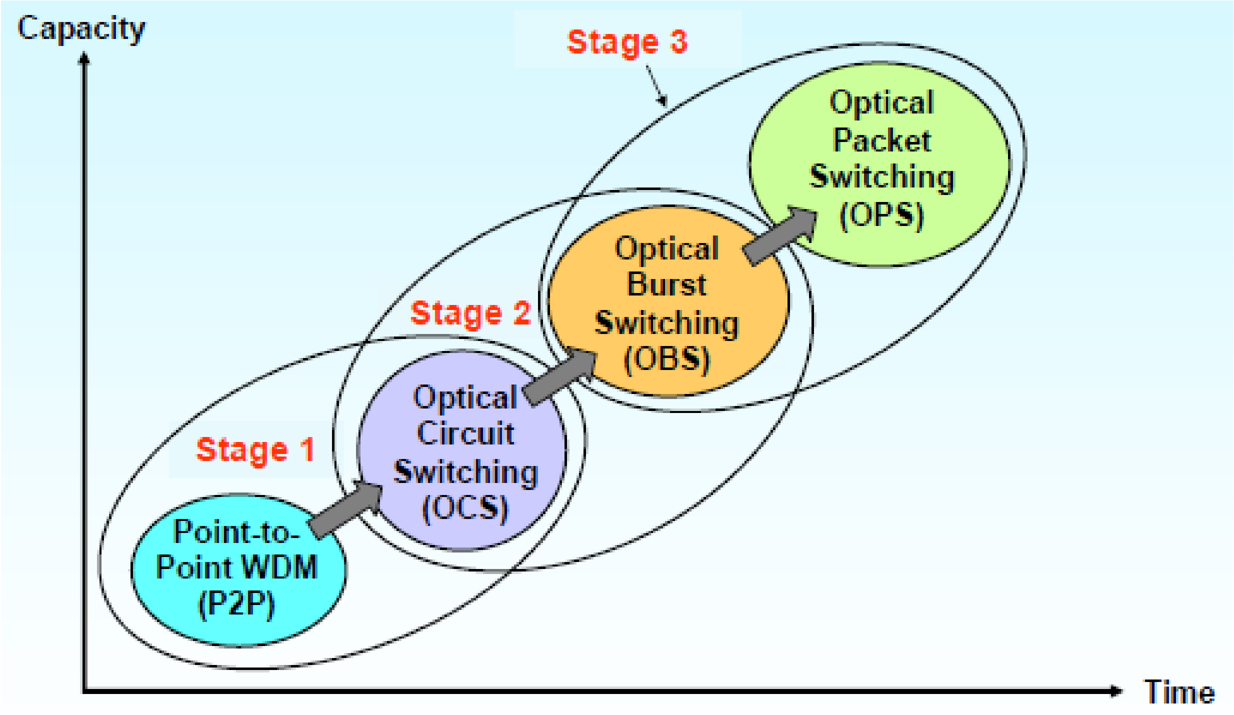
- Internet traffic: large share of predictable services (e.g. video)
  – Circuit switching = EE
- Pipeline forwarding
  – No buffers & no header processing
  – ++ faster
- Application: video file/stream per optical circuit



Source: Mario Baldi , Yoram Ofek: Time for a "Greener" Internet

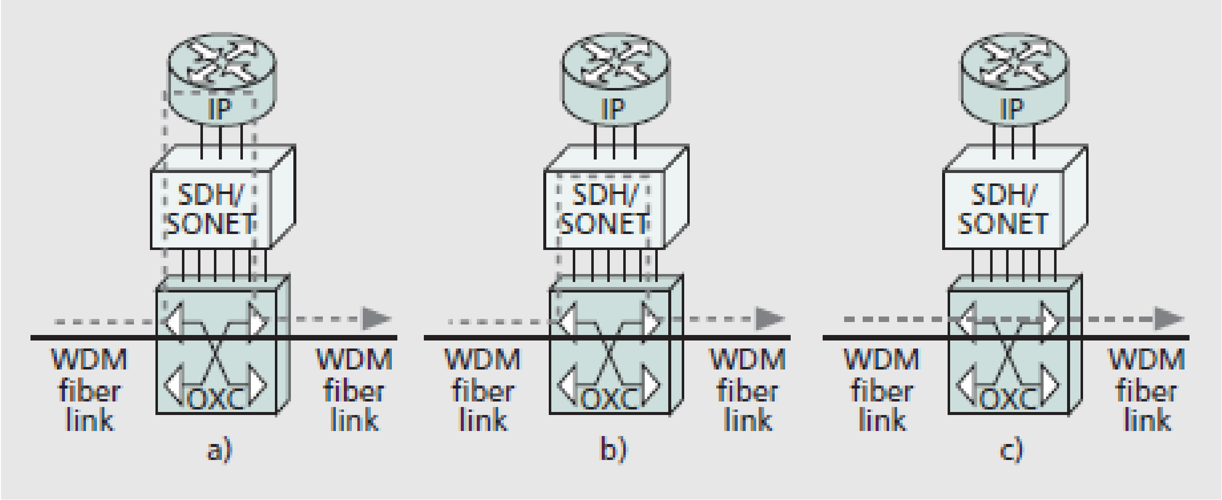


Switching: the evolution



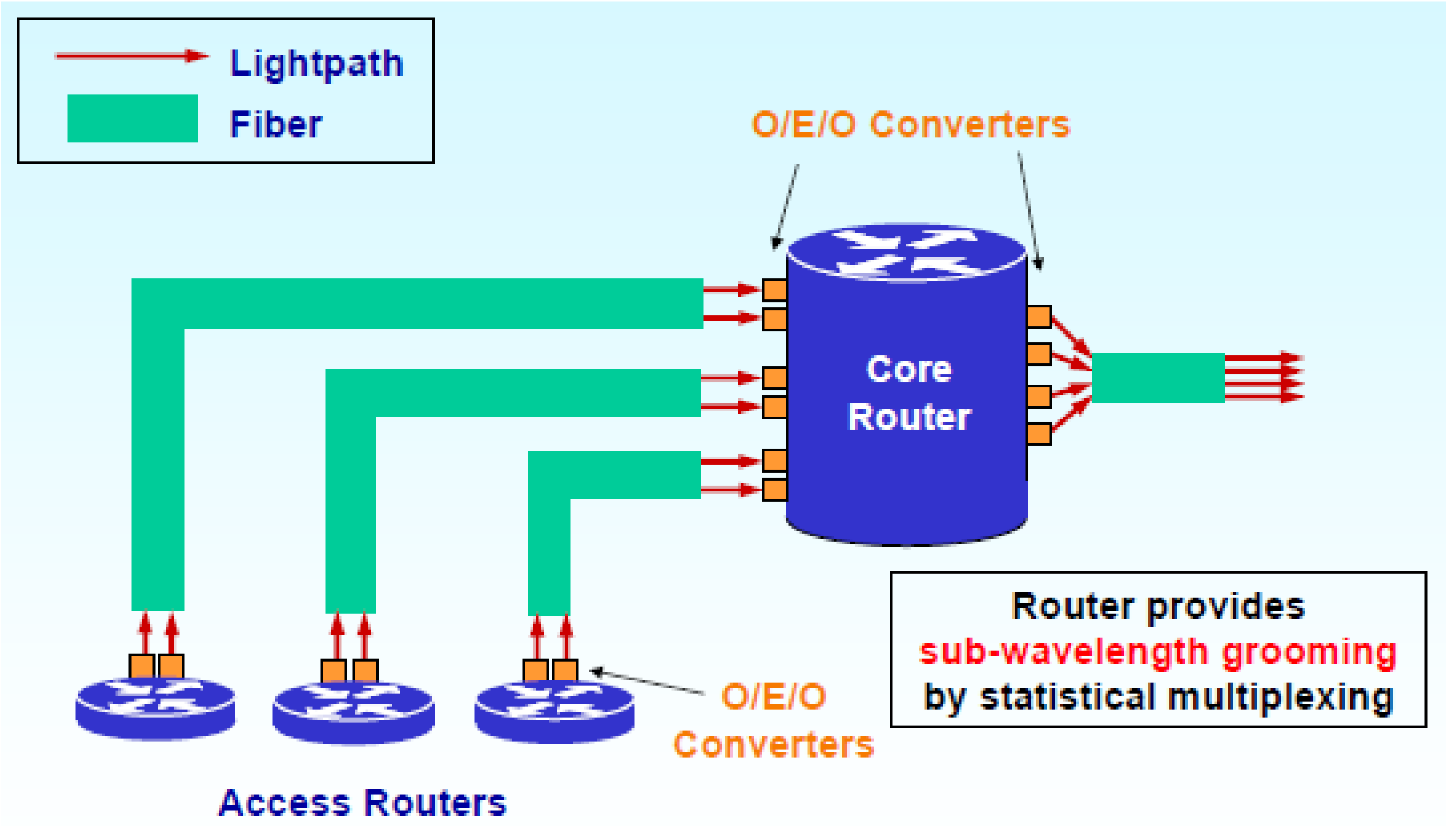
Source: Tucker et al

SDH/SONET + WDM

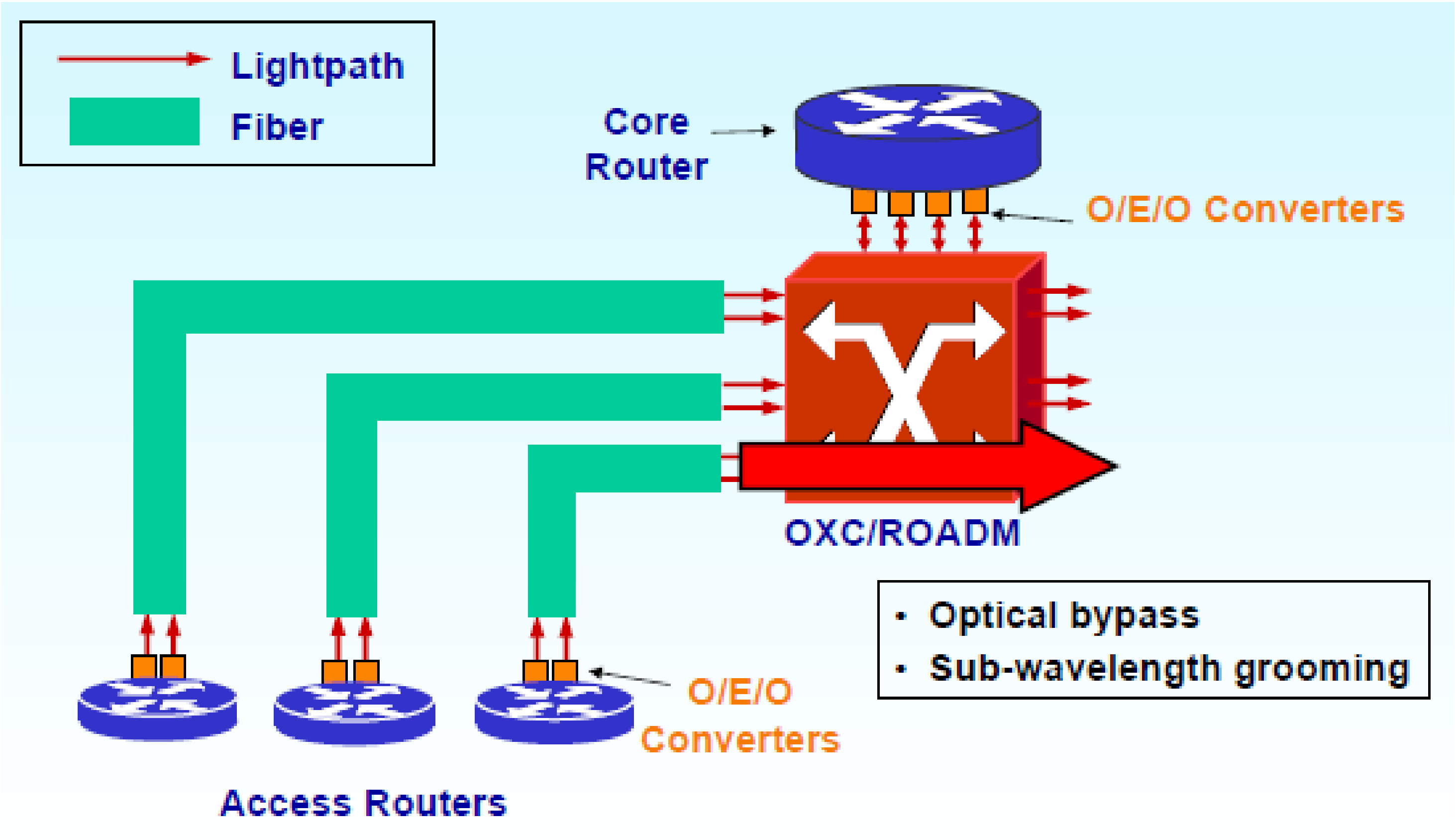


a) All traffic is passed up through the lower layers and processed by the IP router
b) Traffic is processed by the SDH/SONET switch, bypassing the IP router
c) Traffic is switched by the optical cross-connect, bypassing both the SDH/SONET and IP layers. Lower layers are progressively more energy efficient.

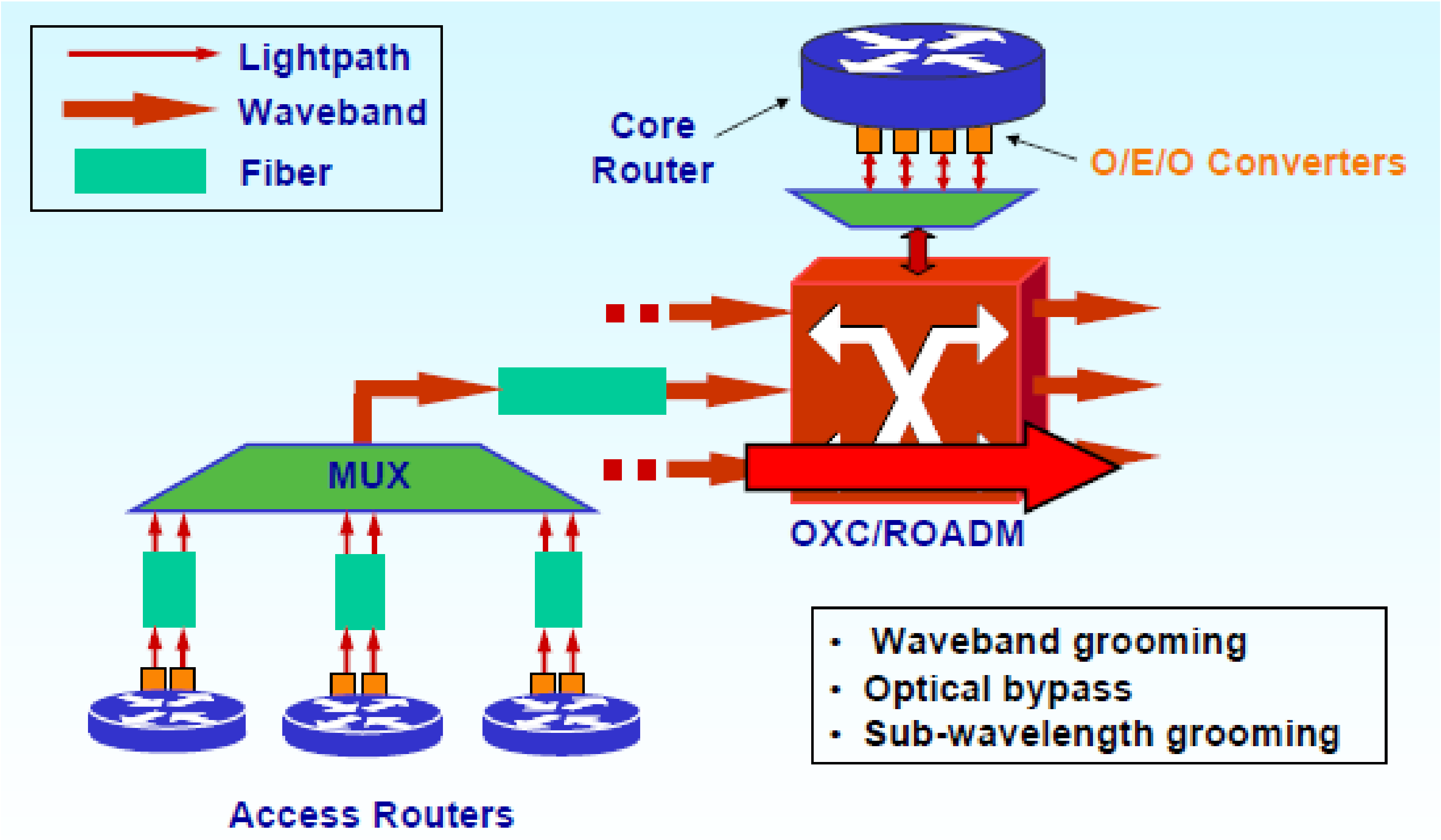
Point to point WDM netowork

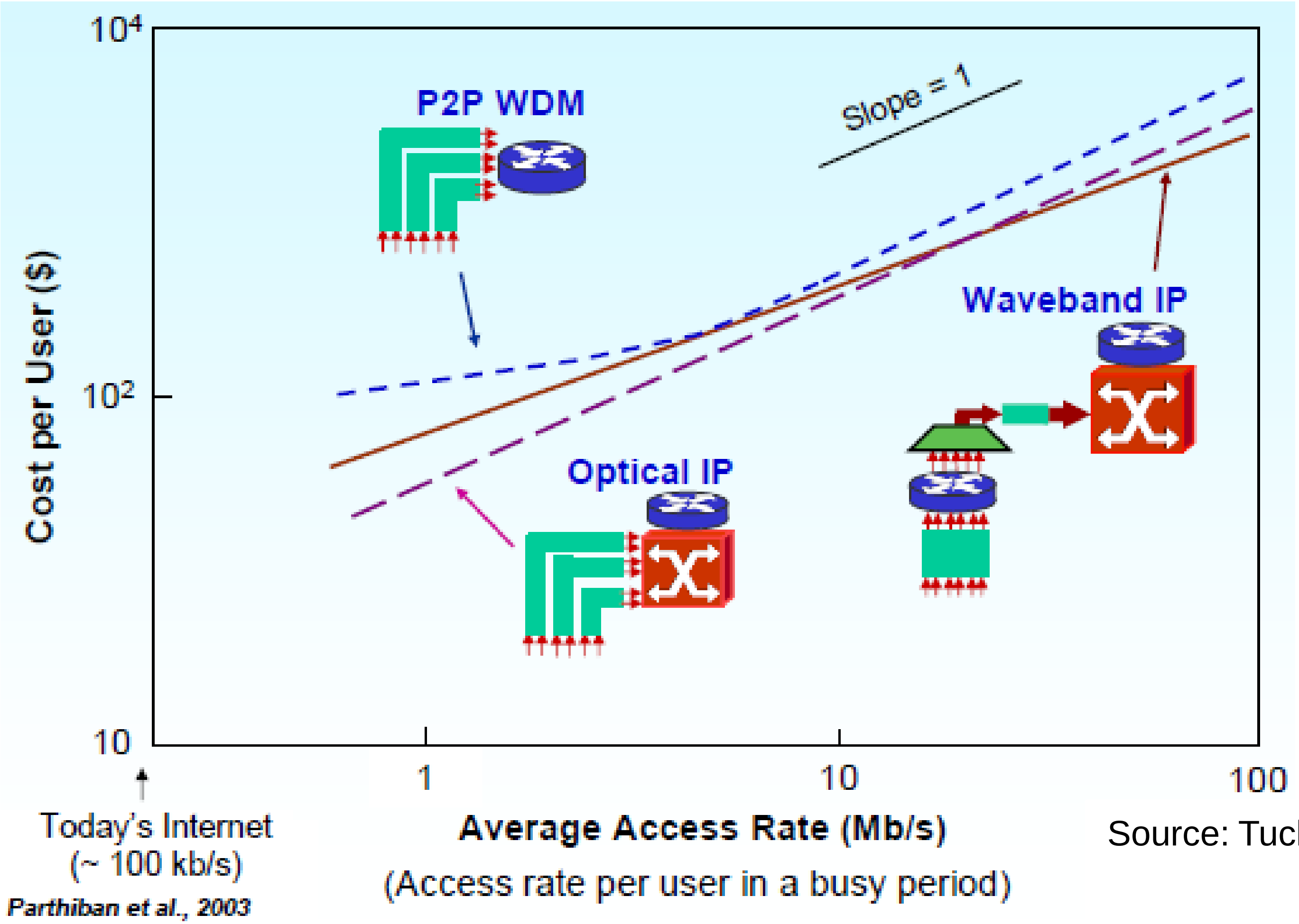


Optical IP network



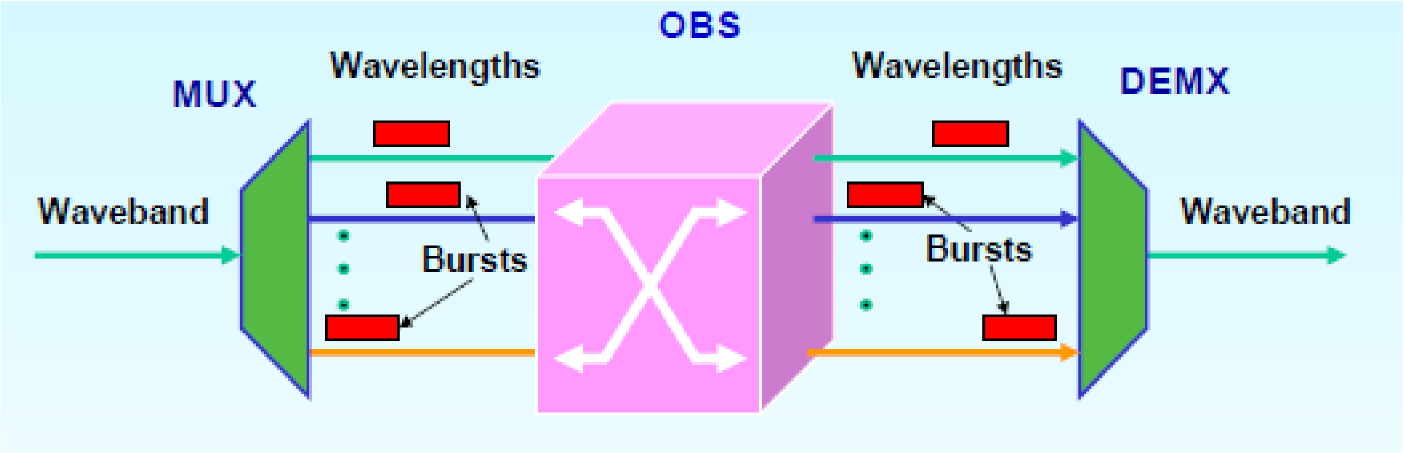
Wabeband IP network





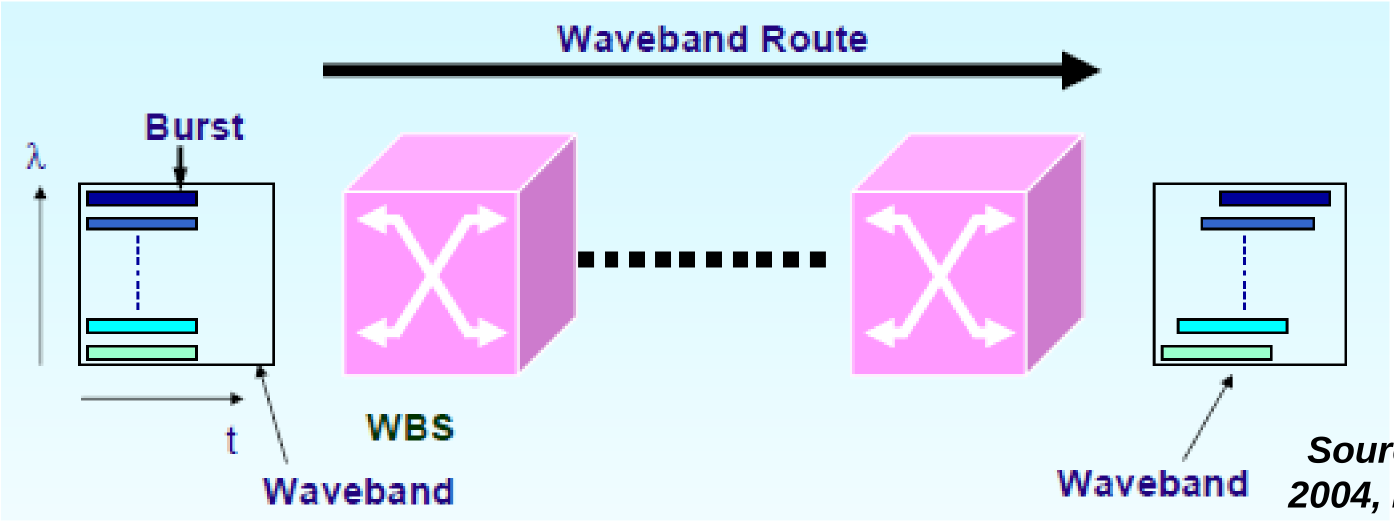
Source: Tucker et al

Optical Burst switching



- Requires increased number of lightpaths for a given blocking probability
- Switch technology requires fast reconfiguration time:
  - More costly per port than “slow”OXC’s(MEMS etc.)

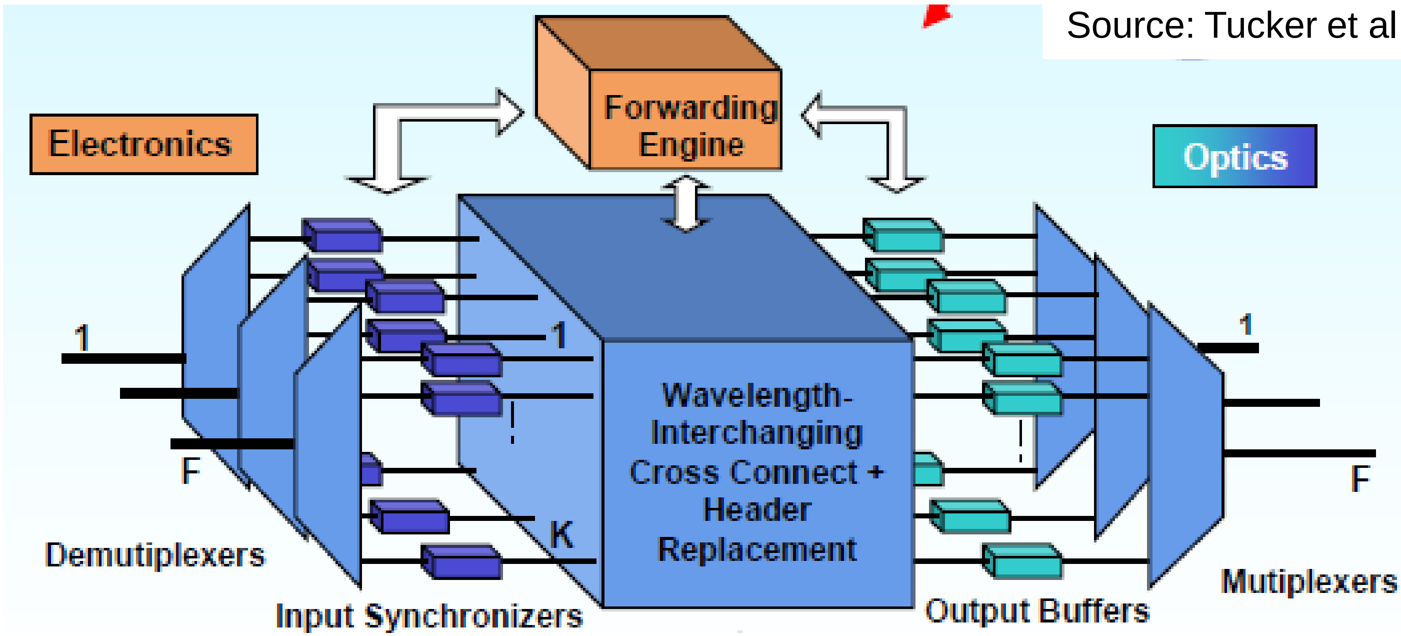
OBS: application



Source: Y. Huang et al., OFC 2004, Pathibanet al., OFC 2006

- Pro’s
  - Requires fewer OXC ports
- Con’s
  - OXC ports must be wideband
  - Requires waveband (i.e. multi-channel) wavelength conversion
  - Dispersion issues

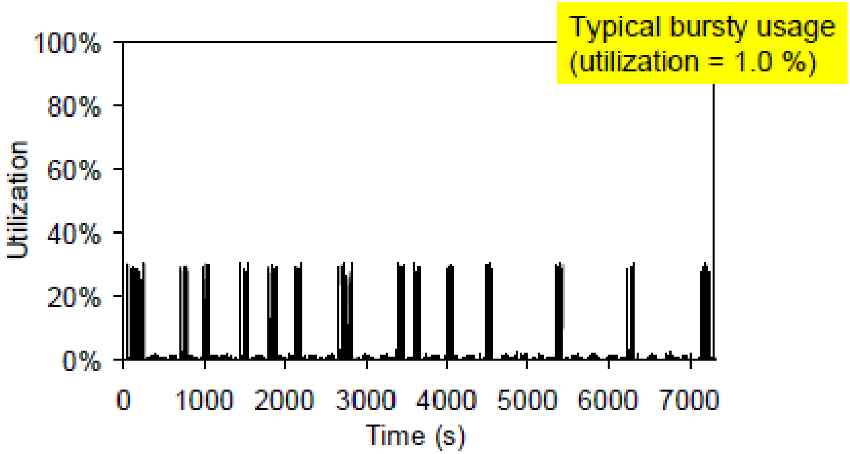
Optical packet switching



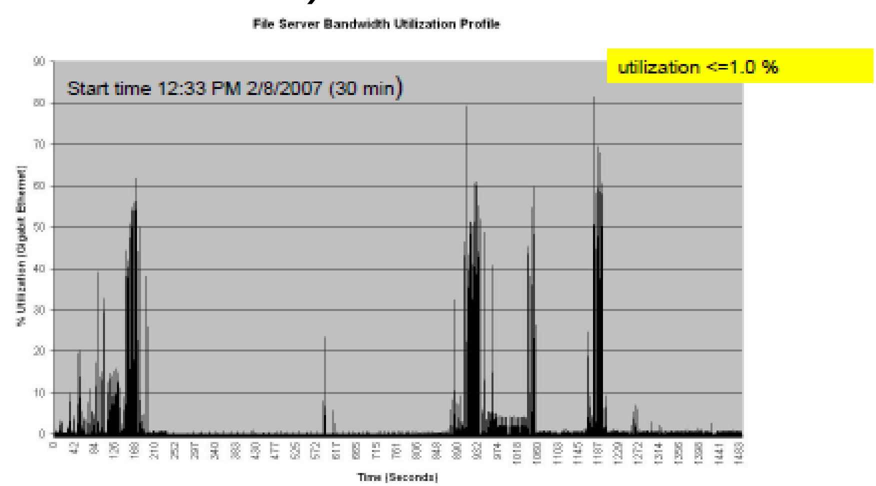
- No viable optical buffering technology in sight
  - Optical switch fabrics may become competitive with CMOS
  - Not clear whether optical packet switching will solve the energy bottleneck problem

Slow down techniques

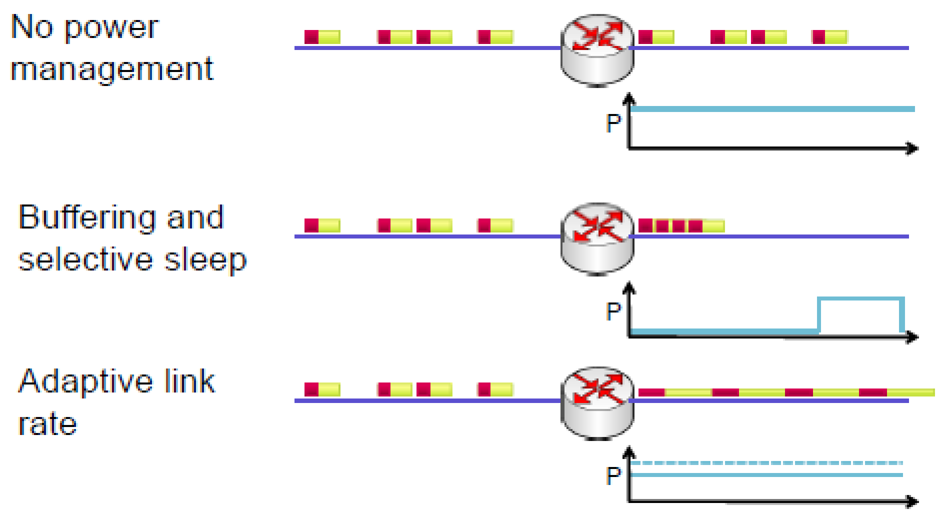
- Desktop links have low utilization
  - Snapshot of a typical 100 Mb Ethernet link
  - Shows time versus utilization (trace from Portland State Univ.)



- Some Server links have low utilization
  - Snapshot of a File Server with 1 Gb Ethernet link
  - Shows time versus utilization (trace from LBNL)

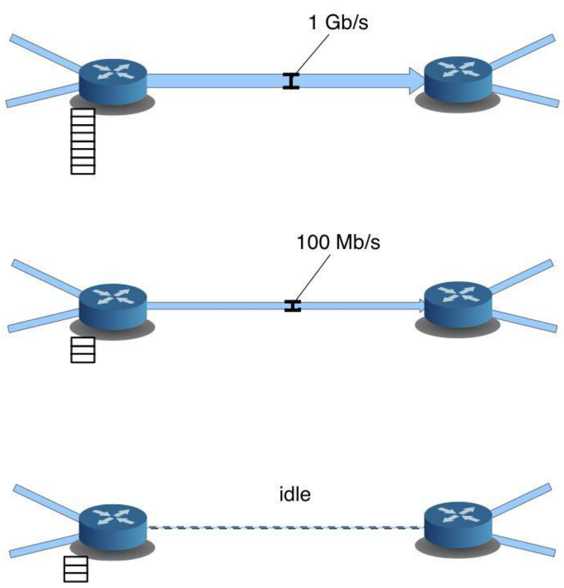


Slow down & buffering



- **Buffering a Selective sleep:**
  - Buffering the packets to larger bursts
- Two variations
  - Managed: monitors schedules links being up
  - Autonomous: waits depending on buffer size
- Disadvantage:
  - More bursty traffic
  - Lower QoS

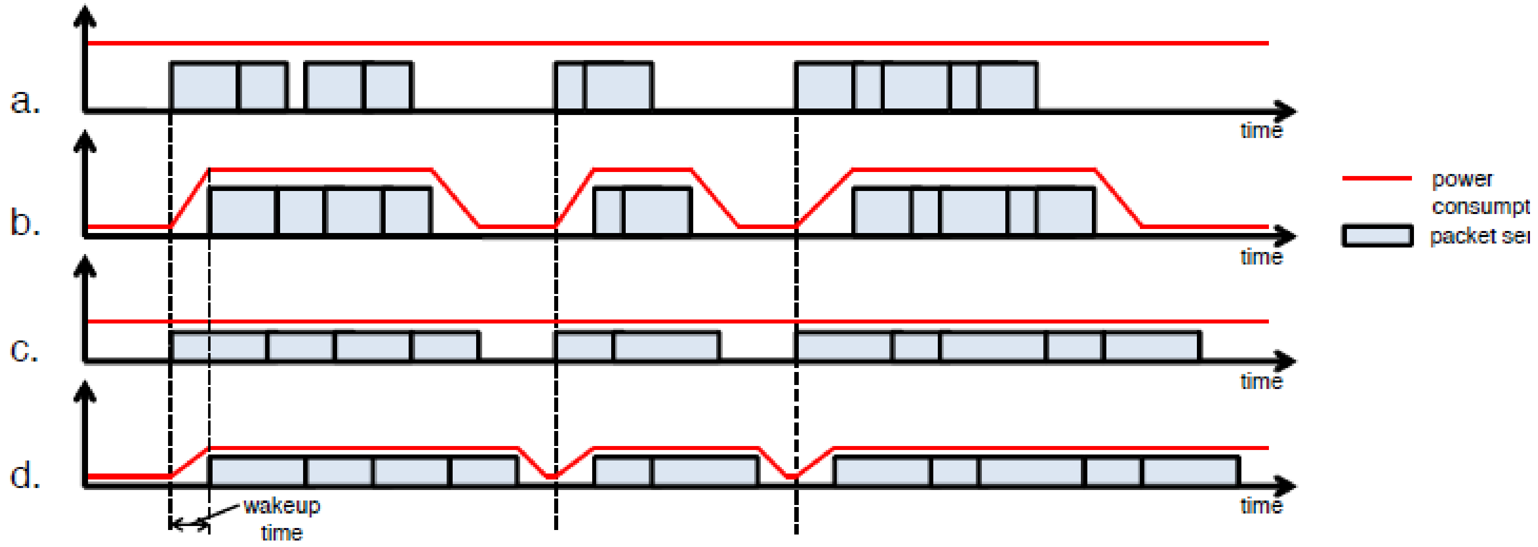
Adaptive link rate



Source Bianzino et al

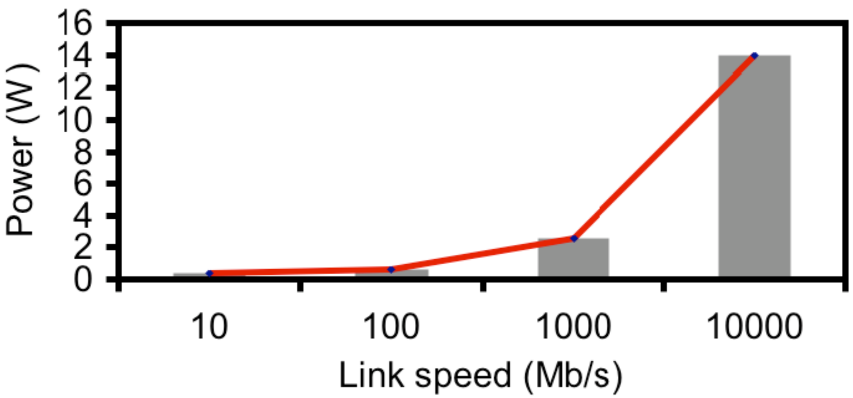
- **Based on works of Dr. Ken Christensen from University of South Florida and Bruce Nordman from LBNL**
  - ***"Ethernet Adaptive Link Rate: System Design and Performance Evaluation"*, Gunaratne, C., Christensen, K.; Proceedings 2006 31st IEEE Conference on Local Computer Networks, Nov. 2006 Page(s):28 - 35**

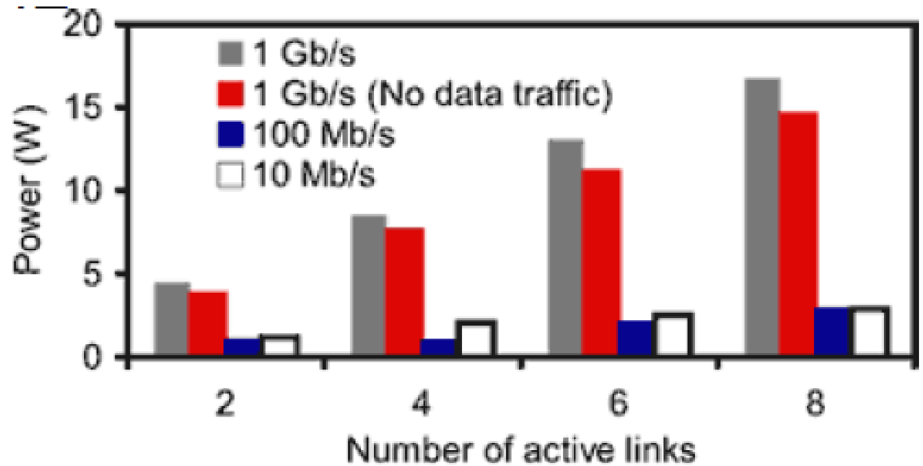
Adaptive Link Rate



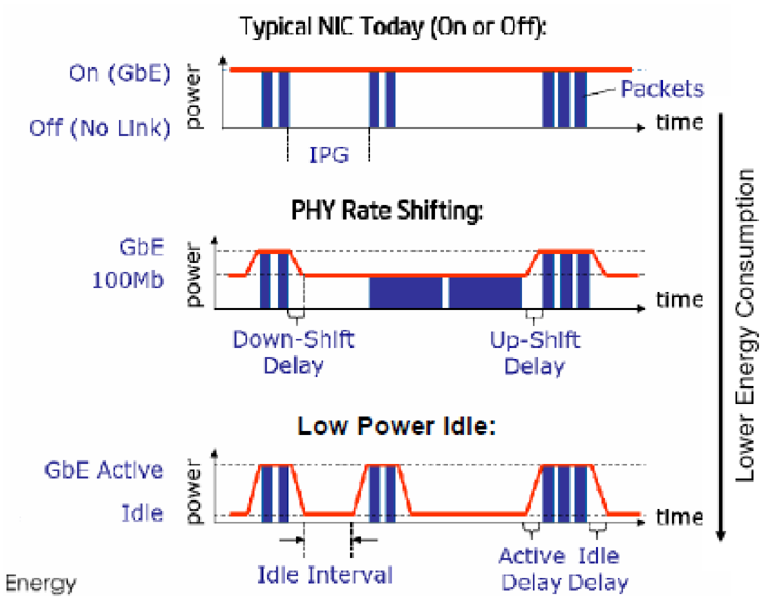
a. No power-aware optimizations
b. Only idle logic
c. Only performance scaling
d. Performance scaling and idle logic

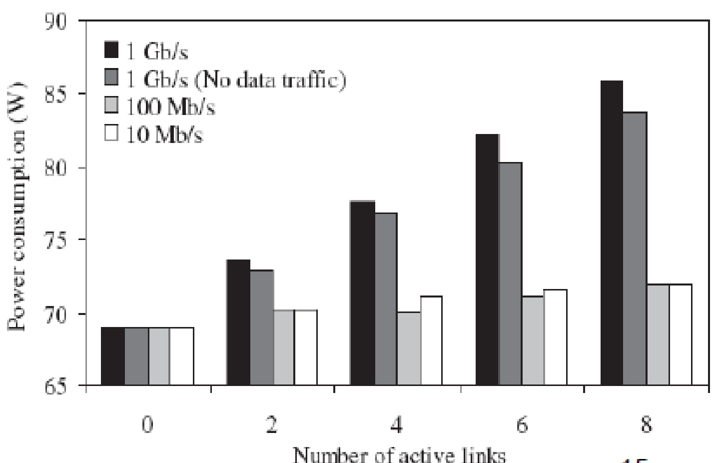
Adaptive Link Rate: expected results





Source: http://efficientnetworks.lbl.gov/enet-adaptive.html





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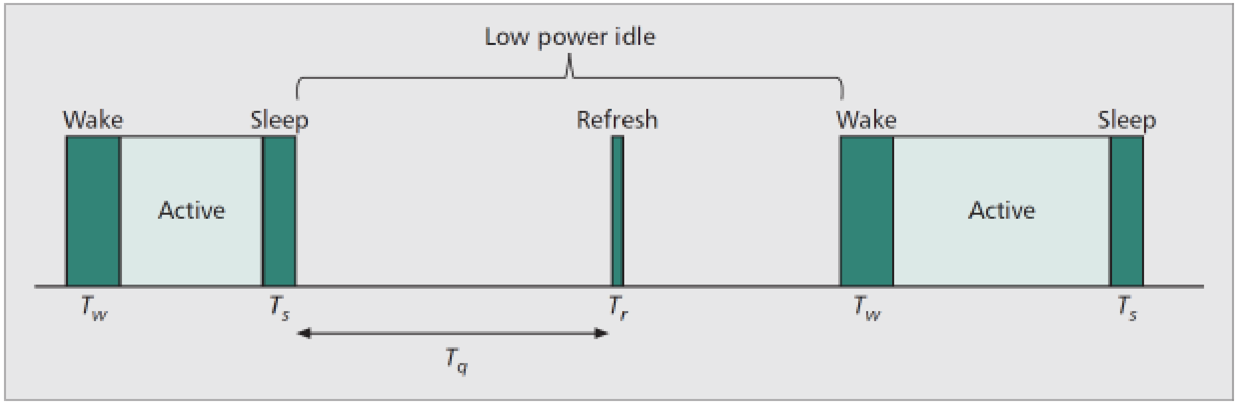
LAN switch power consumption

Low power idle

- Smart switching of interface to low power mode
  - LPI replaces the continuous IDLE signal
  - Energy consumption around 10% of active mode
- Synchronisation is kept with signalling during short periodic refresh intervals (Tr)
  - Trade-off energy for latency
- Transitions between active/sleep modes take time
  - Ts – Time to go to low power (sleep) mode
  - Tw – Time to wake up link

LPI

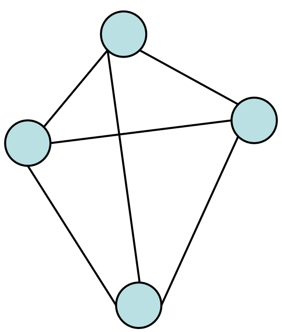


T_s: Time to low power idle (sleep)
T_w: Time to go to active (wake)
T_q: Interval without signalling
T_r: Refresh signalling interval

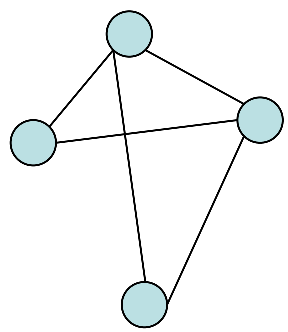
- Combined with Adaptive Link Rate is the basis of 802.3az
  - September 2010 – IEEE Std 802.3az approved

Turn off hardware

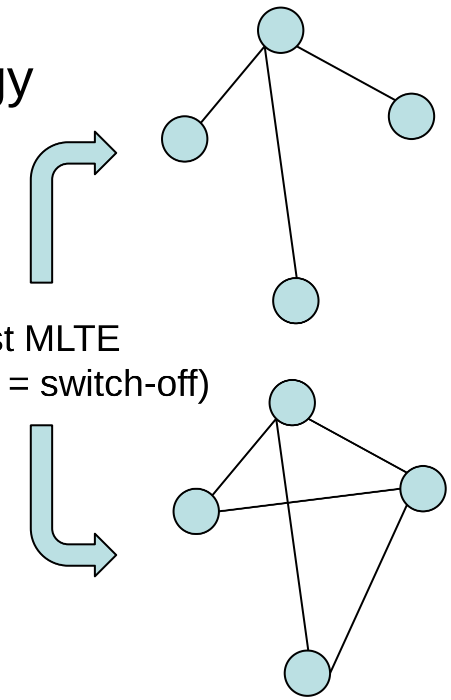
- Multilayer Traffic Engineering
  - Control IP/MPLS flow routing & logical topology
  - Adapt these to changing traffic demand



Static full mesh



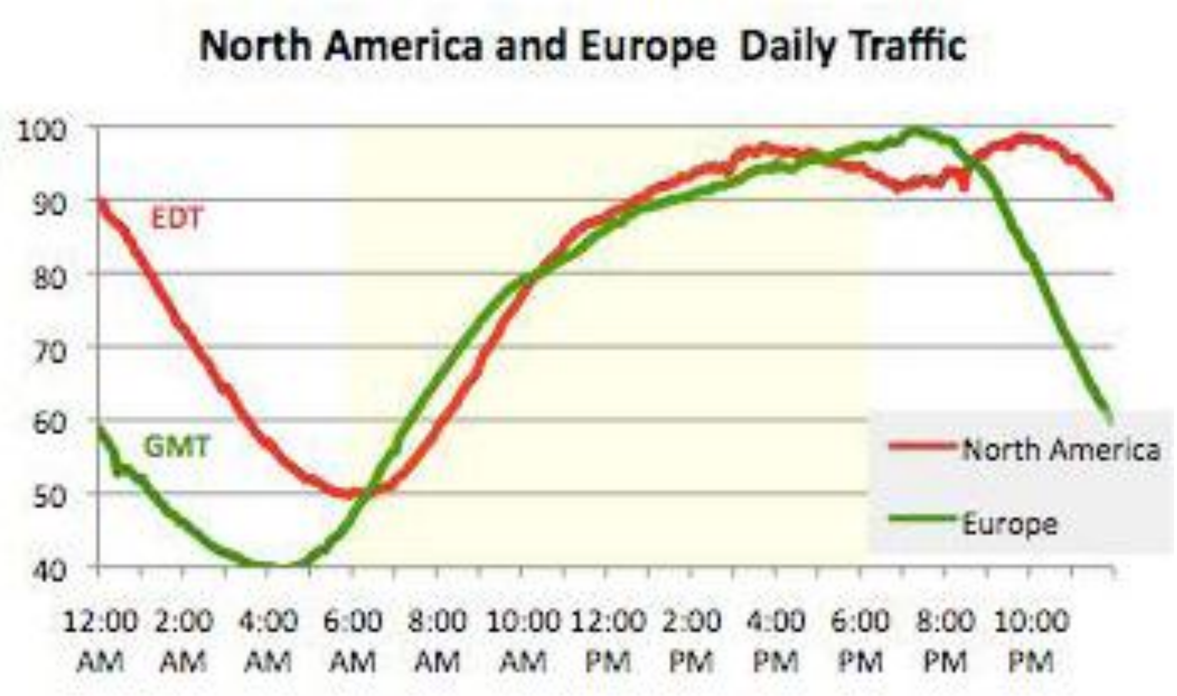
Slow MLTE
(Adapt network to traffic)



Fast MLTE
(off-peak = switch-off)

Source: “Power reduction Techniques in MLTE, Bart Puype et al, IBCN

Turn off based on traffic demand



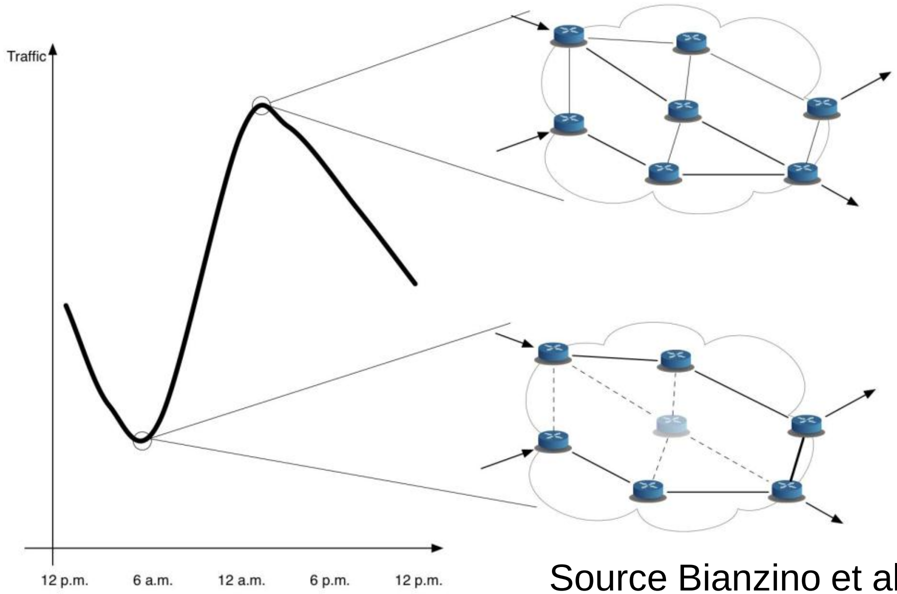
Source: http://asert.arbornetworks.com/2009/08/what-europeans-do-at-night

EE Power over Ethernet

Technology	How much it could save	When will the saving kick-in	Number of Ethernet Links shipped per year
EEE over GbE	~1W per link	Power saving is instantaneously when link is idle	200M and growing
EEPoE with .3af	~0.6W per link	Power saving will occur as long as power is on	40M and growing
EEPoE with .3at	~2.1W per link	Power saving will occur as long as power is on	30M and growing
Total Savings for EEE + EEPoE	***3.13W per link***		

Source: "Power over Ethernet (PoE): An Energy-Efficient Alternative", Roman Kleinerman, Marvell
and Daniel Feldman, Microsemi Corporation, in Marvell Whitepaper, 2011

Energy-aware routing

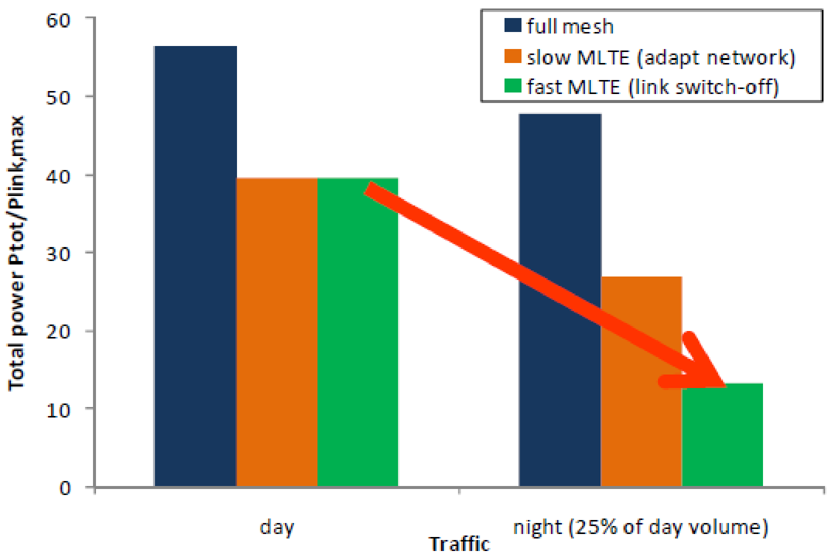


Source Bianzino et al

- **R**outers are put to sleep when the network load is low, while preserving connectivity. This technique may increase the load on some links

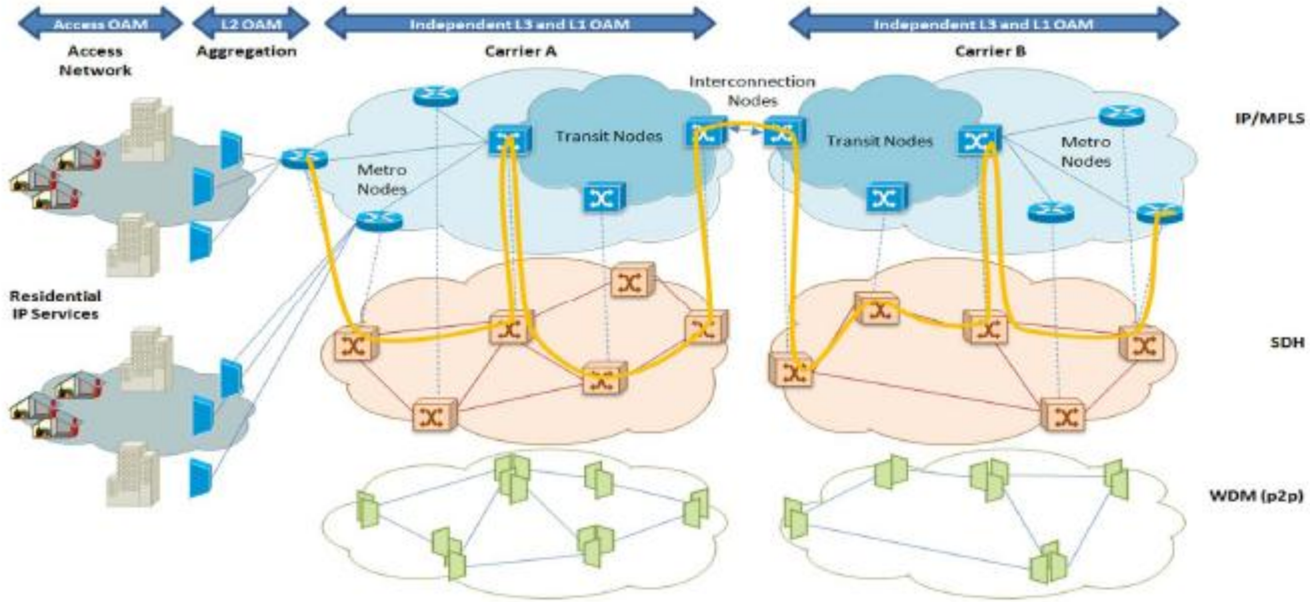
MLTE results

- Two optimization modes:
  - Slow: days/week
  - Fast: hours
- Power scales
  - Better with traffic volume as MLTE acts faster



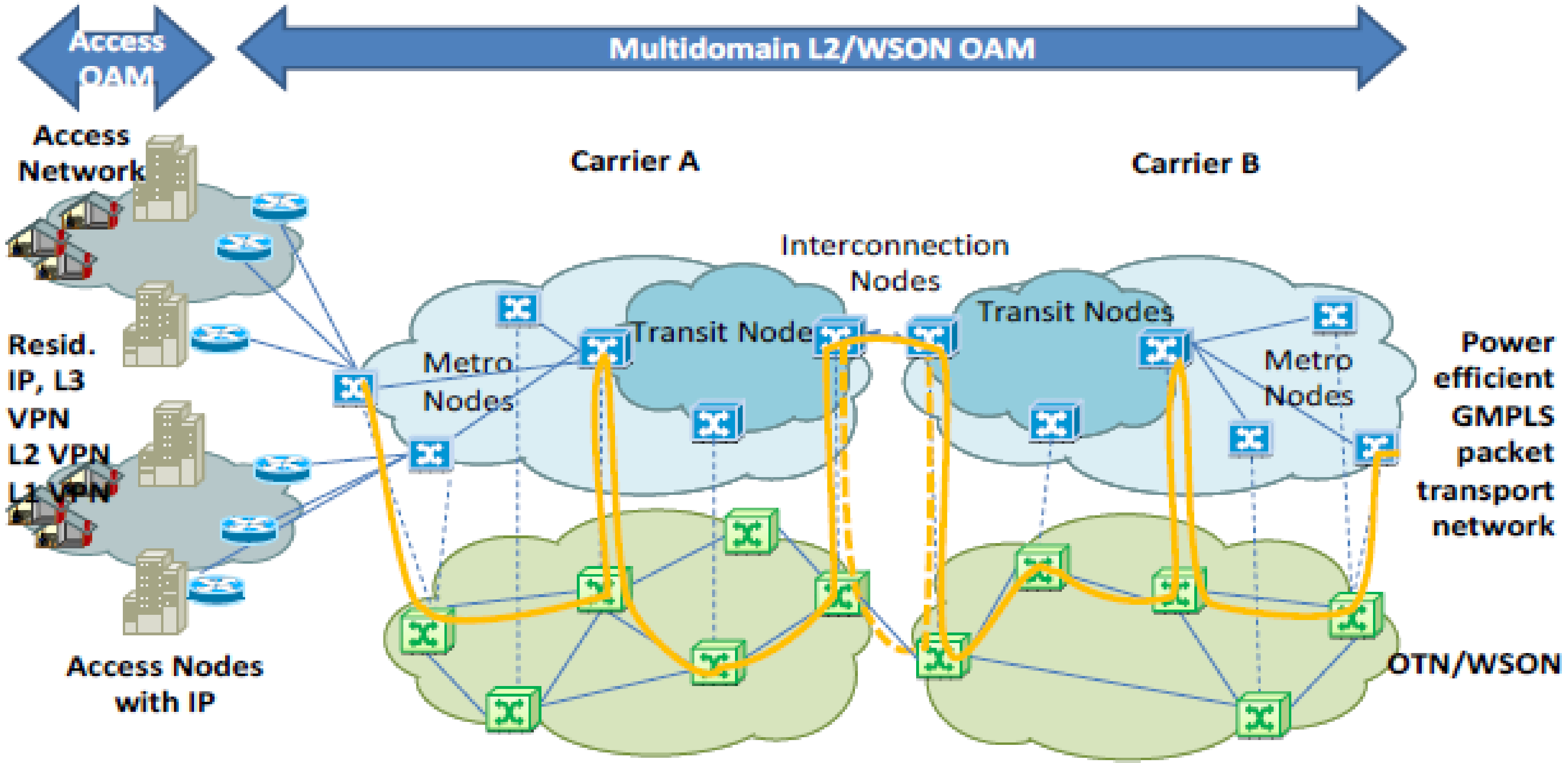
Source: “Power reduction techniques in multilayer traffic engineering”, Bart Puype et al, IBCN

current situation: IP over SDH /DWDM



- Completely inefficient architecture, due to massive IP switching
  - With increasing bit rates the power consumption for routers is becoming a bottleneck.
  - Routers have exponentially increasing power consumption as a function of the bit-rate

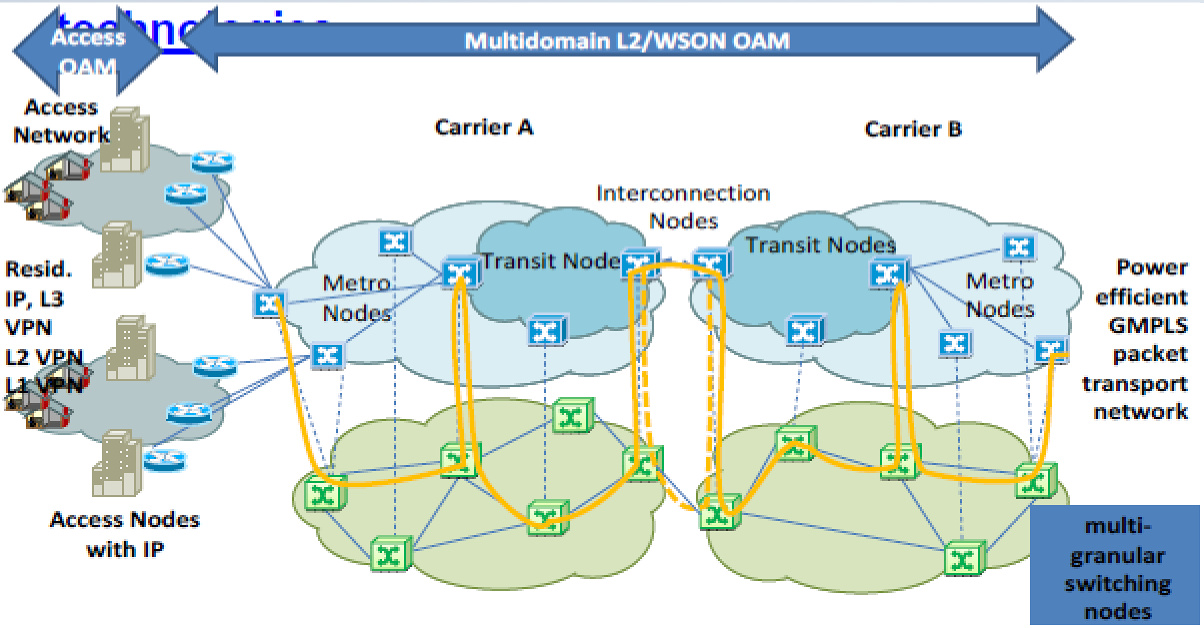
IP only at the edge



IP only at the edge

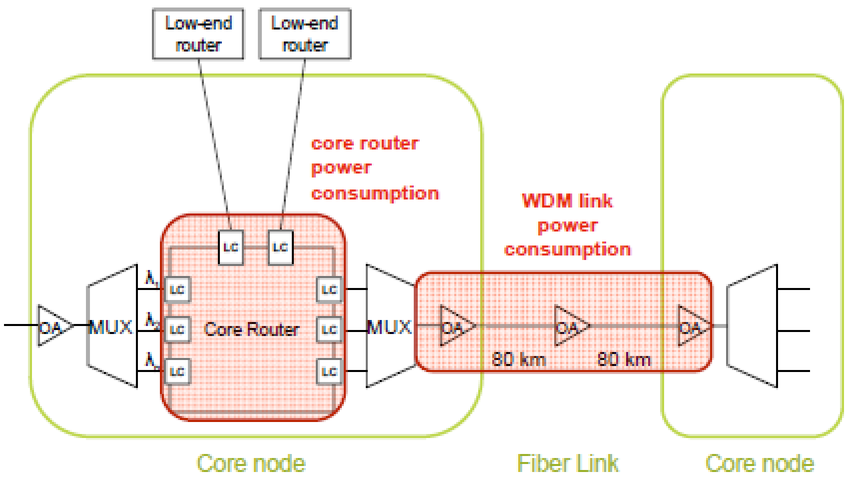
- Traffic is mainly switched at packet transport or optical level instead of IP
  - Lower power consumption per bit/s (-60% power consumption)
  - Carrier class devices avoiding dualling (-40% power consumption)
- Control plane enhancement enabling dynamic traffic engineering
  - Multi-layer traffic engineering (-30% power consumption)
  - Powering down, sleep/idle modes and burst-mode operation (-10% power consumption)
  - Dynamic (on-the-fly) restoration (-30% power consumption)

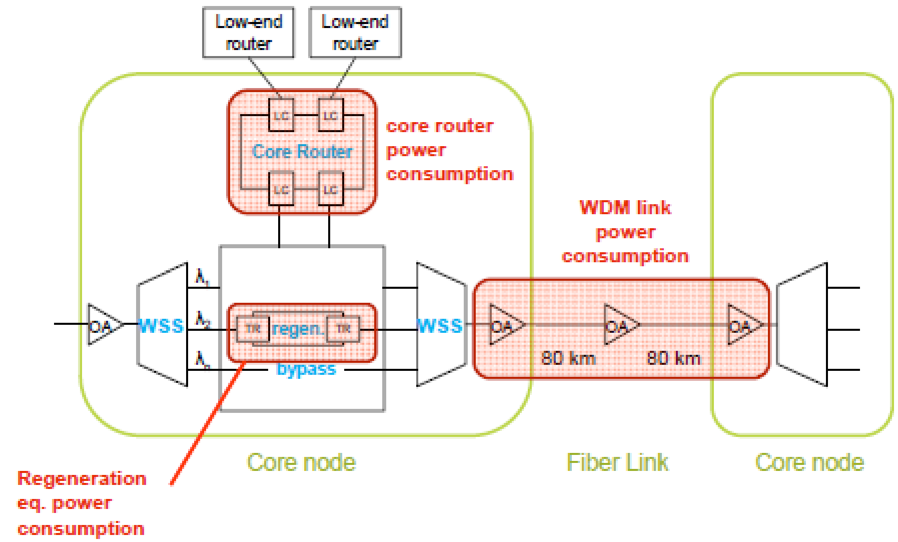
ultra high capacity and EE data plane



- Traffic is mainly switched at optical level, enriched by multi-granular / flexi-grid technologies and sub-lambda switching
  - Complete optical bypass (-90% power consumption)
  - Multi-granular flexigrid (-30% power consumption)

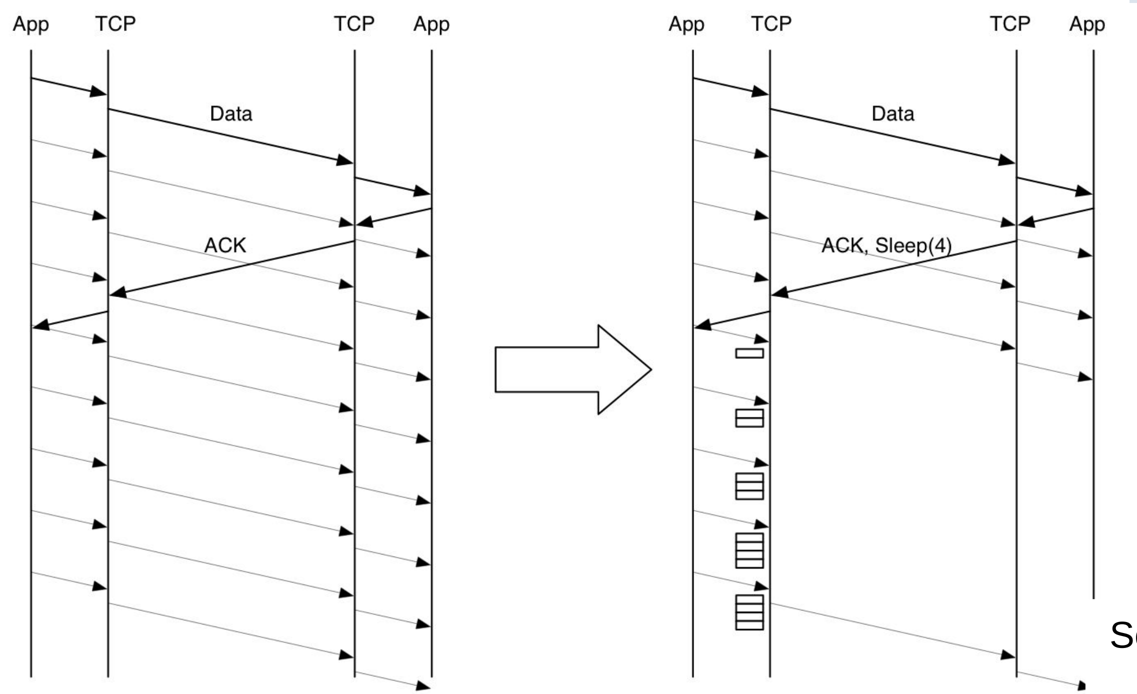
Other solutions: Grooming





- Link-by-link
  - OEO conversion in each node for all traffic
- End-to-end
  - End to end optical path (wavelength)
  - Bypass traffic does not need OEO conversion (except long path > 3000Km)
  - In each node:
    - Core router
    - regenerator

Energy-aware protocols

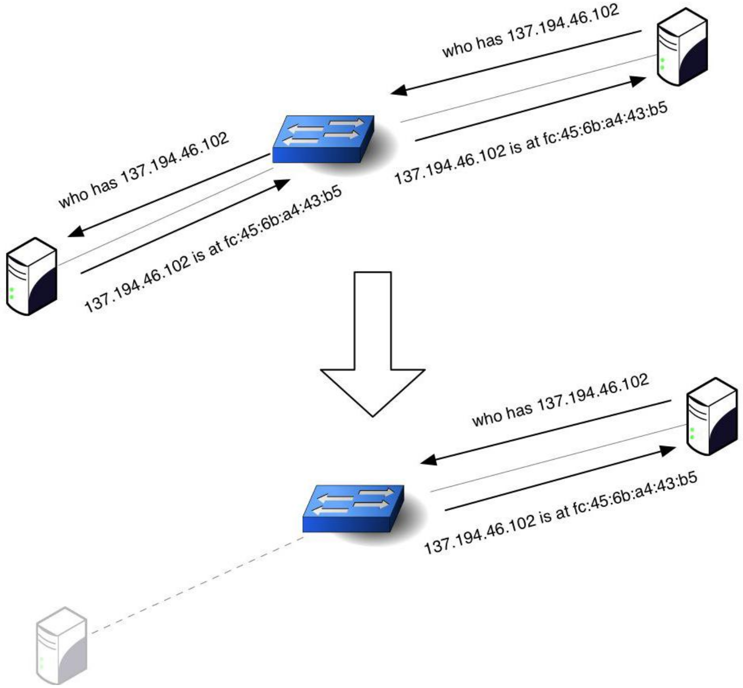


Source Bianzino et al

- In a modified version of TCP the receiver may notify its peer of its intention to sleep. During the sleep period, the source buffers the specified amount of data instead of directly transmitting it.

Proxying

- Variation of turn off interfaces
- NIC proxying:
  - only affect to end elements
- External proxying:
  - translates the activity to the top until required re-connection
- Vitualization and cloud computing are advanced variations of proxying

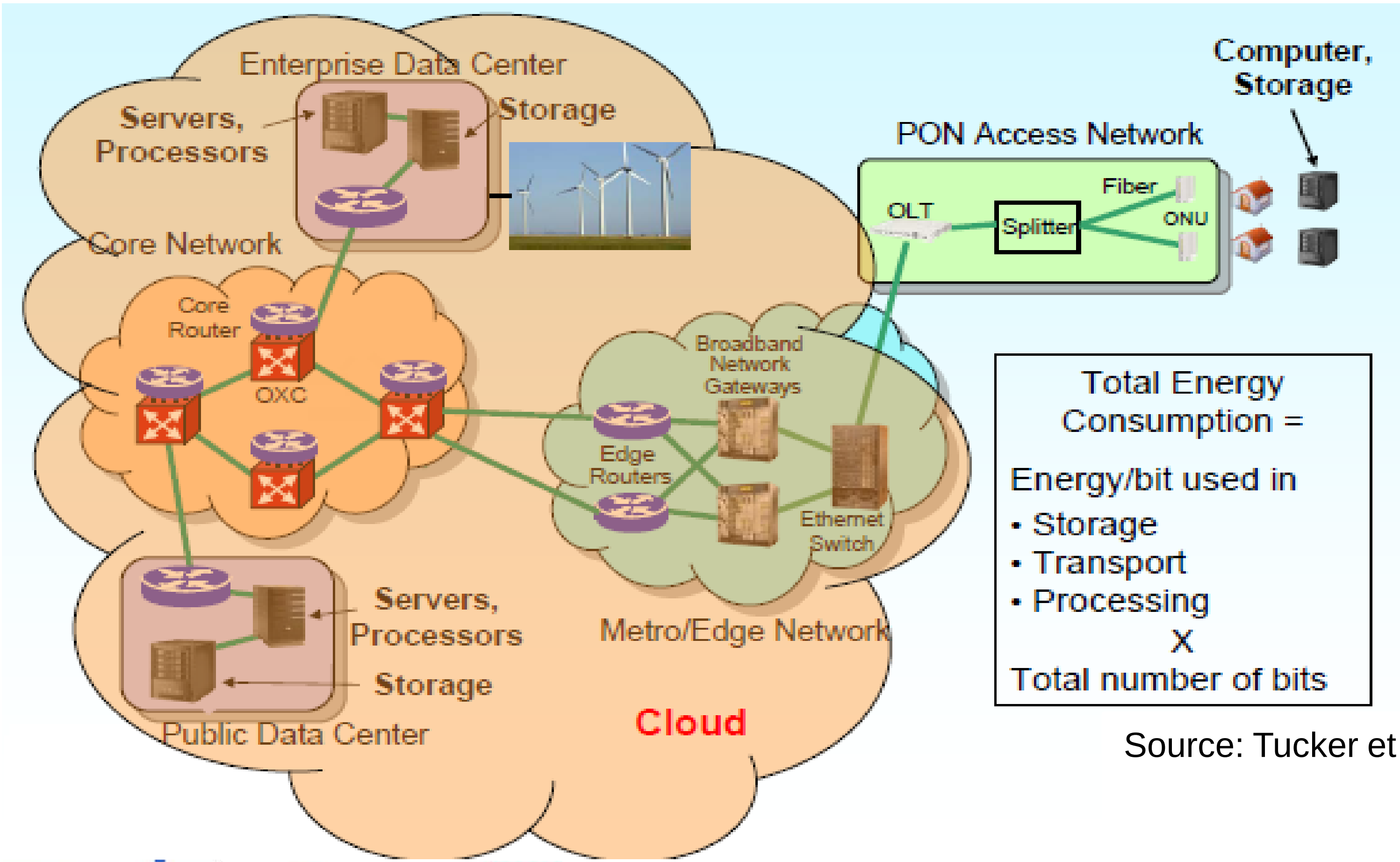


Content Centric Networks

- Content Centric network (CDN – content delivery network)

- Autonomic networking and Cloud computing

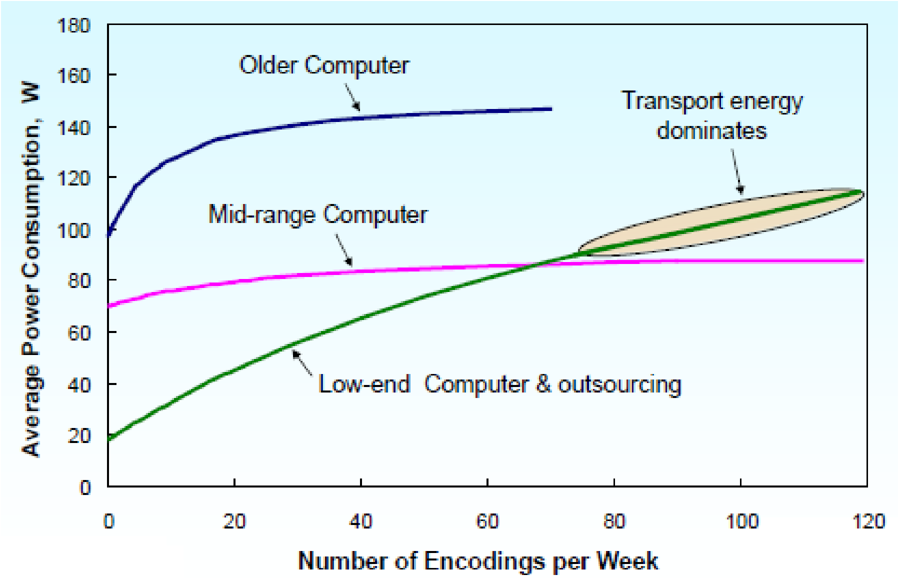
Cloud Computing



Source: Tucker et al

Cloud Computing

- 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)



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  - “Optical Packet-Switched WDM Networks: a Cost and Energy Perspective,” (Invited Paper) Optical Fiber Communication Conference, 2008. Technical Digest. OFC/NFOEC, 24-28 Feb. 2008, San Diego California.
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  - "A Survey of Green Networking Research", Aruna Prem BIANZINO, Claude CHAUDET, Dario ROSSI, Jean-Louis ROUGIER, in IEEE Communications Surveys & Tutorials, vol. 14, no. 2, pp. 3-20, First Quarter 2012.
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  - "Analysis of Power Consumption in Future High-Capacity Network Nodes", Slaviša ***Aleksić, in*** IEEE/OSA Journal of Optical Communications and Networking, vol 1, nº3, pp 245-259, 2009

Branch	Reference	Timescale		Network Layer	Approach	Input Process	Comments
		On-line	Off-line				
Adaptive Link Rate (ALR)	⋆[21] Gupta and Singh	Global		Data Link	Traffic Analysis	Forecast	Position paper, motivates ALR, Coordinate Sleeping mode, based on Arrival Process (AP)
	[22] Gupta et al.	Local		Data Link	Trace Driven Sim.	Forecast	Sleeping mode, AP
	⋆[23] Gunaratne et al.	Local		Data Link	Trace Driven Sim.	Instant.	ALR part of the paper; Rate Switching, based on the Queue occupancy (Q)
	[24] Gunaratne et al.	Local		Data Link	Trace Driven Sim.	Instant.	Rate switching, Q
	[25] Gupta and Singh	Local		Data Link	Traffic Trace	Forecast	Sleeping mode, Q and AP
	⋆[26] Nedevschi et al.	Local		Data Link	Simulation	Forecast	Sleeping mode vs Rate switching, Q and AP; Abilene topology
	[27] Ananthanarayanan and Katz	Local		Data Link	Trace Driven Sim.	History	Switching architecture; Sleeping mode, AP
	[28] Gunaratne et al.	Local		Data Link	Math Model & Sim.	History	Trace and synthetic traffic; Rate switching, Q
Interface Proxying	⋆[23] Gunaratne et al.	Local		Cross	Traffic Analysis	Instant.	Proxying part of the paper; motivates NIC and External
	[29] Purushothaman et al.	Local		Application	Trace Driven Sim.	Instant.	NIC Proxying for Gnutella protocol
	[30] Jimeno and Christensen	Local		Application	Hw prototype	Instant.	External Proxying for Gnutella protocol
	[31] Sabhanatarajan and Gordon-Ross	Local		Network	Trace Driven Sim.	Instant.	NIC Proxying; packet inspection
	[32] Agarwal et al.	Local		Cross	Hw prototype	Instant.	NIC Proxying; *Somniloquy* prototype
	[33] Nedevschi et al.	Local		Cross	Sw prototype	Instant.	Trace Driven evaluation; External Proxying
Energy aware infrastructures	⋆[21] Gupta and Singh		Dim.	Network	Traffic Analysis	History	Position paper, motivates Energy-aware routing
	⋆[26] Nedevschi et al.	Global		Data Link	Simulation	Instant.	Coordinate sleeping; Abilene topology
	[34] Baldi and Ofek		Design	Cross	Architectural	-	Clean slate design
	[35] Chiaraviglio et al.		Dim.	Network	Numerical solution	History	Energy-aware routing; Heuristic solution of ILP problem
	[36] Chabarek et al.		Design	Network	Operational Research	History	*Energy-aware infrastructure*, Router power-profiling
	[37] Sansò and Mellah		Design	Network	Operational Research	History	QoS/Energy tradeoff
	[38] Da Costa et al.	Global		Application	Trace Driven Sim.	Instant.	Grid5000 management
Energy aware applications	[39] Irish and Christensen	Local		Transport	Sw Prototype	Instant.	TCP split connection; protocol modification
	[40] Wang and Singh		Design	Transport	Sw Prototype	-	TCP optimization of FreeBSDv5
	[41] Blackburn and Christensen	Local		Application	Sw Prototype	Instant.	Telnet protocol modification
	[42] Blackburn and Christensen	Local		Application	Simulation (ns2)	Instant.	BitTorrent protocol modification