ECO net
low Energy COnsumption NETworks

Green Future Internet and Green Energy: A Profitable Liaison

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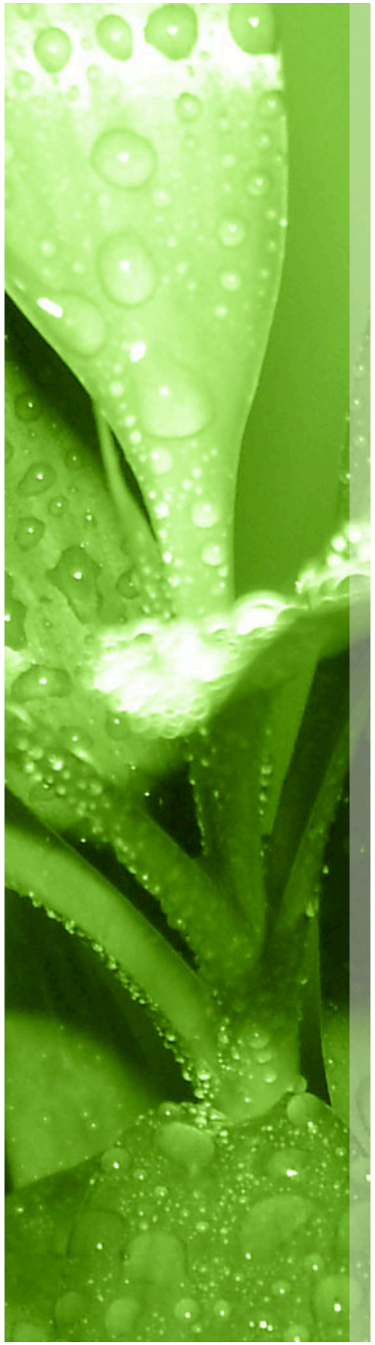
Auckland and Christchurch, New Zealand, Aug. 2011

New Zealand (North & South) IEEE Communications Chapter



Outline

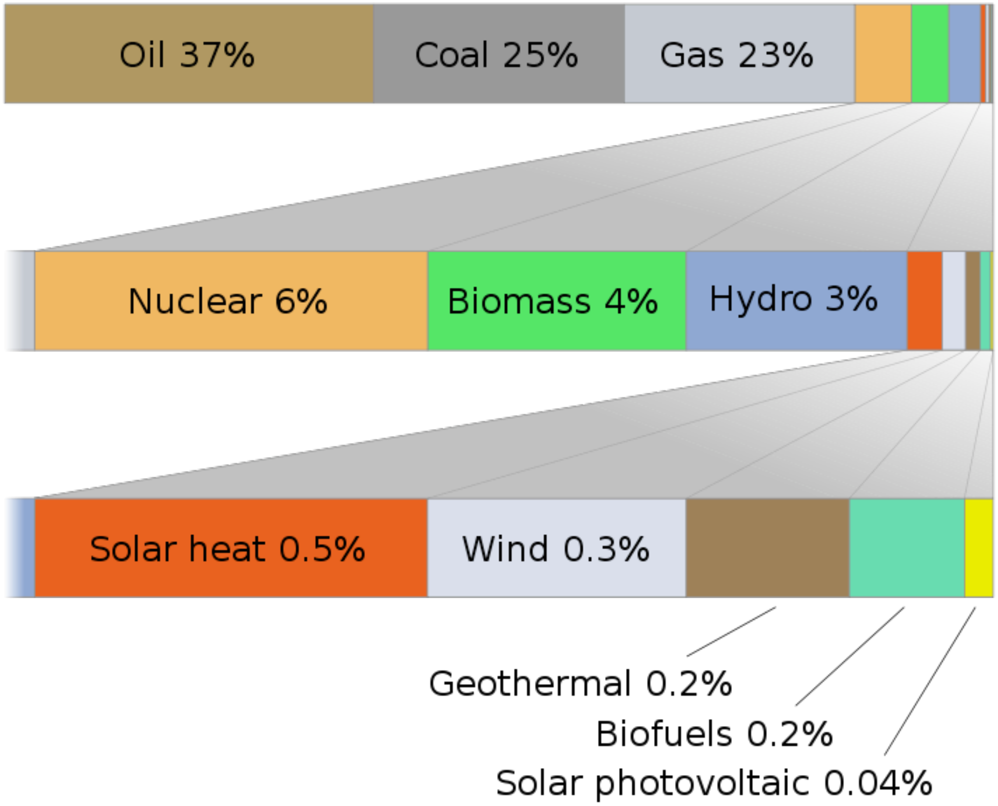
- Reasons for *going green*
- Carbon footprint
- Does the fixed network matter (in terms of consumption and OPEX)?
- Energy consumption breakdown
- Taxonomy of Green Networking Approaches
- Potential savings (or, is there room for network energy optimization?)
- Data Centres, Grids and Clouds
- Putting it all together
- Some eScience applications
- Projects in the Wired Networking environment
- Research challenges

Why Going Green?

- ICT has been historically and fairly considered as a key objective to reduce and monitor "third-party" energy wastes and achieve higher levels of efficiency.
  - Classical example: Video-Conferencing Services
  - New example: Smart Electrical Grid
- However, until recently – with the notable exceptions of wireless networks and data centres - ICT had not applied the same efficiency concepts to itself, not even in fast growing sectors like networking and the Internet.
- There are two main motivations that drive the quest for "green" ICT:
  - the environmental one, which is related to the reduction of wastes, in order to impact on CO_2 emission;
  - the economic one, which stems from the reduction of operating costs (OPEX) of ICT services.

The Carbon FootPrint & Energy Consumption

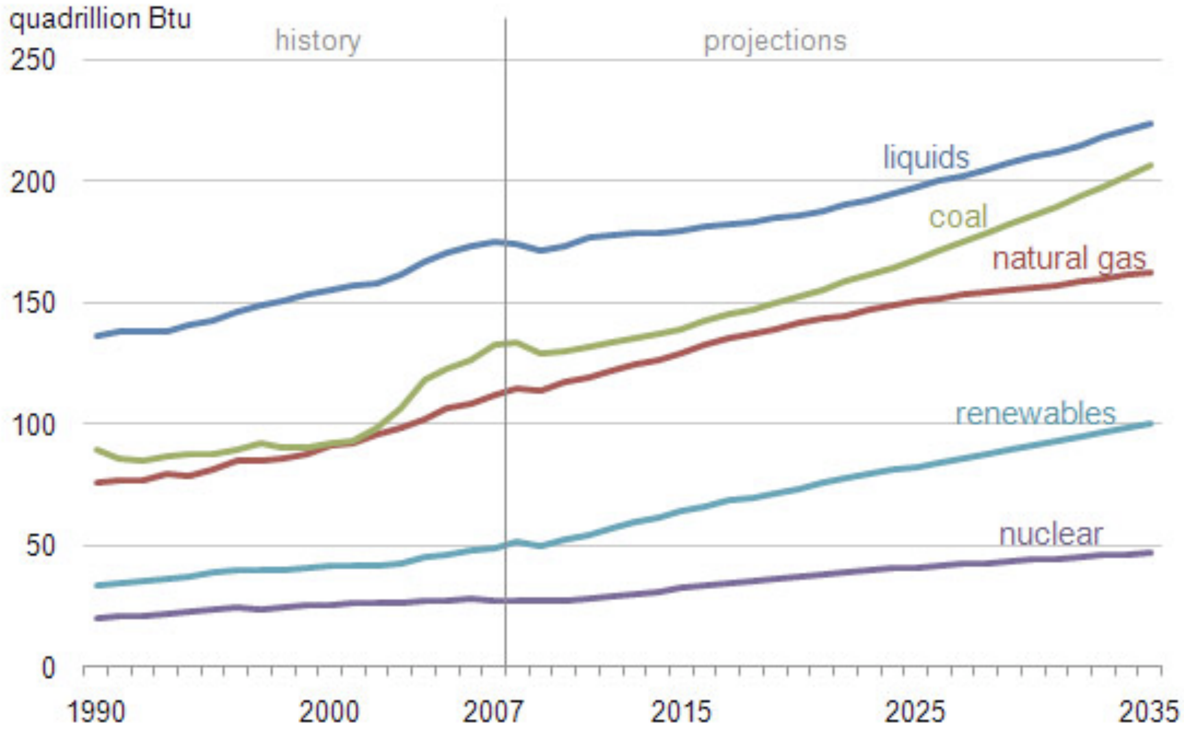
- Today, more than 95% of energy is produced by “brown” sources (oil, coal, gas, nuclear, biomass).
- The renewable energy sources account only for about 4%...
- On the average, the production of 1 kWh is supposed to cause about 0.5 kg of CO_2 - source: International Energy Agency (IEA).



Source: “Renewables, Global Status Report 2006,” Renewable Energy Policy Network for the 21st Century, 2006.

The Carbon FootPrint & Energy Consumption

1 BTU (British Thermal Unit) ≈ 1,055 J



World marketed energy use by fuel type. *Source*: U.S. Energy Information Administration (EIA), International Energy Outlook 2010, Report #:DOE/EIA-0484(2010) Release Date: May 25, 2010.

How much does energy cost ?

- In the U.S.A.:
  - A kWh is about $0.10 (US national average billing rate)
  - 1 TWh is about $100 million
- In Italy:
  - A kWh is about €0.085 (rate based on a typical residential consumption of 2700 kWh for 1 year, under 3 kW)
  - So, a TWh is €85 million (= ~$125 million)

Average Energy Price					
	2006	2007	2008	2009	2010
Million $ per TWh	89	91	99	101	95

Cost of the electrical energy according to the U.S. Energy Information Administration (EIA).

The Embodied Carbon Footprint

- Beyond the carbon footprint from direct usage, we have also to take into account the greenhouse gas emissions needed to produce devices (embodied carbon).
- For example, in a PC:
  - Carbon from usage (energy consumption): 4200 kWh = 2.1 tons of CO_2 (5 years of life)
  - Embodied carbon: 2000 kWh = 1 ton of CO_2

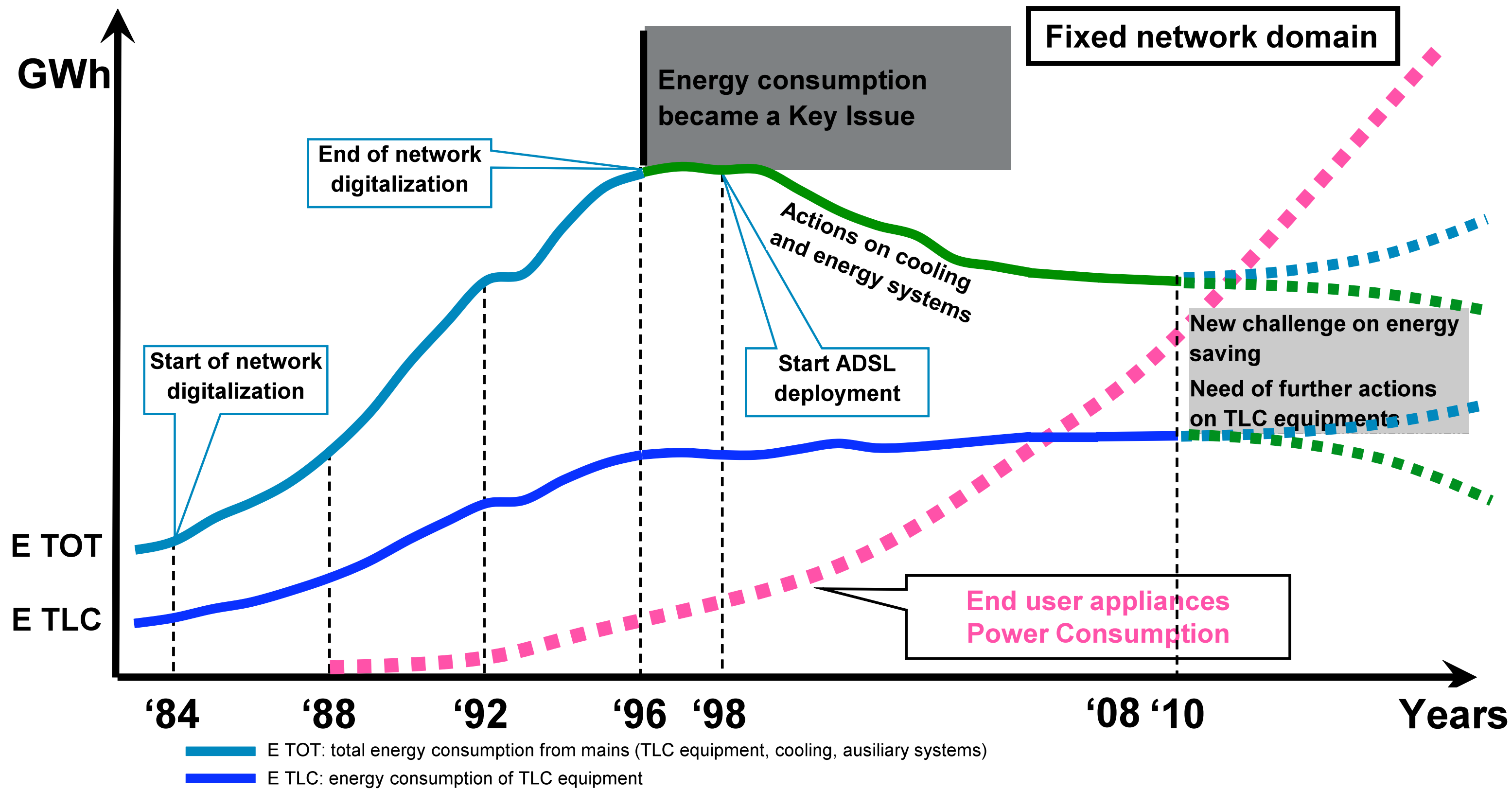
Source: E. Williams, "Revisiting Energy Used to Manufacture a Desktop Computer: Hybrid Analysis Combining Process and Economic Input-Output Methods," *Proc. IEEE Internat. Symp. on Electronics and the Environment*, pp. 80-85, 2004.

Some Data from Telcos

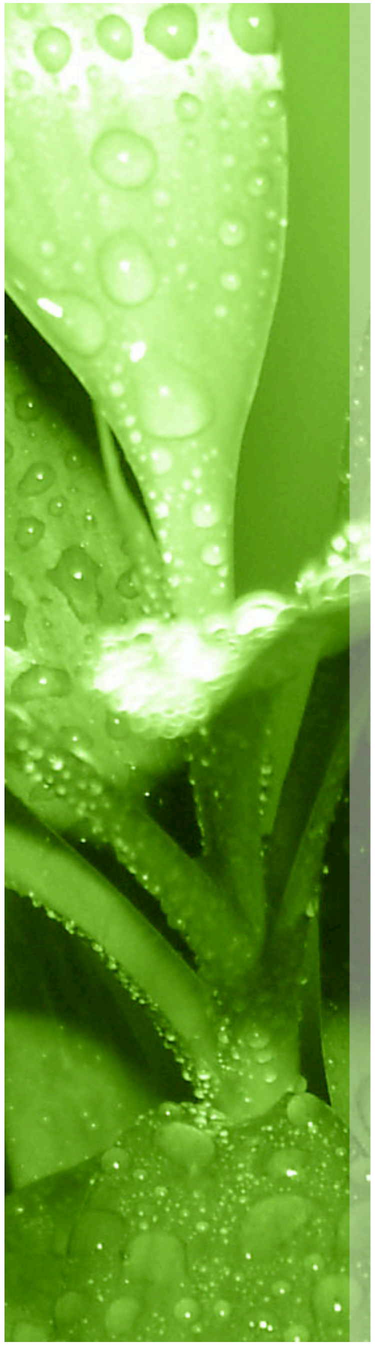
Energy Consumption (TWh per year)					
Telecom	**2006**	**2007**	**2008**	**2009**	**2010**
Deutsche Telekom (World)	7.10	7.22	7.84	7.91	-
France Telecom (World)	3.66	3.47	4.57	4.38	-
Telecom Italia	2.10	2.15	2.13	2.14	-
British Telecom (UK)	1.94	1.99	2.03	2.28	2.28
British Telecom (World)	-	-	2.6	2.71	3.12
AT&T (World)	-	-	-	11.07	11.14
Verizon	8.90	-	-	10.27	10.24
NTT	-	2.76	2.76	2.75	-
Telefonica	1.42	-	4.76	5.05	6.37
SwissCom	-	-	0.43	0.40	0.40
China Mobile	-	-	9.35	10.62	11.94
SK Telecom	-	-	0.94	1.09	1.09

The figures refer to the whole corporate consumption. As such, they account for numerous sources, other than the operational absorption of the networking equipment (e.g., offices' heating and lights). Notwithstanding, they give an idea of the general trend.

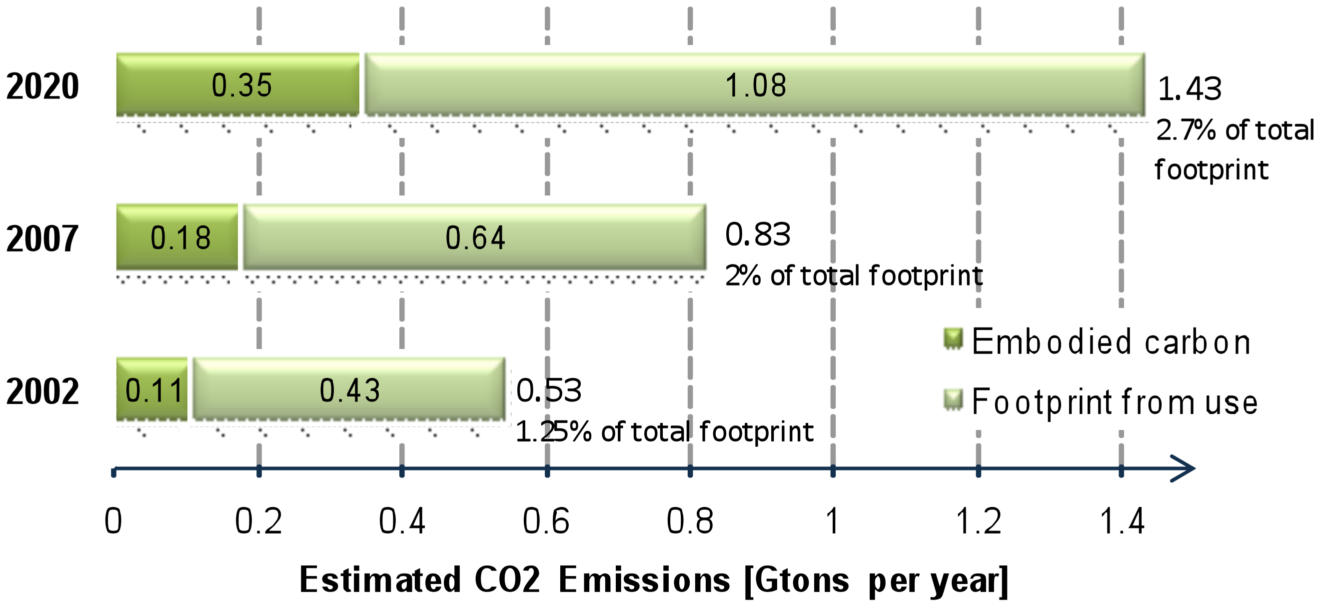
Some Data from Telecoms



Source: C. Bianco, F. Cucchietti, G. Griffa, " Energy consumption trends in the Next Generation Access Network - a Telco perspective, " *IEEE INTELEC 2007.*



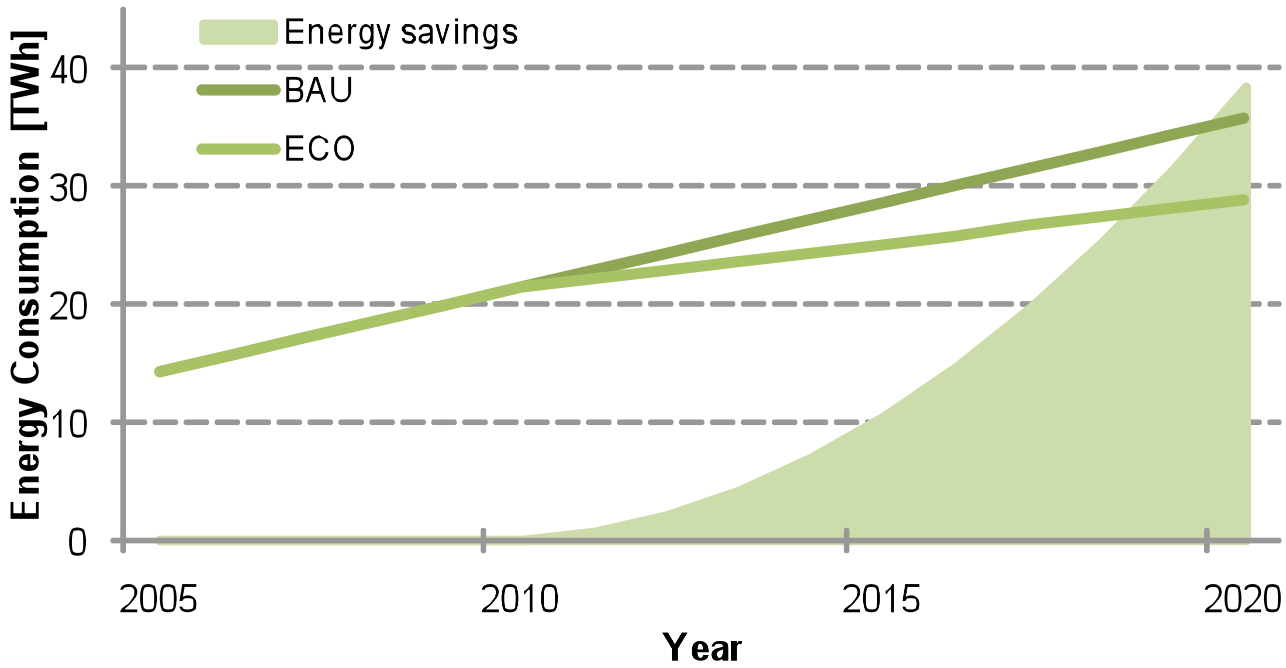
…and the Future?



Estimate of the global carbon footprint of ICTs (including PCs, telcos' networks and devices, printers and datacenters).

Source: Smart 2020 report by Global e-Sustainability Initiative (GeSI)

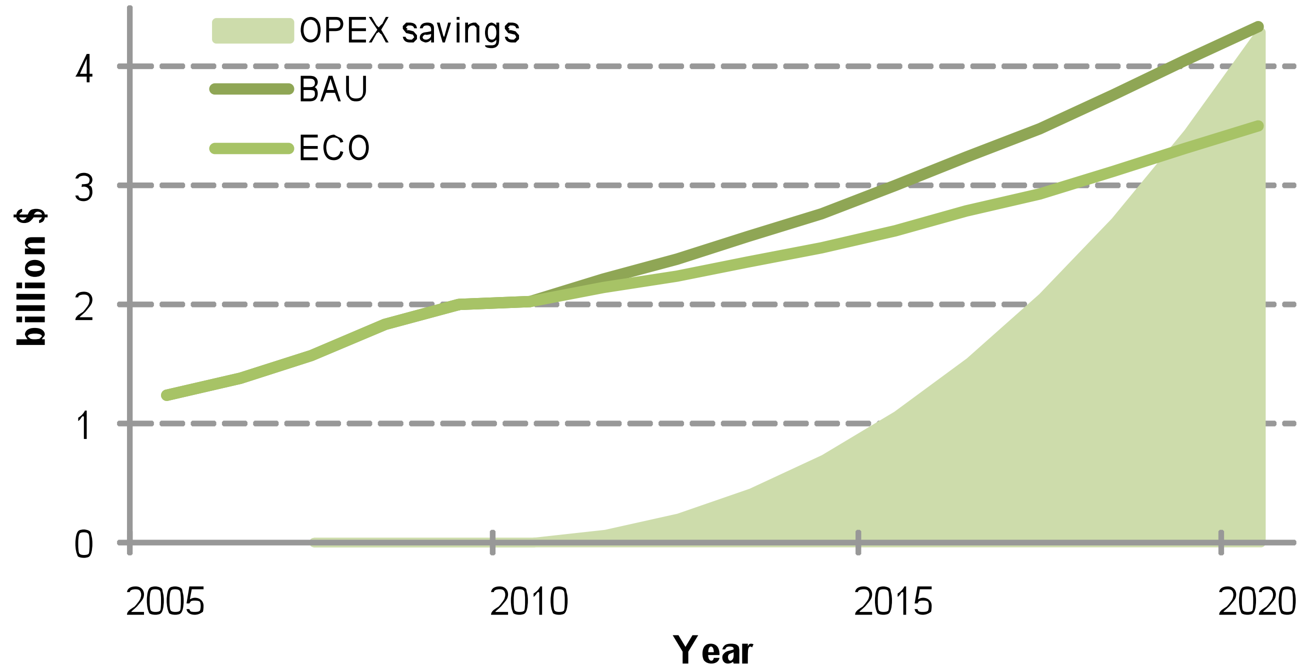
...and the Future?



Energy consumption estimation for the European telcos' network infrastructures in the "Business-As-Usual" (BAU) and in the Eco sustainable (ECO) scenarios, and cumulative energy savings between the two scenarios.

Source: European Commission DG INFSO report

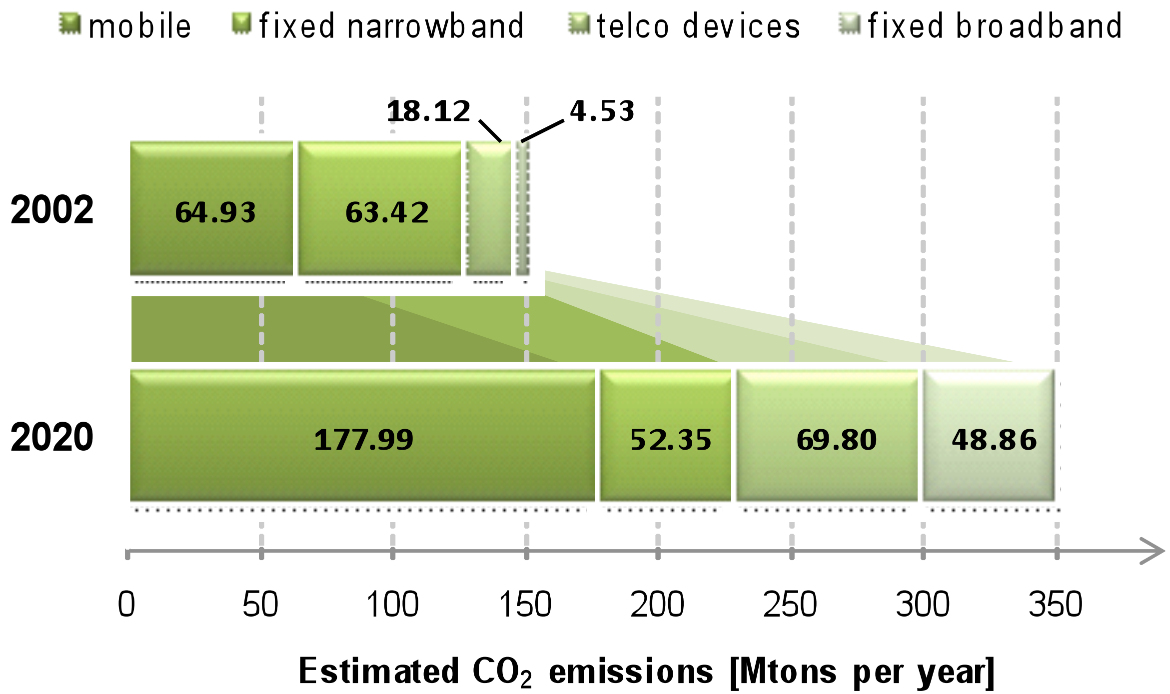
...and the Future?



OPEX estimation related to energy costs for the European telcos' network infrastructures in the "Business-As-Usual" (BAU) and in the Eco sustainable (ECO) scenarios, and cumulative savings between the two scenarios.

Source: R. Bolla, R. Bruschi, F. Davoli, F. Cucchietti, "Energy Efficiency in the Future Internet: A Survey of Existing Approaches and Trends in Energy-Aware Fixed Network Infrastructures," *IEEE Communications Surveys & Tutorials,* vol. 13, no. 2, pp. 223-244, 2nd Qr. 2011.

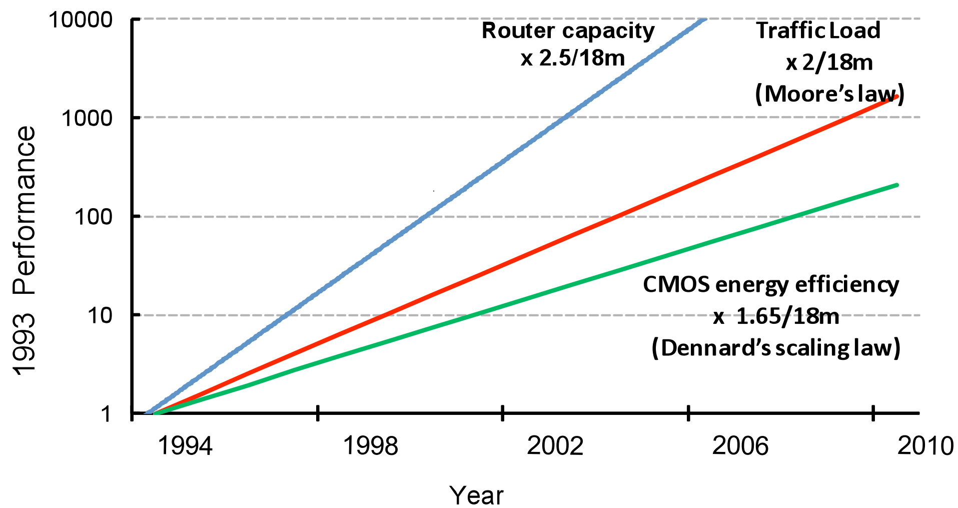
Which are the Sources?



Source: Smart 2020 report by Global e-Sustainability Initiative (GeSI)

And the Reasons?

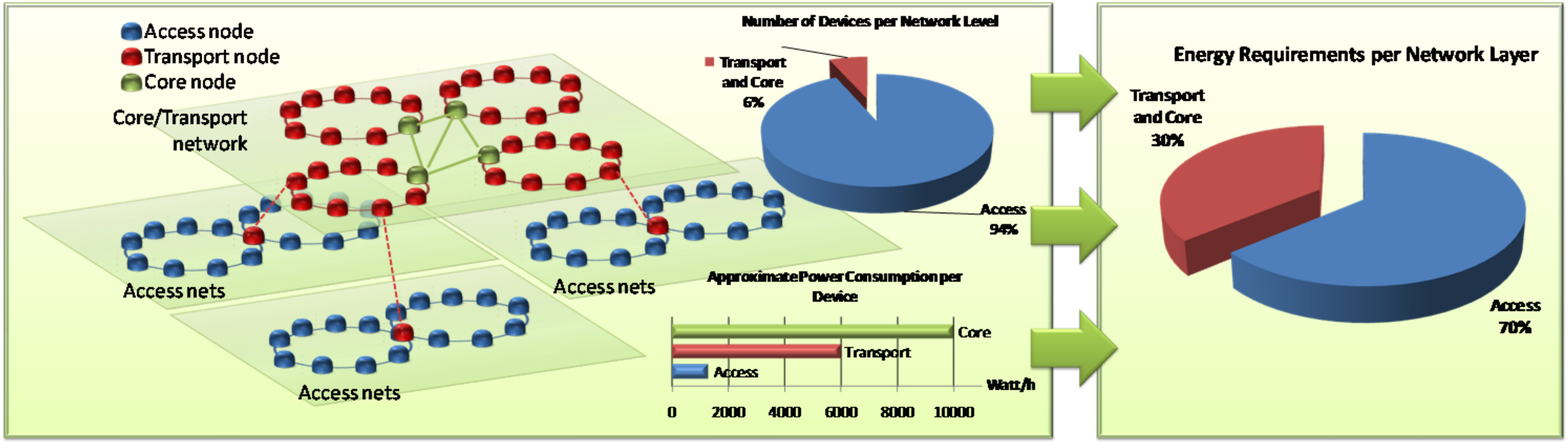
- To support new generation network infrastructures and related services for a rapidly growing customer population, telcos and ISPs need:
  - an ever larger number of devices,
  - devices with sophisticated architectures able to perform increasingly complex operations in a scalable way.
- The sole introduction of novel low consumption silicon technologies cannot clearly cope with such trends, and be enough for drawing ahead current network equipment towards a greener Future Internet.



Evolution from 1993 to 2010 of high-end IP routers' capacity (per rack) vs. traffic volumes (Moore's law) and energy efficiency in silicon technologies.

Source: R. Bolla, R. Bruschi, F. Davoli, F. Cucchietti, "Energy Efficiency in the Future Internet: A Survey of Existing Approaches and Trends in Energy-Aware Fixed Network Infrastructures," *IEEE Communications Surveys & Tutorials,* vol. 13, no. 2, pp. 223-244, 2nd Qr. 2011.

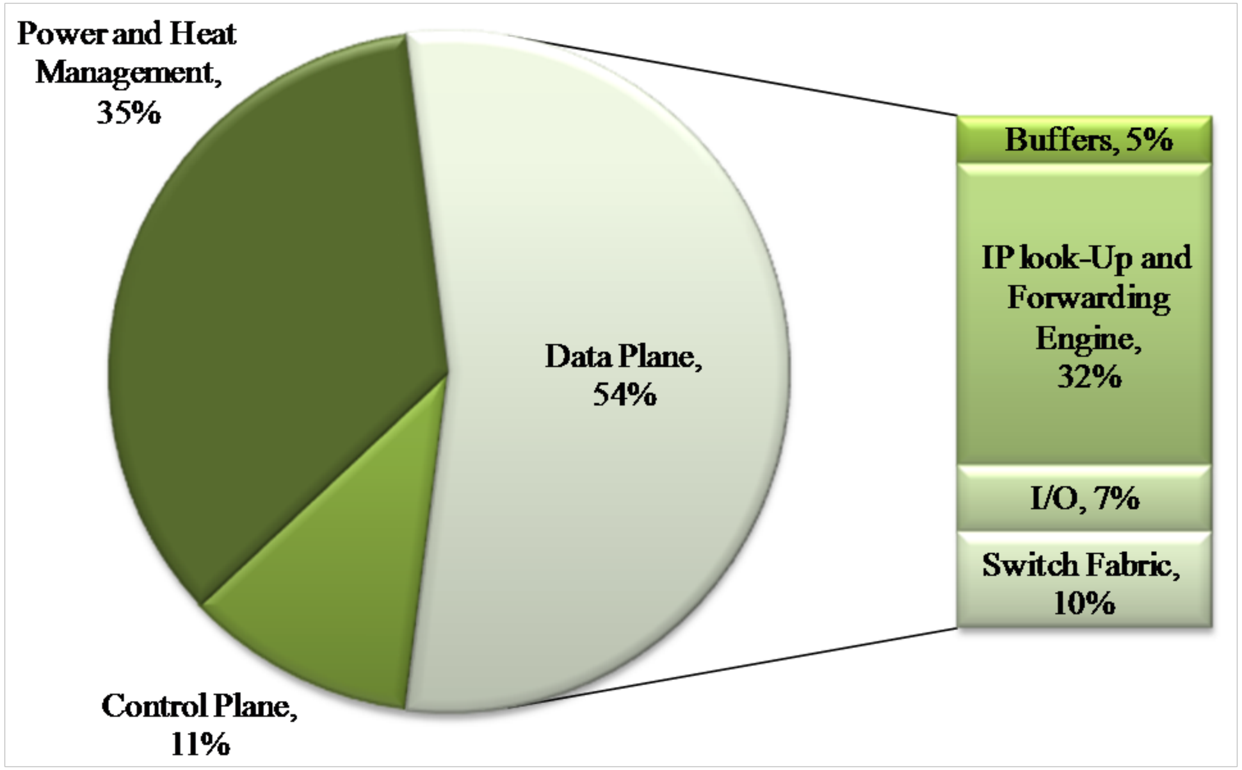
Decomposing the Energy Consumption in the Wired Network



Typical access, metro and core device density and energy requirements in today's typical networks deployed by telcos, and ensuing overall energy requirements of access and metro/ core networks.

Source: R. Bolla, R. Bruschi, F. Davoli, F. Cucchietti, "Energy Efficiency in the Future Internet: A Survey of Existing Approaches and Trends in Energy-Aware Fixed Network Infrastructures," *IEEE Communications Surveys & Tutorials,* vol. 13, no. 2, pp. 223-244, 2^{nd} Qr. 2011.

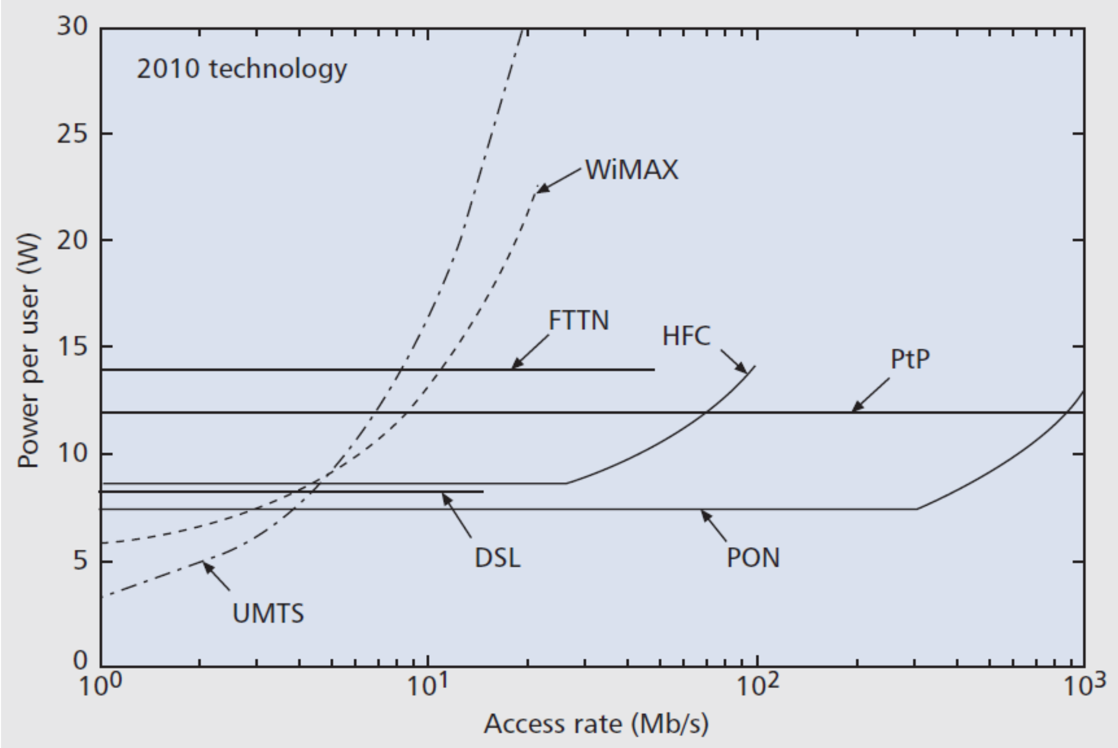
Decomposing the Energy Consumption



Estimate of power consumption sources in a generic platform of high-end IP router.

Source: R. Tucker, “Will optical replace electronic packet switching?”, *SPIE Newsroom,* 2007.

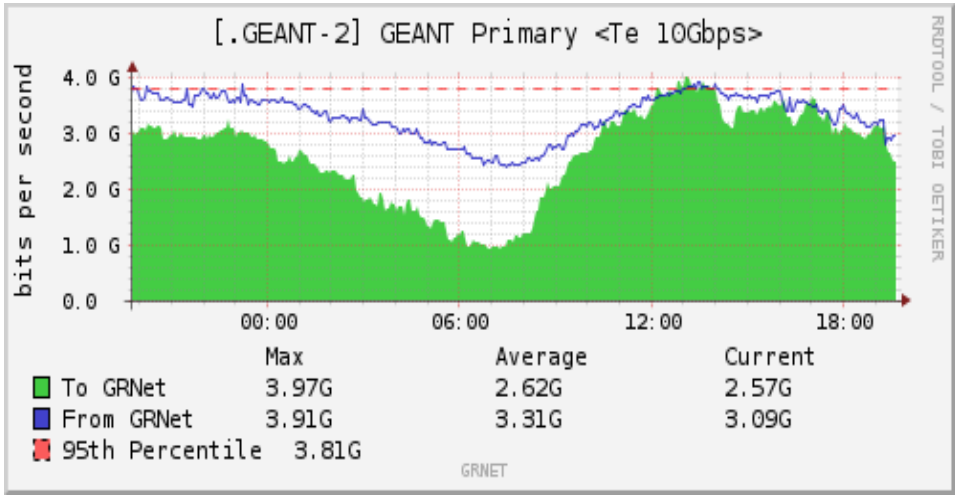
Access Technologies

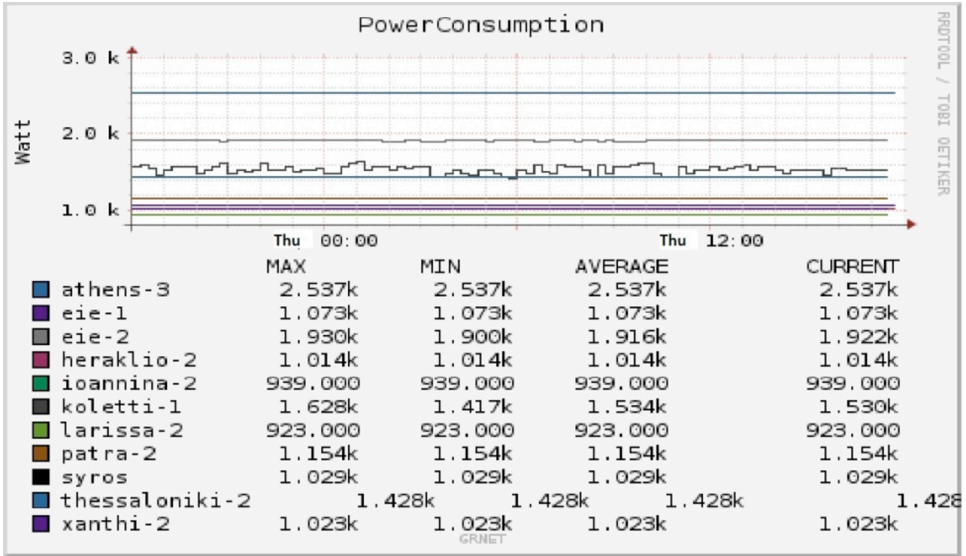


Power consumption of DSL, HFC, PON, FTTN, PtP, WiMAX, and UMTS as a function of access rate with an oversubscription rate of 20. The technology used is fixed at 2010 vintage for all access rates.

Source: Baliga, J.; Ayre, R.; Hinton, K.; Tucker, R.S.; , "Energy consumption in wired and wireless access networks," *IEEE Communications Magazine,* vol. 49, no. 6, pp. 70-77, June 2011.

Is the energy consumption currently load-dependent?



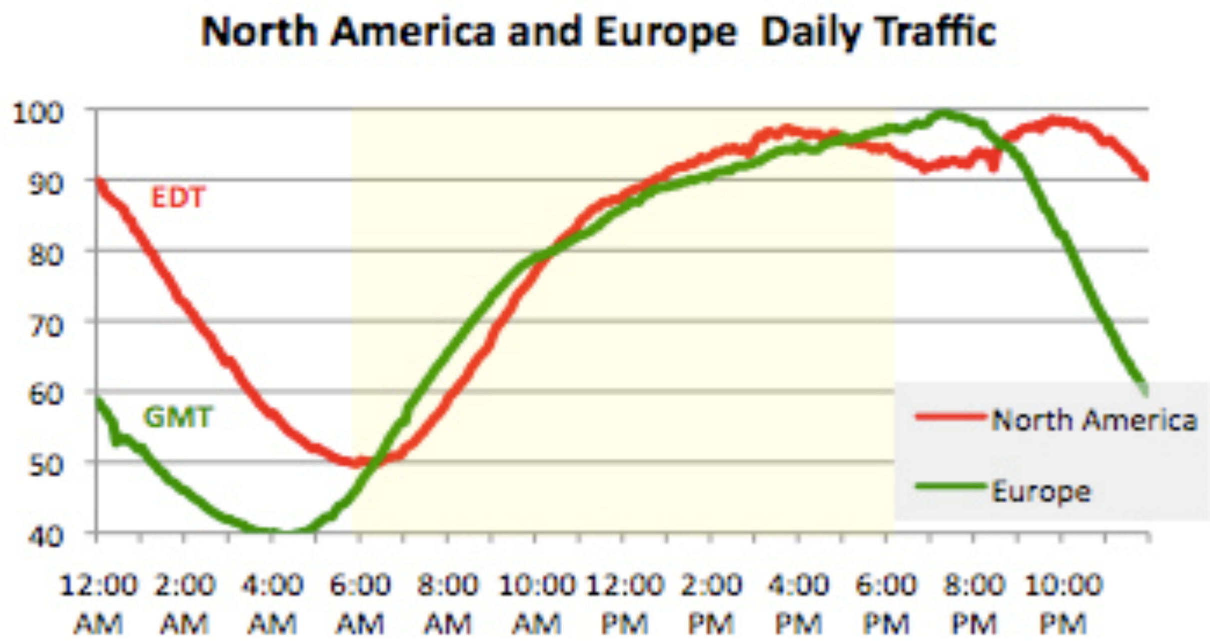


Network engineers only speak about the capacity of a device or of a link interface…

…as a matter of fact, device and link are specifically designed to work at the maximum speed…

Source: The ECONET Consortium, "End-user requirements, technology specifications and benchmarking methodologies," *Deliverable 2.1*.

Day & Night Traffic Profiles



Percentage w.r.t. peak level.
The profiles exhibit regular, daily cyclical traffic patterns with Internet traffic dropping at night and growing during the day.

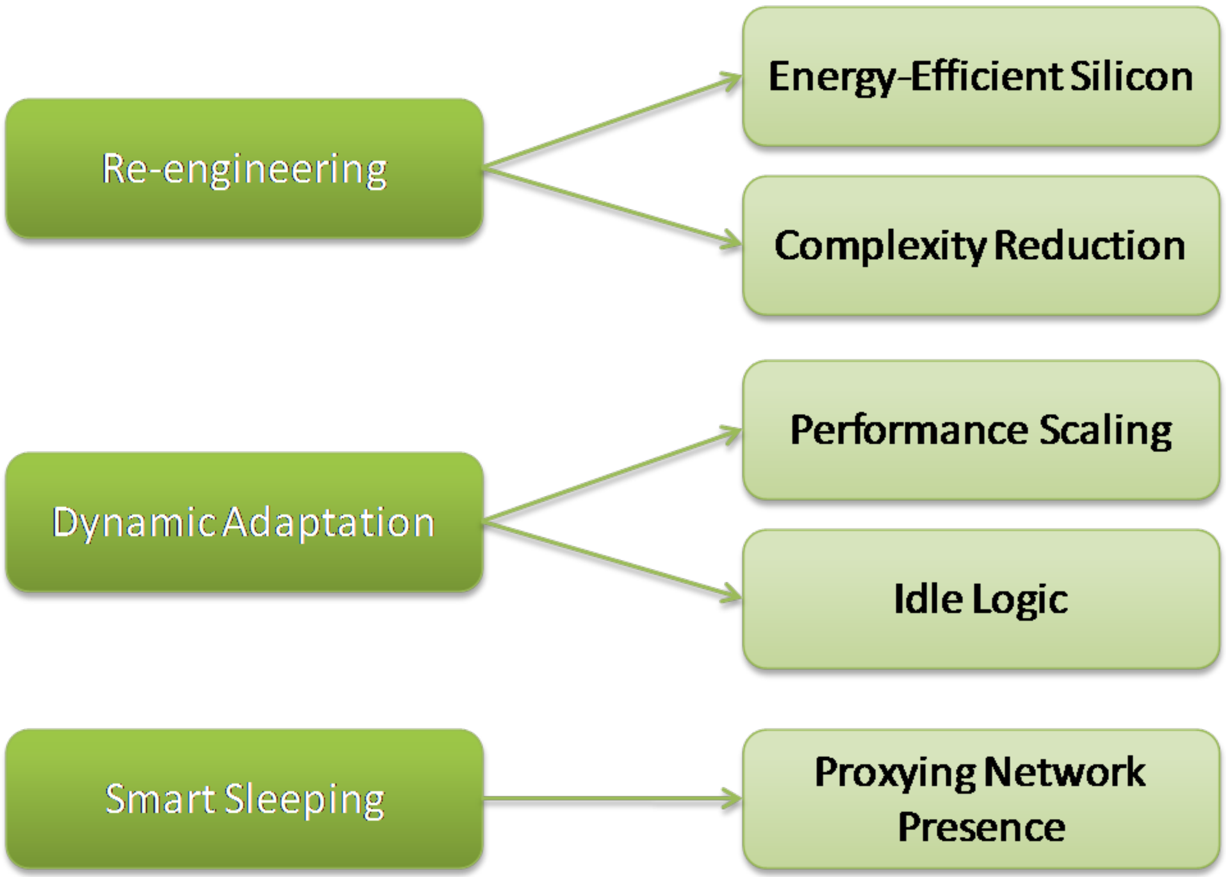
Traffic load fluctuation at peering links for about 40 ISPs from USA and Europe

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

Energy wastes

- Networks and devices are lightly utilized.
  - Often peak loads during rush hours are generally much lower than capacities of links and devices.
    - It is well known that the «overdimensioning» is the best design strategy for assuring QoS levels…
  - Moreover, traffic loads follow well-known day & night fluctuations.
- On the other hand, the energy requirements of network devices remain substantially flat according to their workload.

A Taxonomy of Undertaken Approaches



Techniques can be applied at device, link, and network levels.

Most of them pertain not only to network resources (wired and wireless), but can be applied in different form to the computational environment (data centre, grid, cloud).

Source: R. Bolla, R. Bruschi, F. Davoli, F. Cucchietti, "Energy Efficiency in the Future Internet: A Survey of Existing Approaches and Trends in Energy-Aware Fixed Network Infrastructures," *IEEE Communications Surveys & Tutorials*, vol. 13, no. 2, pp. 223-244, 2nd Qr. 2011.

Re-engineering

- Re-engineering approaches aim at:
  - introducing and designing more energy-efficient elements for network device architectures
  - suitably dimensioning and optimizing the internal organization of devices
  - reducing their intrinsic complexity levels.

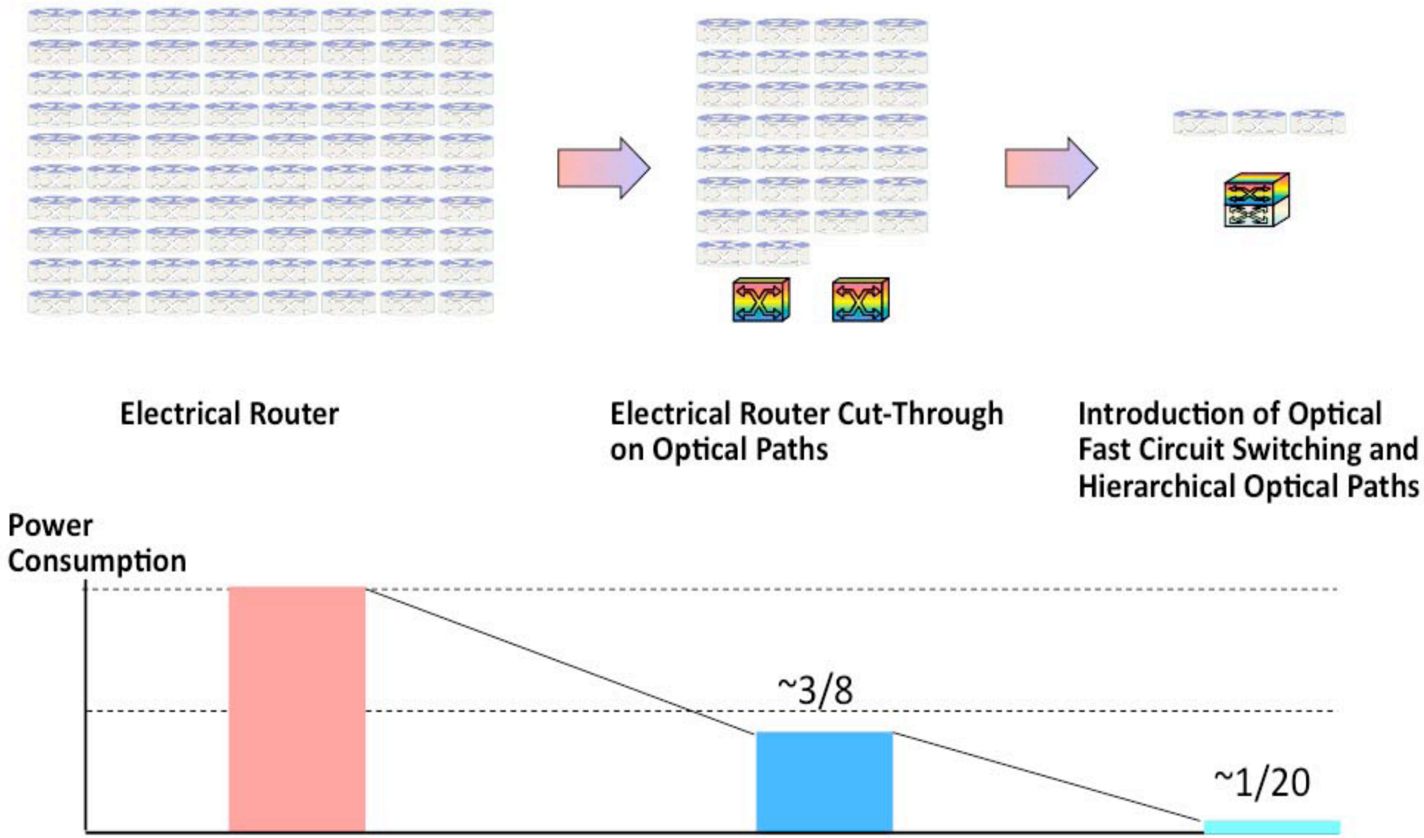
Energy-Efficient Silicon

- Adoption of pure optical switching architectures:
  - They can potentially provide terabits of bandwidth at much lower power dissipation than current network devices.
  - But their widespread adoption is still hindered by technological challenges: problems mainly regard the limited number of ports and the feasibility of suitable buffering schemes.
- Decreasing feature sizes in semiconductor technology have contributed to performance gains:
  - allowing higher clock frequencies
  - designing improvements such as increased parallelism.
  - the same technology trends have also allowed for a decrease in voltage that has reduced the power per byte transmitted by half every two years, as suggested by Dennard's scaling law.

Re-engineering

Optical Backbone Networks

The creation of optical paths (via DWDM) within optical backbone networks has been utilized for the dynamic establishment of high capacity circuits with reduced energy demands

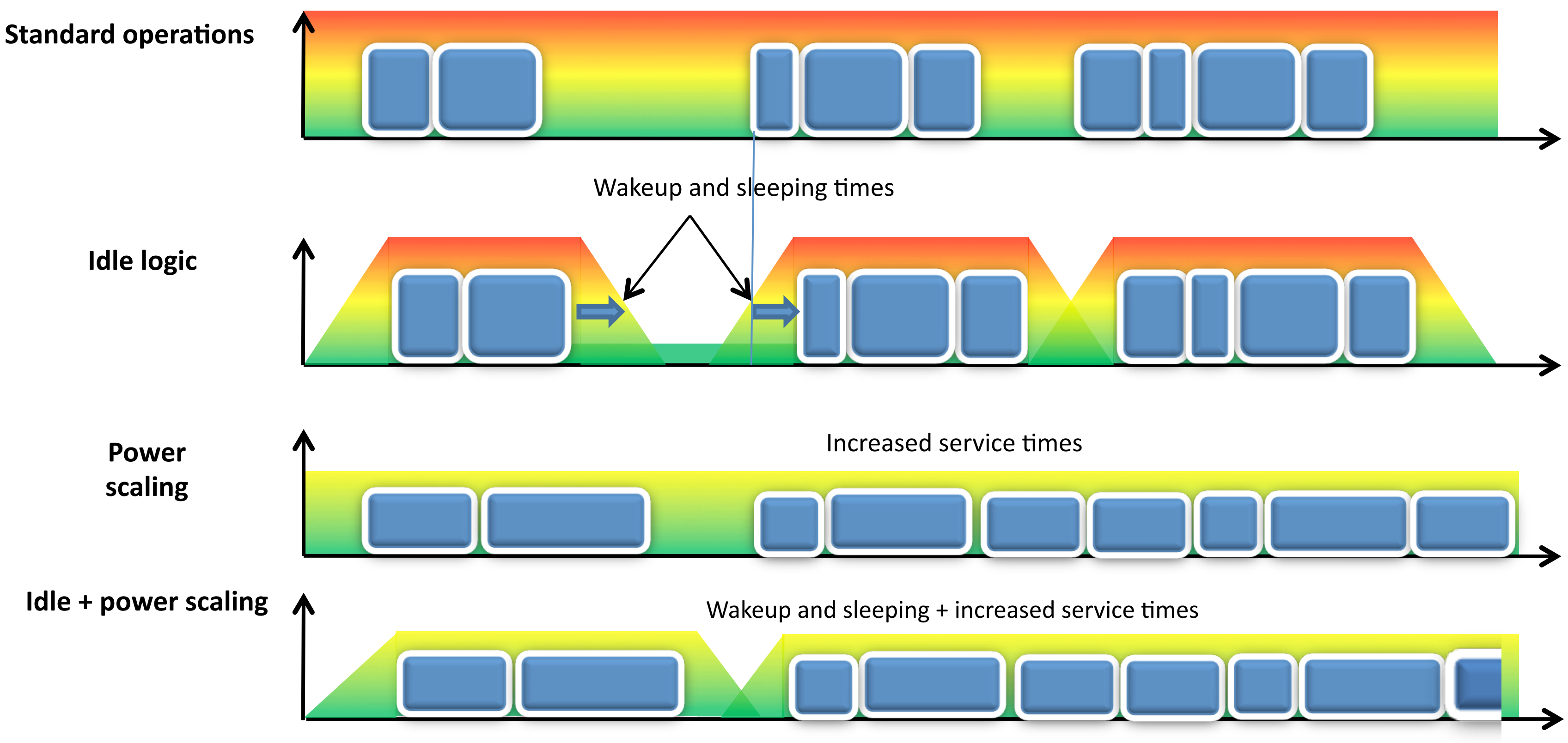


Source: The ECONET Consortium, "End-user requirements, technology specifications and benchmarking methodologies," Deliverable 2.1.

Dynamic Adaptation

- The dynamic adaptation of network/device resources is designed to modulate capacities of packet processing engines and of network interfaces, to meet actual traffic loads and requirements.
- This can be performed by using two power-aware capabilities, namely, dynamic voltage scaling and idle logic, which both allow the dynamic trade-off between packet service performance and power consumption.

Dynamic Adaptation



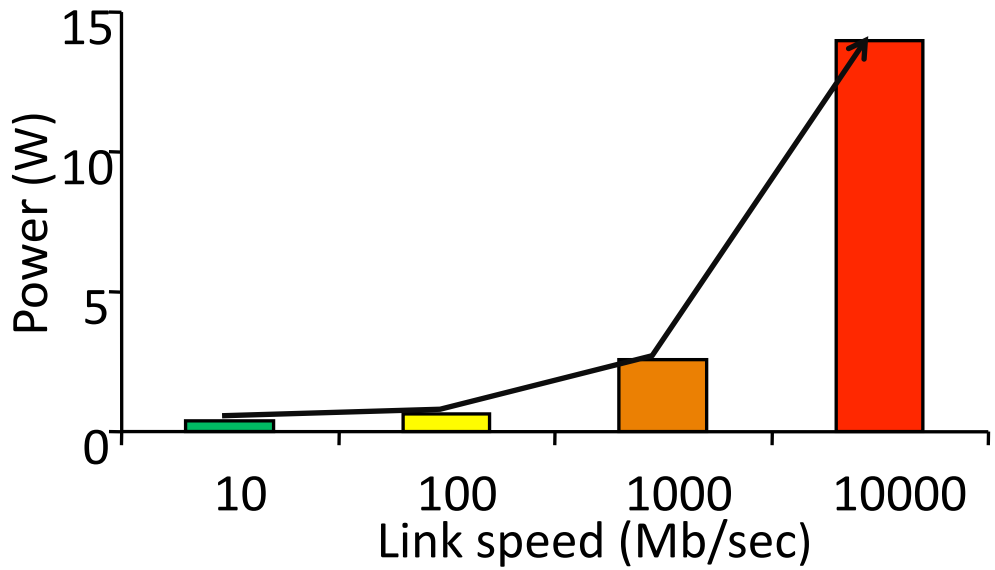
Dynamic Adaptation

IEEE 802.3 az

- Green Ethernet (IEEE 802.3 az):
  - First version: Adaptive Link Rate proposed by Christensen and Nordman

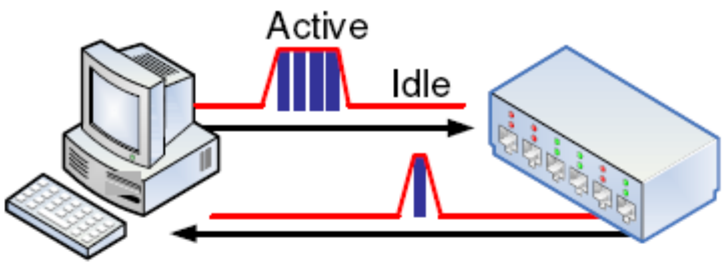
Background:

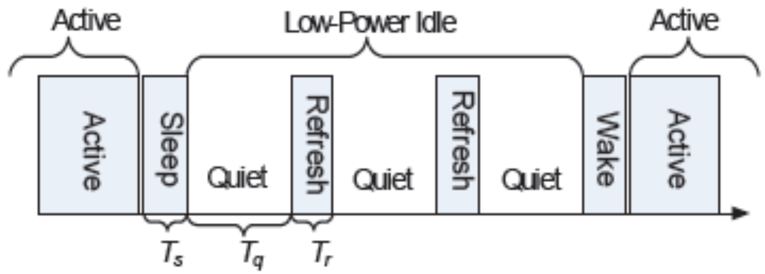
Typical Power Consumption of Ethernet interfaces at different link speeds



IEEE 802.3 az

- Final Version: based on the "low power idle" concept, proposed by Intel.
  - **Idea:** transmit data at the maximum speed, and put the link to sleep when it is idle.





  - **Effect:** LPI has two transitions for each packet (or block of packets) : Link wake-up and sleep
    - LPI can possibly be asynchronous (one direction awake, the other asleep)
    - Retraining can be done via periodic on intervals (if no packets are being sent)
    - LPI requires no complicated handshaking

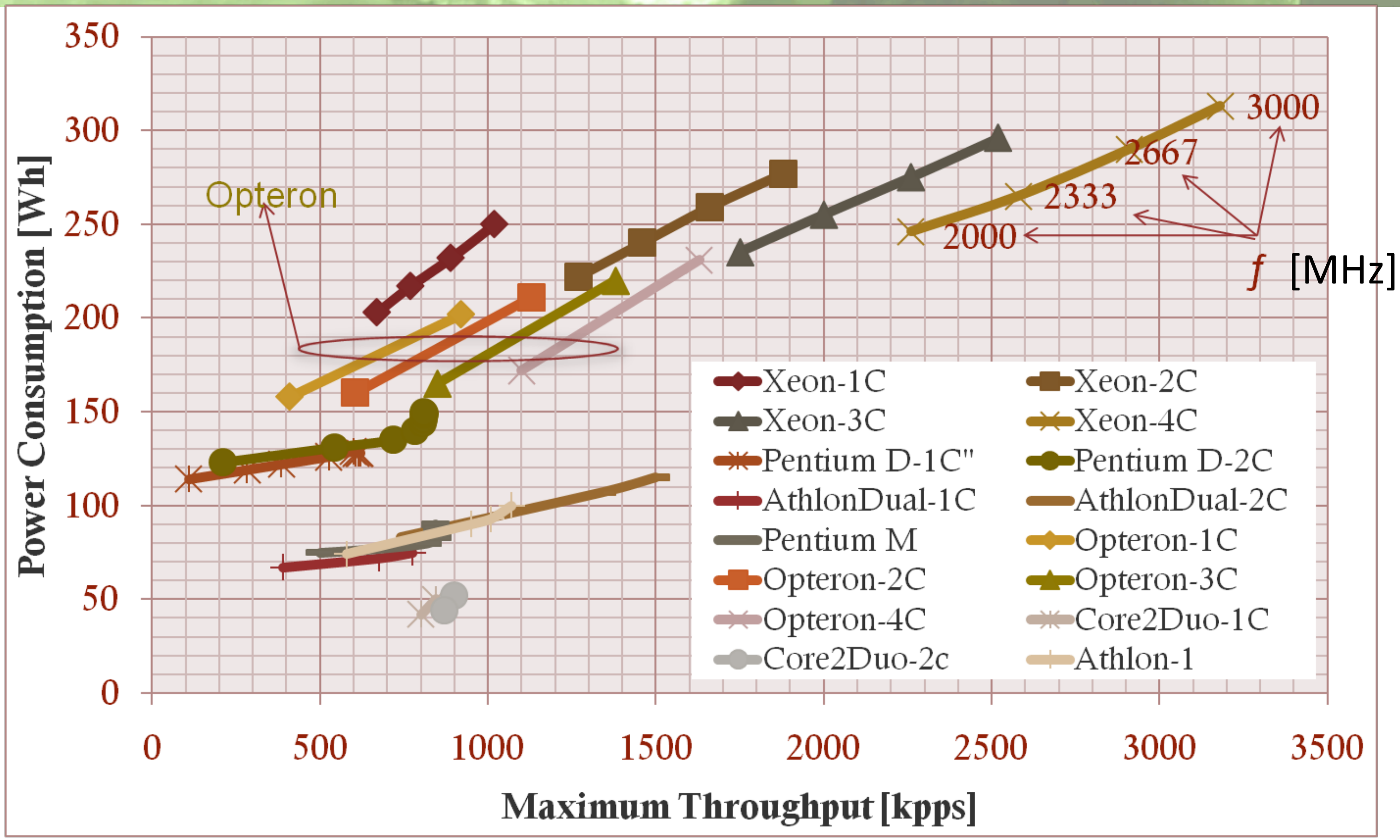
SW Routers & ACPI

- In PC-based devices, the Advanced Configuration and Power Interface (ACPI) provides a standardized interface between the hardware and the software layers.
- ACPI introduces two power saving mechanisms, which can be individually employed and tuned for each core:
  - Power States (C-states)
    - C_0 is the active power state
    - C_1 through C_n are processor sleeping or idle states (where the processor consumes less power and dissipates less heat).
  - Performance States (P-states)

while in the C_0 state, ACPI allows the performance of the core to be tuned through P-state transitions.
P-states allow to modify the operating energy point of a processor/core by altering the working frequency and/or voltage, or throttling the clock.

Dynamic Adaptation

SW Routers & ACPI

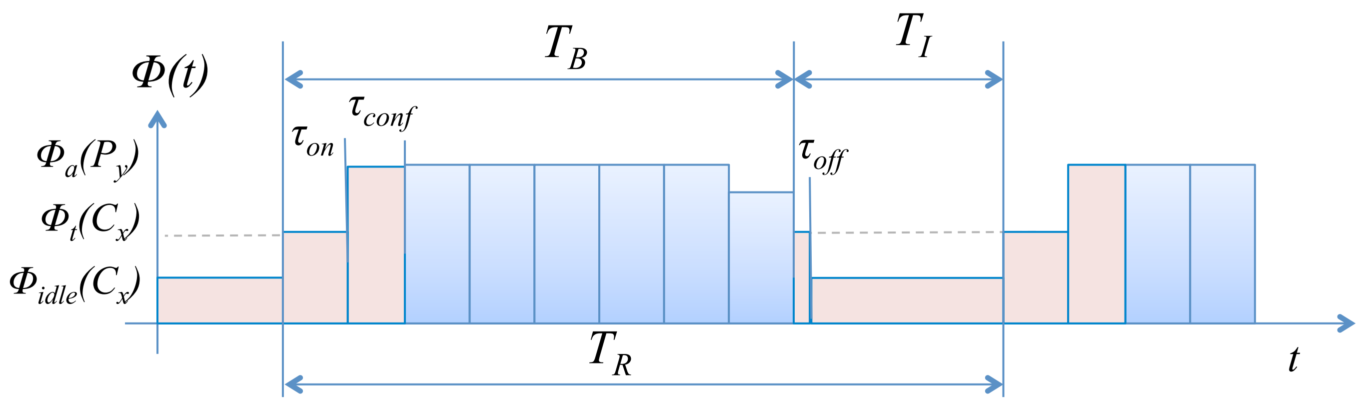


Source: R. Bolla, R. Bruschi, A. Ranieri, “Green Support for PC-based Software Router: Performance Evaluation and Modeling”, *Proc. IEEE ICC 2009*, Dresden, Germany, June 2009. Best Paper Award.

Understanding the Power-Performance Tradeoff

Modeling and Control

- We recently proposed a simple model, based on classical queueing theory, which allows representing the trade-off between energy and network performance in the presence of both AR and LPI capabilities.
- The model is aimed at describing the behaviour of packet processing engines.
- It is based on a $M^x/D/1/SET$ queueing system.

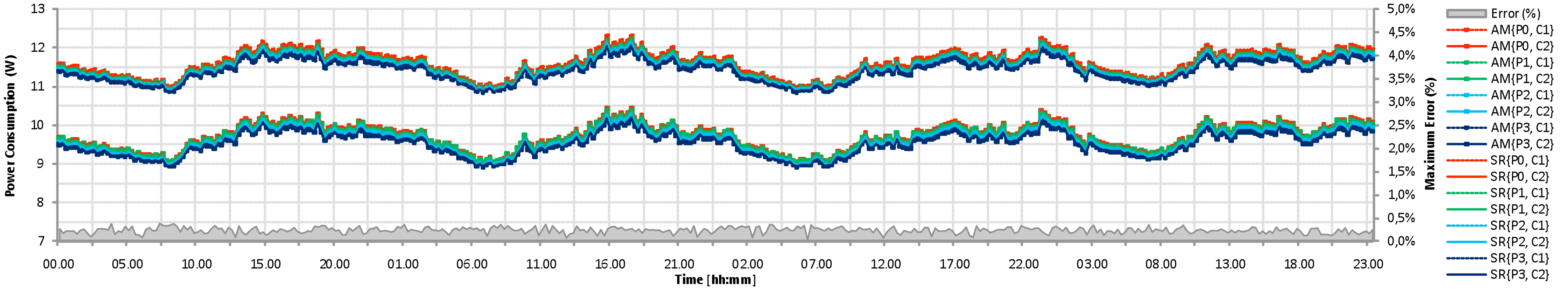


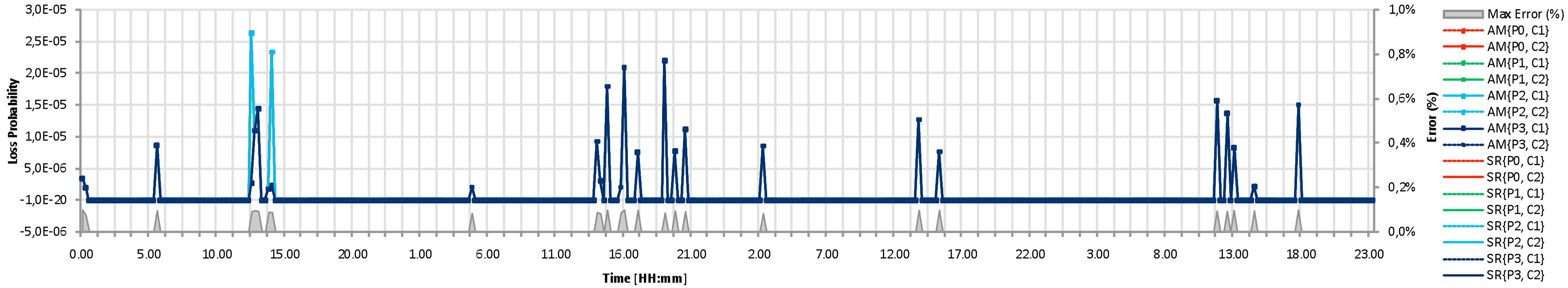
Source: R. Bolla, R. Bruschi, A. Carrega, F. Davoli, "Green Network Technologies and the Art of Trading-off," *Proc. IEEE INFOCOM 2011 Workshop on Green Communications and Networking*, Shanghai, China, April 2001, pp. 301-306.

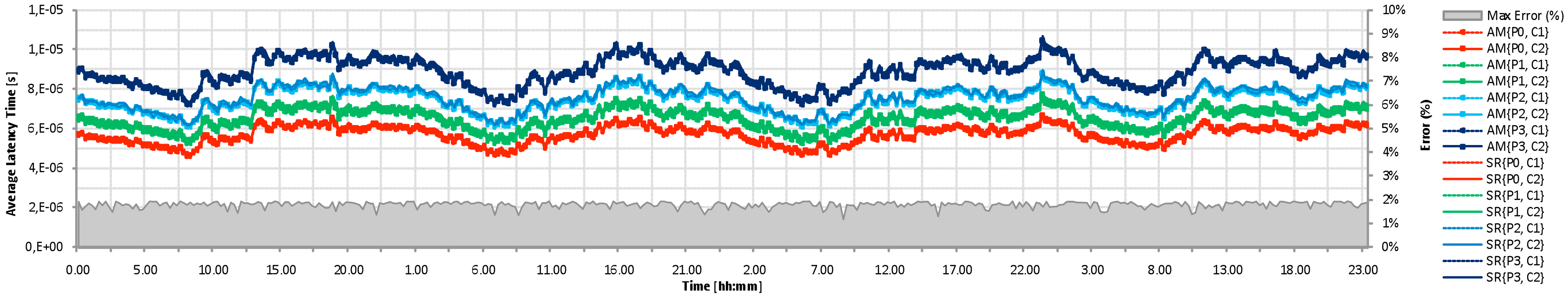
Dynamic Adaptation

Understanding the Power-Performance Tradeoff

Modeling and Control







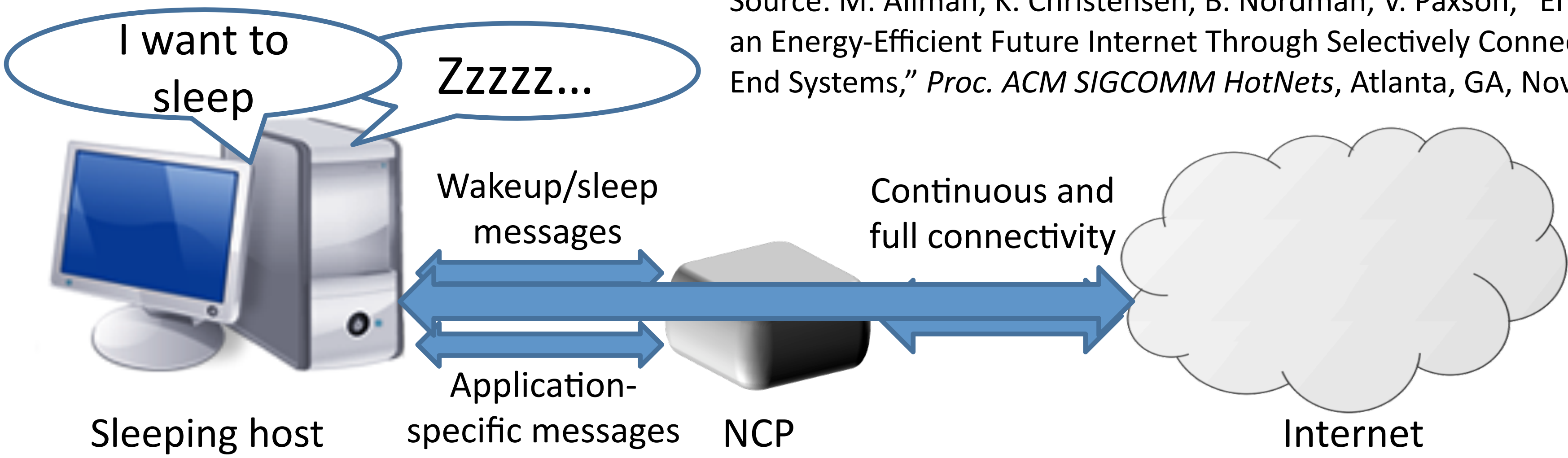
Sleeping/standby

- Sleeping/standby approaches are used to smartly and selectively drive unused network/device portions to low standby modes, and to wake them up only if necessary.
- However,
  - since today's networks and related services and applications are designed to be continuously and always available,
  - standby modes have to be explicitly supported with special techniques able to maintain the "network presence" of sleeping nodes/components.

Proxying the Network Presence

- **Scenario**: networked hosts (PCs, consumer electronics, etc.);
- **Problem**: when an end-host enters standby mode, it freezes all network services, and it is not able to maintain its network presence;
- **Idea**: introduce a Network Connection Proxy (NCP), which is devoted to maintain the network presence of sleeping hosts.

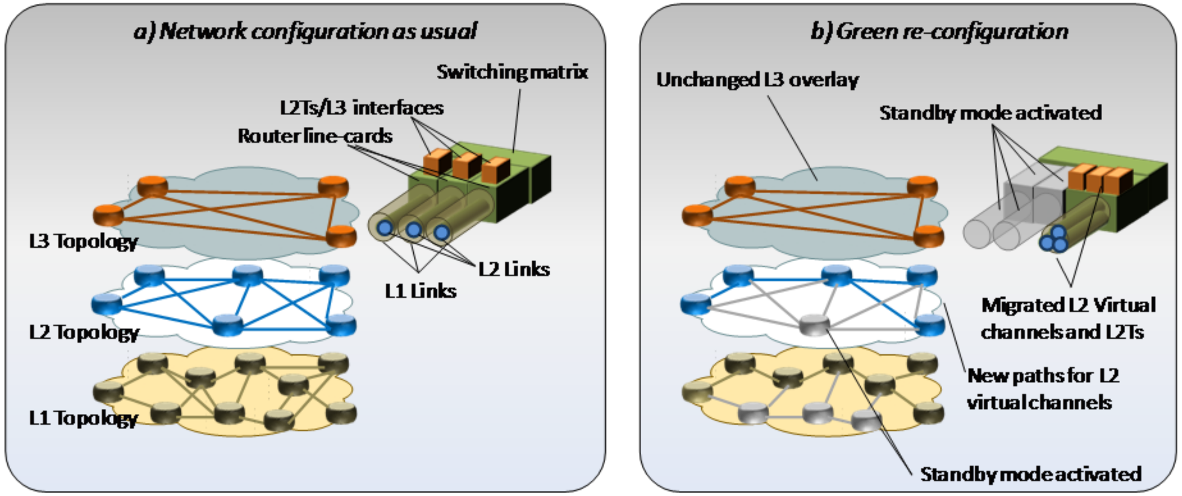
Source: M. Allman, K. Christensen, B. Nordman, V. Paxson, "Enabling an Energy-Efficient Future Internet Through Selectively Connected End Systems," *Proc. ACM SIGCOMM HotNets*, Atlanta, GA, Nov. 2007.



Sleeping/standby

Proxying the Network Presence

- **Scenario**: Core Networks
- **Idea**: put links, interfaces and part of nodes (e.g., line-cards) to sleep
- **Problem**: Network stability, convergence times at multiple levels (e.g., MPLS traffic engineering + IP routing)



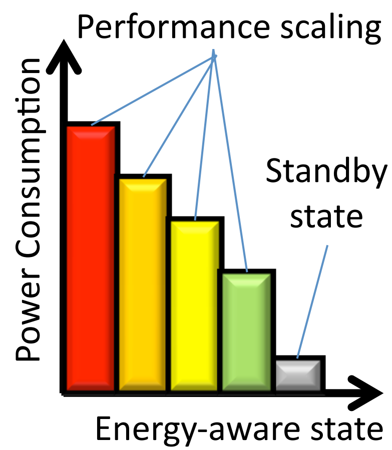
Source: R. Bolla, R. Bruschi, A. Cianfrani, M. Listanti, "Putting Backbone Networks to Sleep," *IEEE Network Magazine*, Special Issue on "Green Networking", vol. 25, no. 2, pp. 26-31, March/April 2011.

Proxying the Network Presence

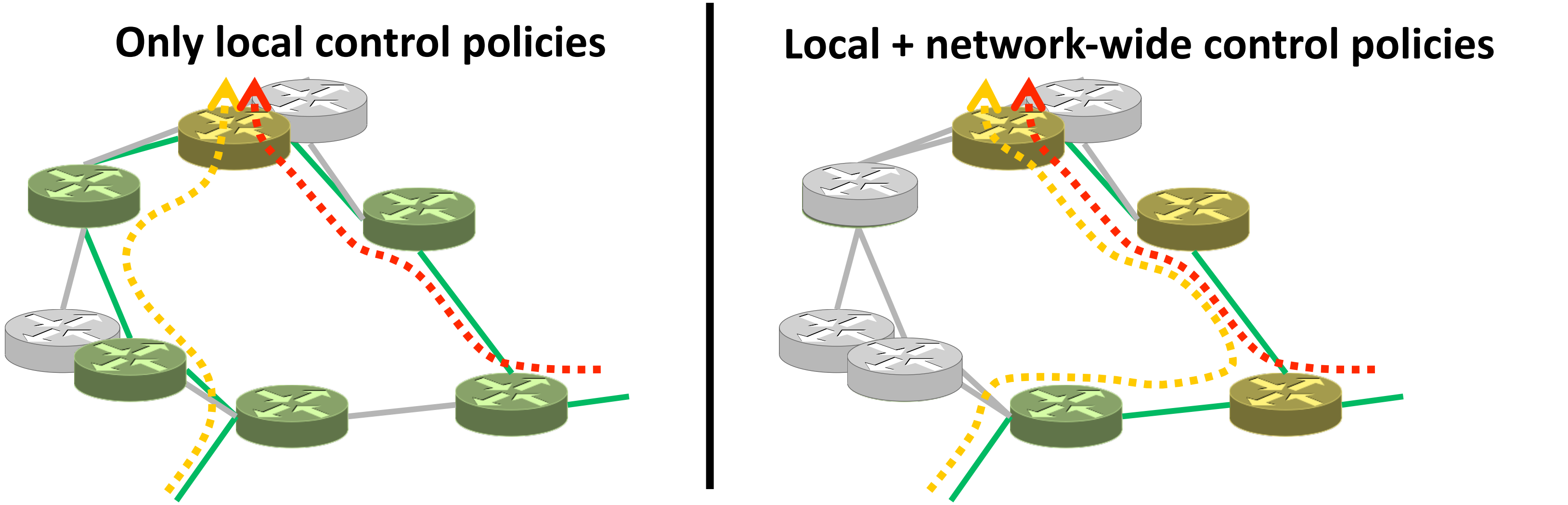
- **Solution**: they exploited two features already present in today's networks and devices:
  - network resource virtualization
  - modular architecture of network nodes.
- This approach allows to:
  - Put physical resources to sleep (e.g., links, linecards, etc.);
  - Move the logical entities working on physical elements going to sleep, to other physical elements on the device.
- If suitable L2 protocols are used, the complexity of standby management can be hidden from the IP layer, and totally managed inside traffic engineering procedures.

Green network-wide control: traffic engineering and routing

- **Standby states have usually much lower energy requirements than active states.**
- Network-wide control strategies (i.e., routing and traffic engineering) give the possibility of moving traffic load among network nodes.
- **When a network is under-utilized, we can move network load on few “active” nodes, and put all the other ones in standby.**
  - Different network nodes can have heterogeneous energy capabilities and profiles.
- Recent studies, obtained with real data from Telcos (topologies and traffic volumes) suggested that network-wide control strategies could cut the overall energy consumption by more than 23%.



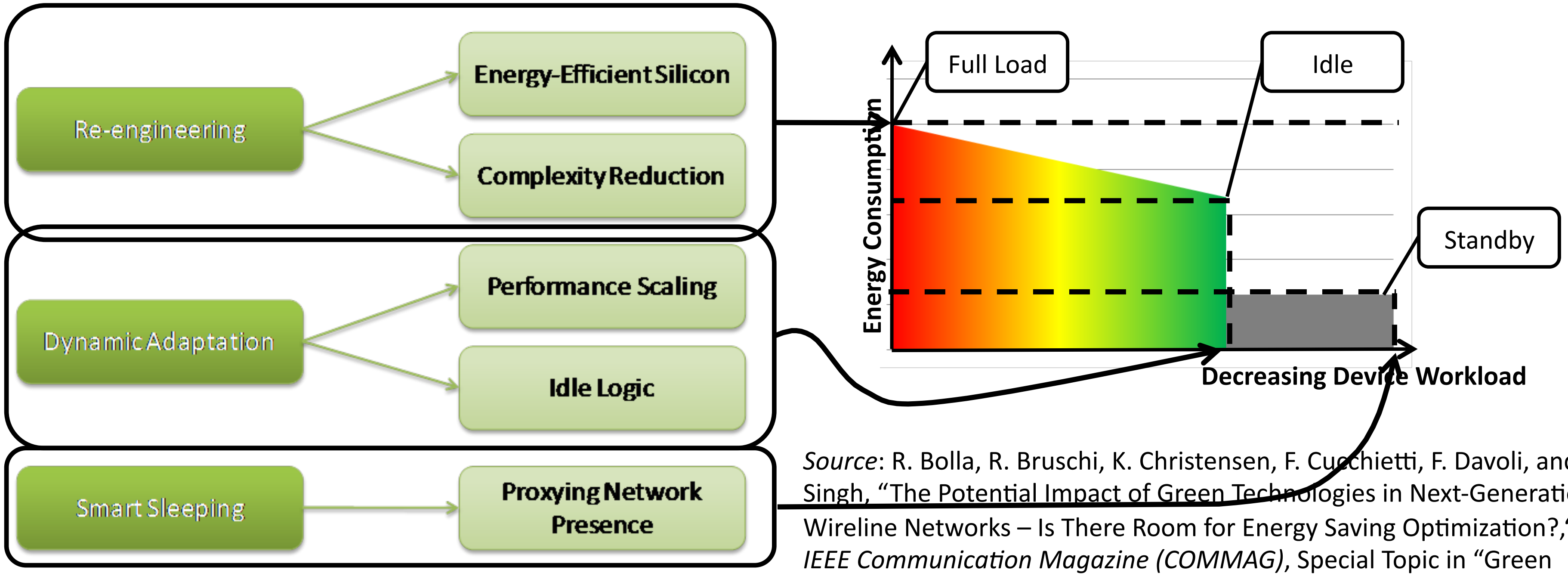
Green network-wide control: traffic engineering and routing



Once network devices will include energy management primitives, further energy reduction will be possible by moving traffic flows among the network nodes, in order to minimize the energy consumption of the entire infrastructure. This is definitely a point of contact between wired and wireless, and where also energy-aware integration with computing resources can take place.

Potential Impact on the Wired Network

- The previously mentioned green technologies allow designing new-generation network devices characterized by “energy profiles”



Source: R. Bolla, R. Bruschi, K. Christensen, F. Cucchietti, F. Davoli, and S. Singh, “The Potential Impact of Green Technologies in Next-Generation Wireline Networks – Is There Room for Energy Saving Optimization?,“ *IEEE Communication Magazine (COMMAG)*, Special Topic in “Green Communications,“ vol. 49, no. 8, pp. 80-86 Aug. 2011 .

Potential Impact on the Wired Network

2015-2020 network forecast: device density and energy requirements

(example based on Italian network)

	power consumption (Wh)	number of devices	overall consumption (GWh/year)
Home	10	17,500,000	1,533
Access	1,280	27,344	307
Metro/transport	6,000	1,750	92
Core	10,000	175	15

Sources: 1) BroadBand Code of Conduct V.3 (EC-JRC) and "inertial" technology improvements to 2015-2020 (home and access cons.)
2) Telecom Italia measurements and evaluations (power consumption of metro/core network and number of devices)

Network load statistics and topology data

Home/Access

customers per DSLAM	640
average usage of a network access	30%
average traffic when a user is connected	10%

Metro/Transport/Core

redundancy degree for metro/transport devices	13%
redundancy degree for core devices	100%
redundancy degree of metro/transport device links	100%
redundancy degree of core device links	50%
average traffic load in metro networks	40%
average traffic load in core networks	40%

Source: forecast based on: carrier grade topologies; traffic analysis and indicators (ETSI TR 102530, ODYSSEE) and projected traffic load.

target

standby efficiency	85%
performance scaling efficiency	50%
network-wide control efficiency	20%
air cooling/power supply efficiency	15%

Sources: BroadBand Code of Conduct V.3 (EC-JRC) and technology improvements to 2015-2020.

Device internal sources of energy consumption

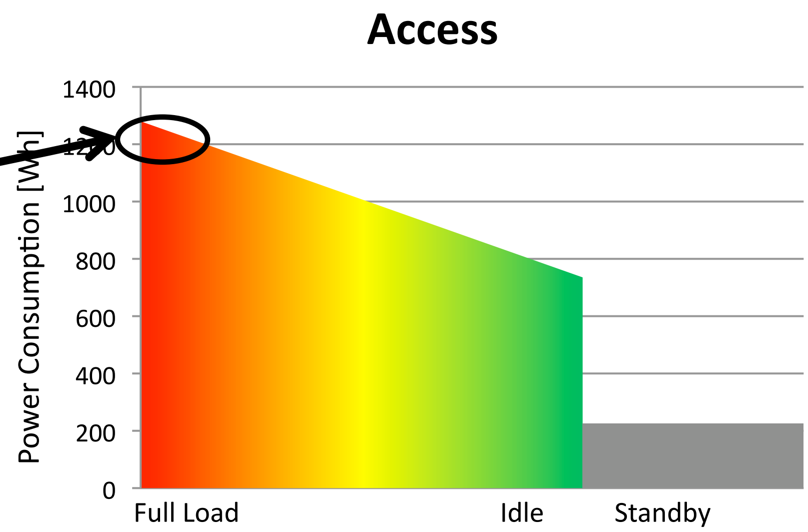
	Data Plane	Control Plane	Cooling/Power Supply
Home	79%	3%	18%
Access	84%	3%	13%
Metro/transport	73%	13%	14%
Core	54%	11%	35%

Sources: Information from vendors.

The Potential Impact

2015-2020 network forecast: device density and energy requirements

	power consumption (Wh)	number of devices	overall consumption (GWh/year)
Home	10	17,500,000	1,533
Access	1,280	27,344	307
Metro/transport	6,000	1,750	92
Core	10,000	175	15



Network load statistics and topology data

average usage of a network access	30.00%
average traffic when a user is connected	10.00%

ECONET target

standby efficiency	1 - 0.85
performance scaling efficiency	1 - 0.50
network-wide control efficiency	0.20
air cooling/power supply efficiency	1 - 0.15

Device internal sources of energy consumption

	Data Plane	Control Plane	Cooling & Power Supply
home	95%	3%	2%
access	80.0%	3%	17%
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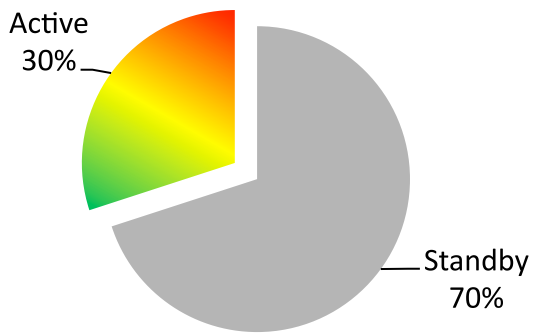

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X

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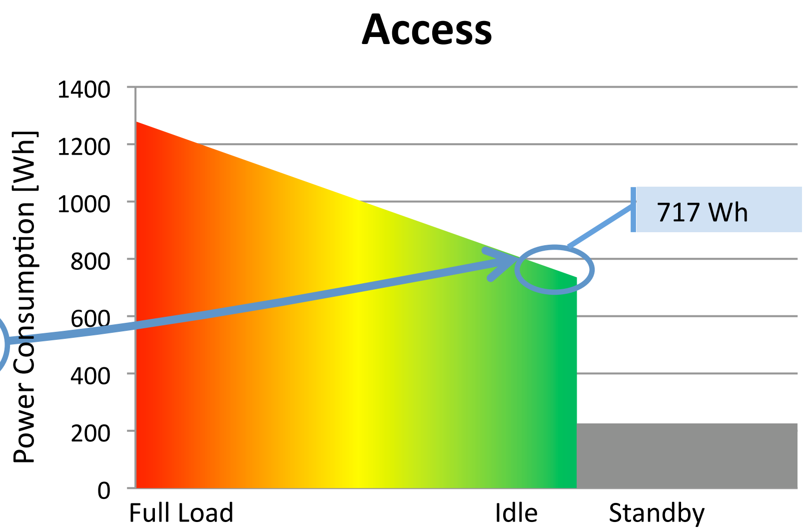
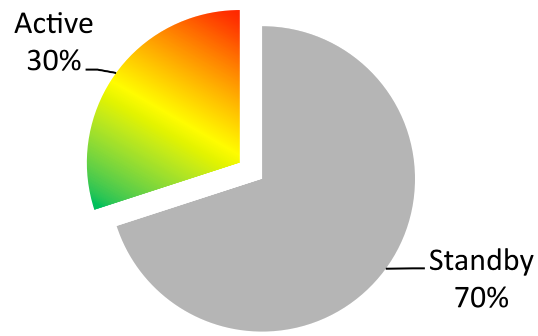
	Data Plane	Control Plane	Cooling & Power Supply
home	95%	3%	2%
access	80.0%	3%	17%
metro/transport	73%	[illegible]	14%
core	54%	[illegible]	35%

Working at 100%





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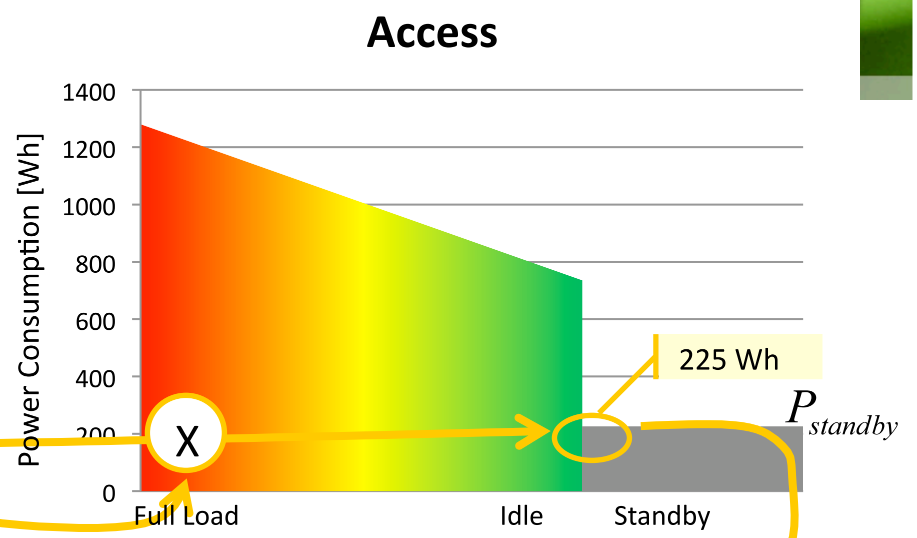
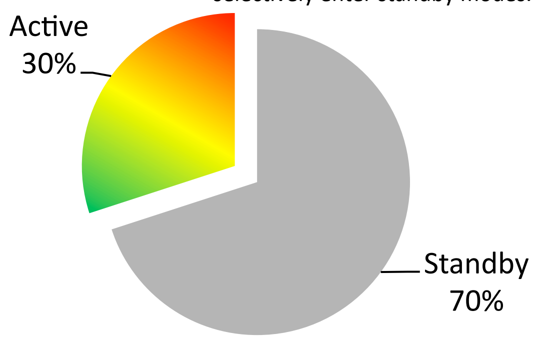


This value of standby power consumption refers to the case where all cable-connected users are not active.
In the reality the ECONET technologies will enable access devices' ports to selectively enter standby modes.



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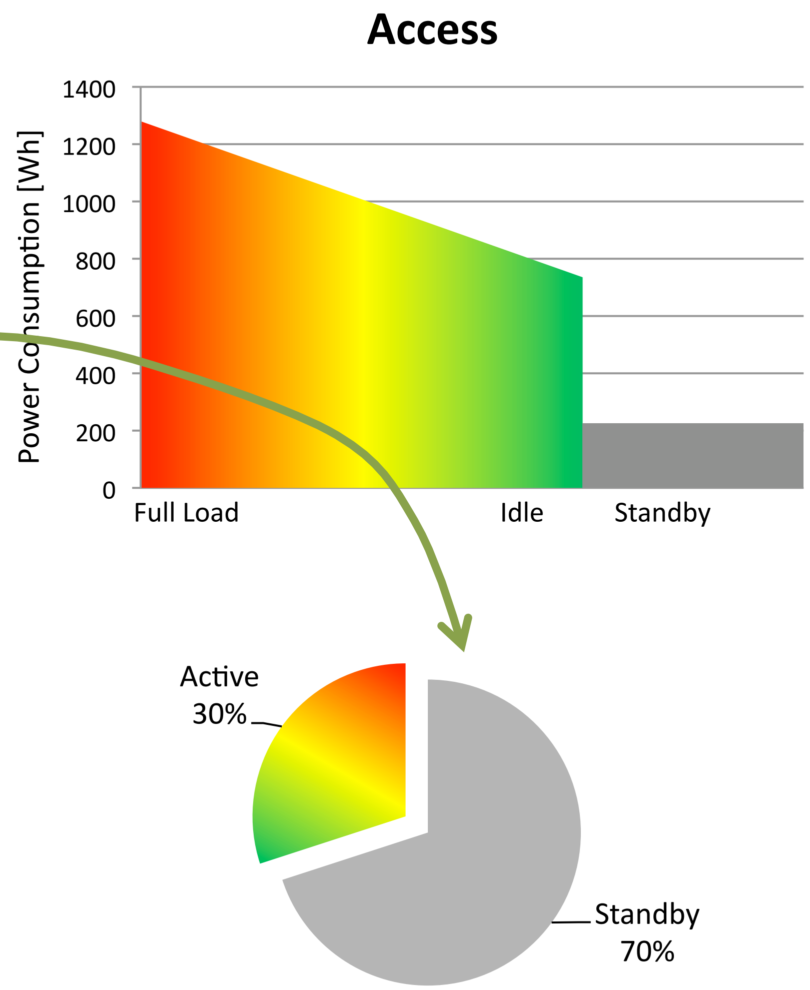

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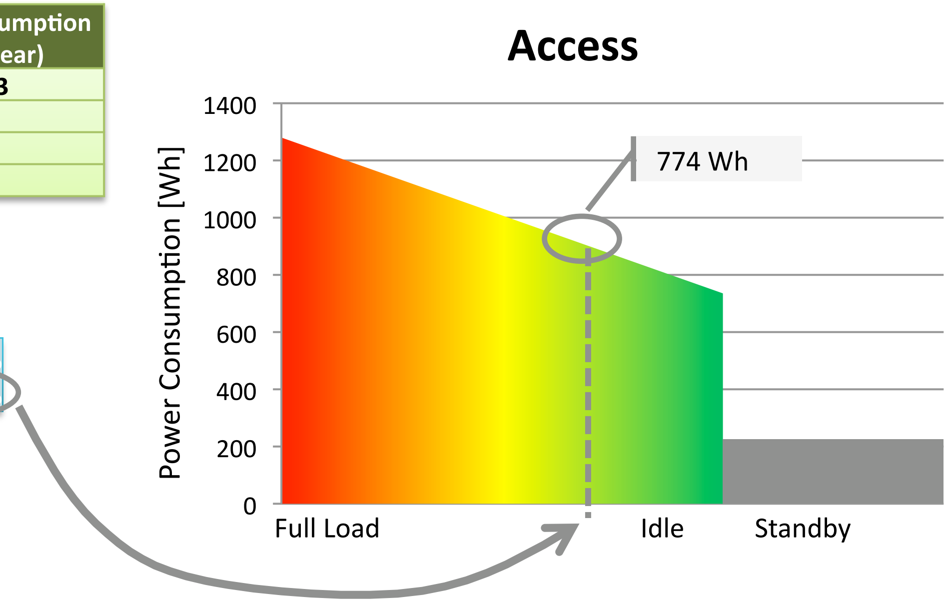

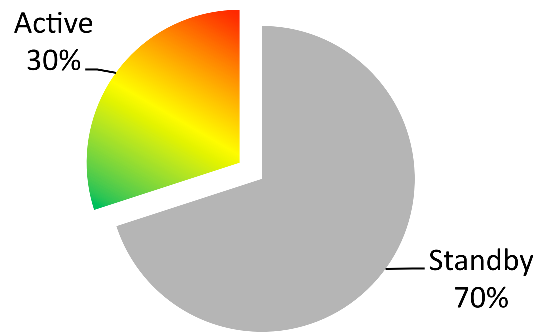

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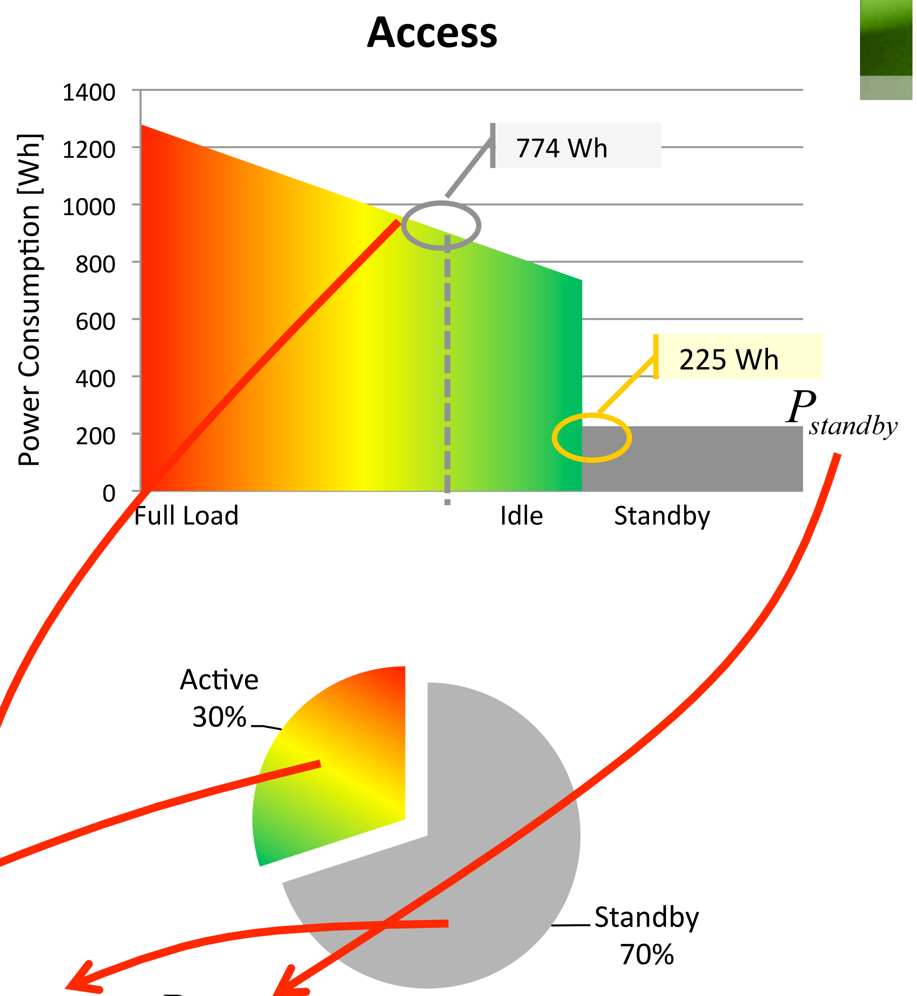
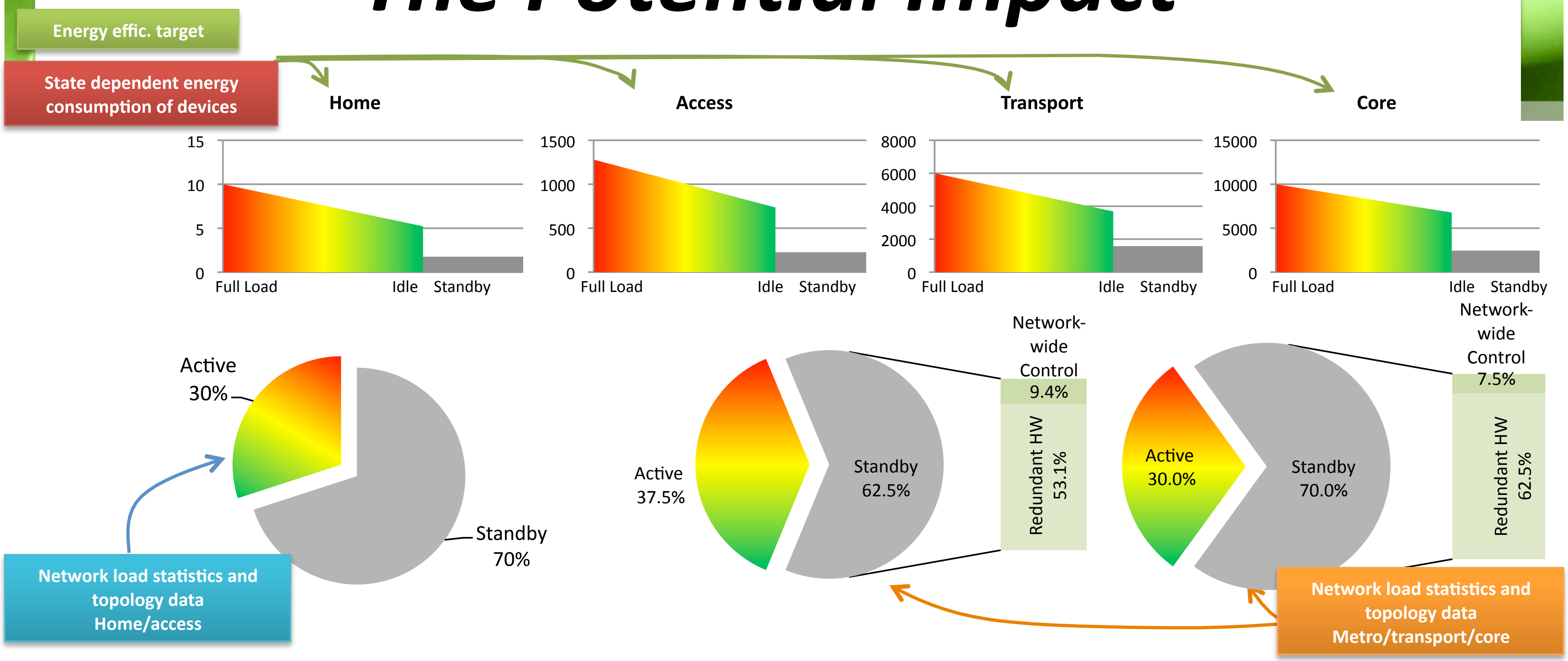


$$\widetilde{P} = \varphi_{active}\widetilde{P}_{active} + \varphi_{standby}P_{standby}$$

	Full load power consumption (W)	Number of devices (relative)	Overall full consumption (GWh /year)	Gains	Energy gains with ECONET technologies (GWh / year)
Access	1,280	27,344	307	**70%**	213

The Potential Impact



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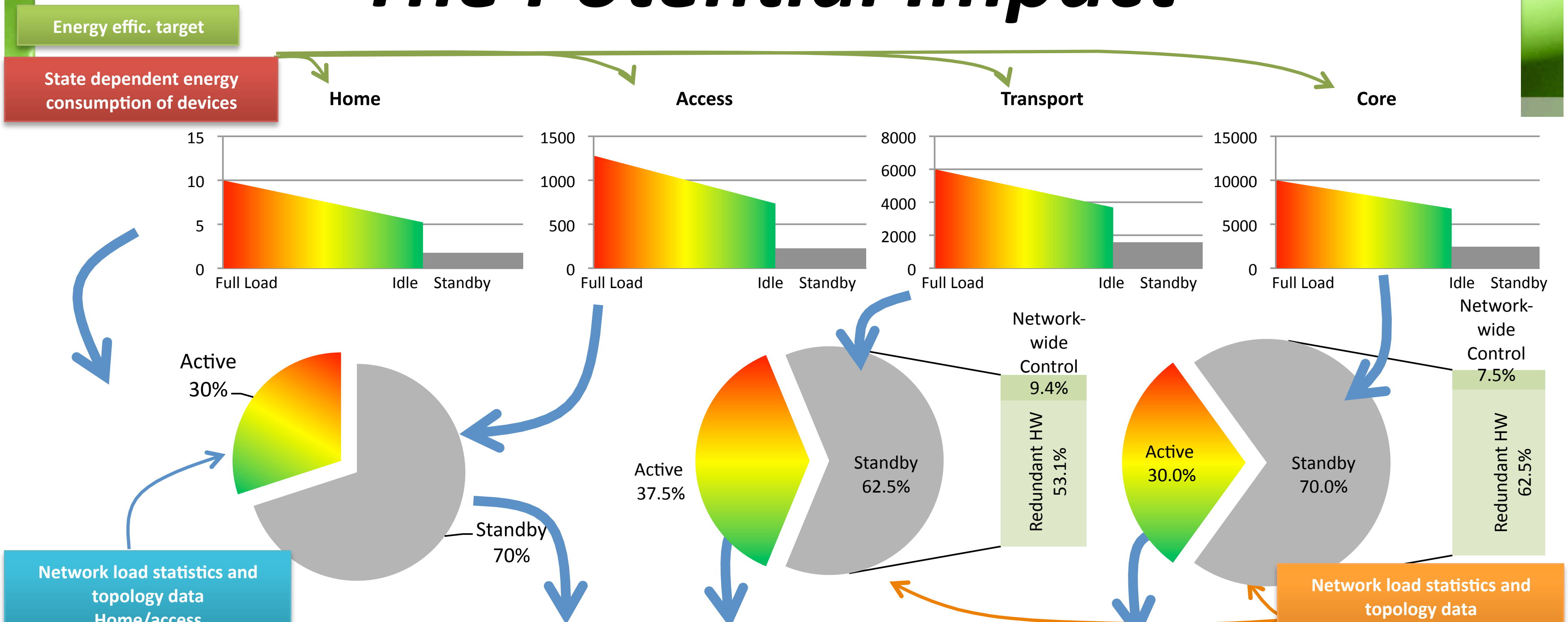


Overall Energy Gains

	full load power consumption (Wh)	number of devices	Overall full consumption (GWh/year)	Gains	Energy gains with ECONET technologies (GWh /year)
Home	10	17,500,000	1533	70%	1060
Access	1,280	27,344	307	70%	213
Metro/transport	6,000	1,750	92	54%	49
Core	10,000	175	15	58%	9
			Overall gain	**68%**	

Total BAU [GWh / year] 1947	**Total ECONET gains [GWh / year] 1331**

Customers' savings	**1060 GWh/year**
Networks' savings	**270 GWh/year**

Per-customer money savings →

	Direct (Home)	Indirect (Telco)	Total
At today's energy cost	12€	2€	14€
At 2020 energy cost*	30€	6€	36€

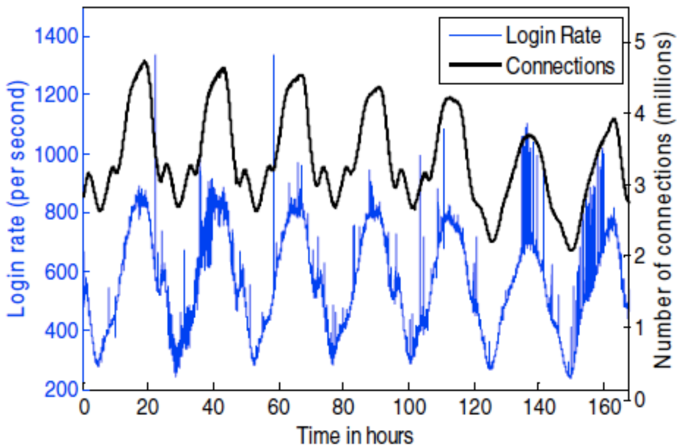
* Based on past 5-year trends in energy costs after inflation

A few words on Data Centres and Clouds

Energy Component	Service type	Software as a Service	Storage as a Service	Processing as a Service
Transport	Public	High frame rates	Always	Medium to high encodings per week
	Private	Never	High download rates	Never
Storage	Public	Never	Low download rates	-
	Private	Never	Low download rates	-
Processing	Public	Few users per server	Never	Medium to high encodings per week
	Private	Few users per server	High download rates	Medium to high encodings per week

Conditions under which energy consumption is significant in cloud services

Source: J. Baliga, R. W. A. Ayre, K. Hinton, R.S. Tucker, "Green Cloud Computing: Balancing Energy in Processing, Storage, and Transport," *Proc. IEEE*, vol. 99, no. 1, pp. 149-167, Jan. 2011.



Energy consumption depends on services, load varies, and resources are overprovisioned

Load variation of Messenger services, normalized to 5 million users and 1400 users/s login rate.

Source: J. Liu, F. Zhao, X. Liu, and W. He, "Challenges towards elastic power management in Internet data centers, in *Proc. IEEE Int. Conf. Distrib. Comput. Syst. Workshops*, Los Alamitos, CA, 2009, pp. 65–72.

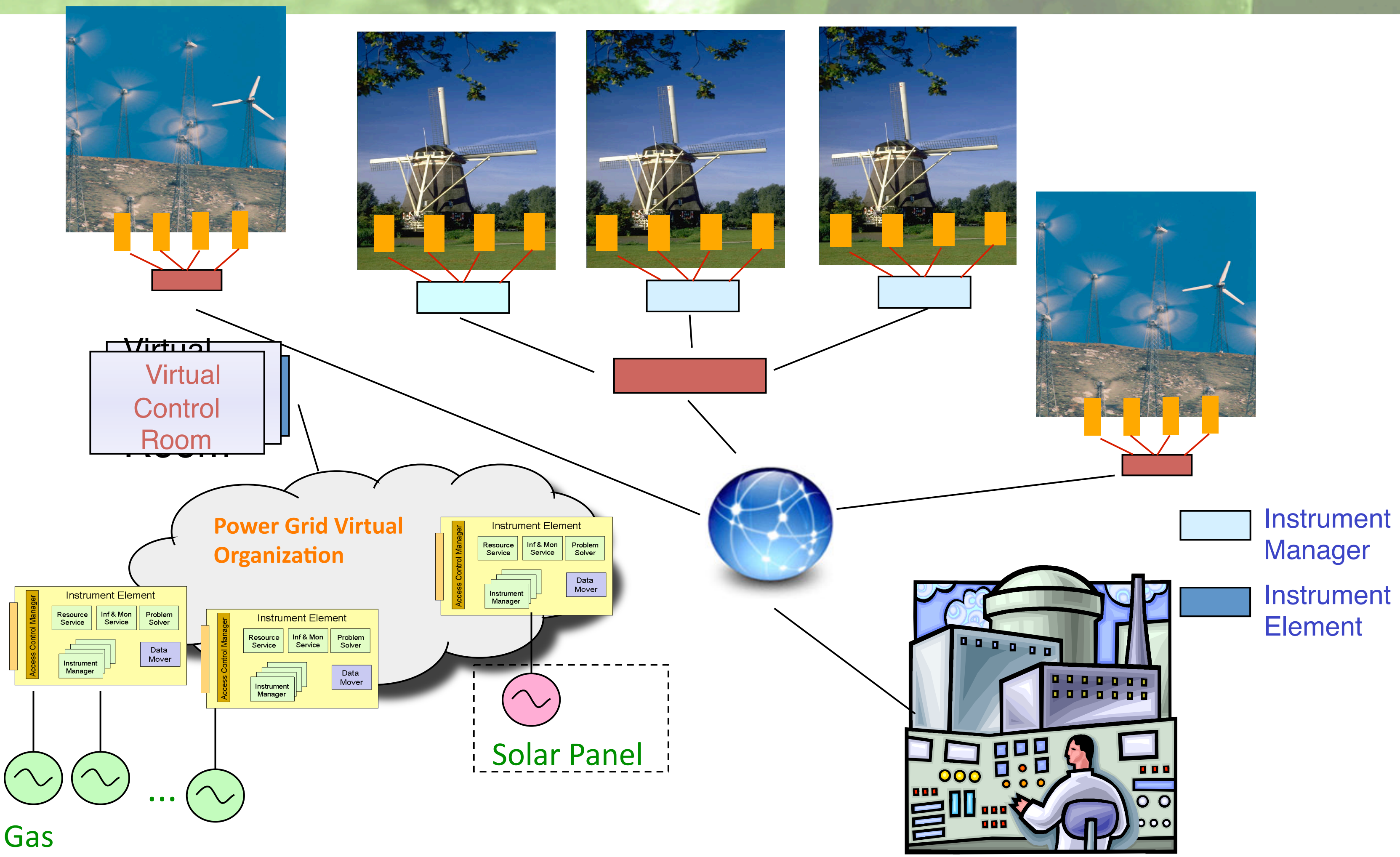
A few words on Data Centres and Clouds

Power Management technologies developed:

- Device architecture (multi-core)
- Dynamic Voltage and Frequency Scaling
- Sleep (ON/OFF) Scheduling
- Virtual Machine Management
- Cooling Management

Source: *Source*: J. Liu, F. Zhao, X. Liu, and W. He, "Challenges towards elastic power management in Internet data centers, in *Proc. IEEE Int. Conf. Distrib. Comput. Syst. Workshops*, Los Alamitos, CA, 2009, pp. 65–72.

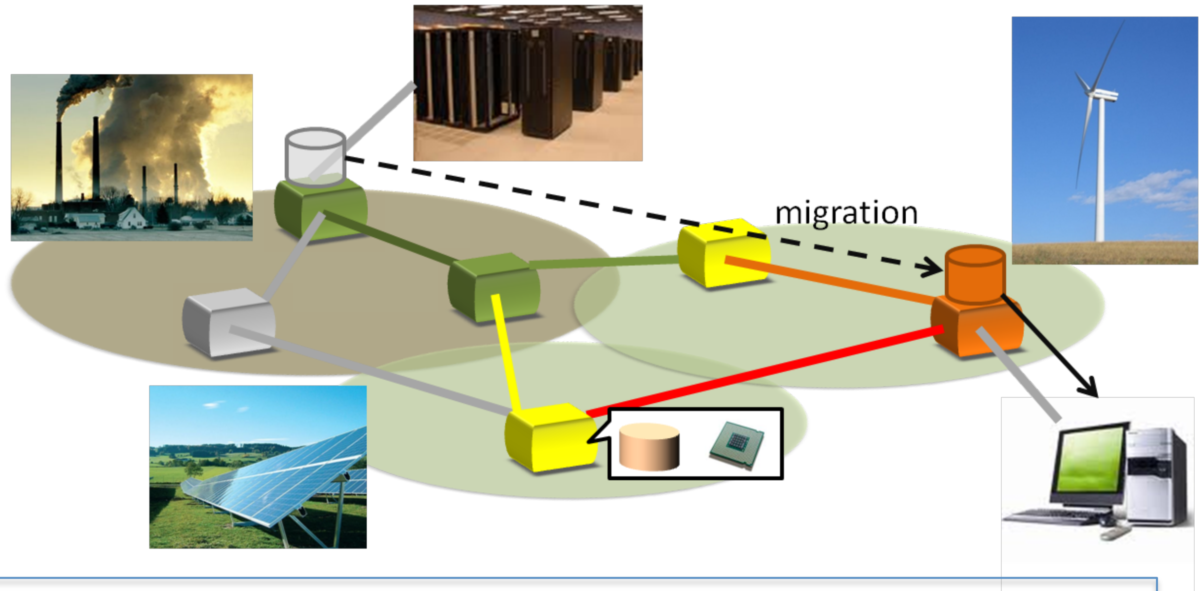
The Smart Power Grid



Linking Green Power Sources & ICT Resources

ICT energy consumption optimization by dynamically managing the computational, storage and networking resources being aware of green energy production:

- Localize and bind computational, storage and networking resources and (green) energy sources.
- Migrate functionalities, tasks and contents to optimize energy efficiency.
- Adapt the energy profiles of devices (smart standby and power modulation) according to the network and computational load allocation.



Potential to coordinate resource allocation in data centres, telecommmunication network and Smart Grid (Cross-domain interaction among **telecommunication network**, **grid/cloud**, and **energy production/distribution network**).

An Integrated Playground: eScience

- Many scientific sectors are increasingly based on experimental infrastructures, which can be highly sophisticated and costly
- A few examples:
  - High Energy Physics experiments (particle accelerators – e.g., the LHC, synchrotron light applications, …)
  - Astronomy, Radioastronomy (e.g., eVLBI – *electronic Very Large Baseline Interferometry*)
  - Seismic Engineering (emulation of earthquake effects by means of shake platforms)
  - Oceanografy (marine biology, environmental monitoring)

eScience Applications – Some examples

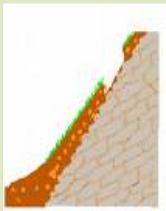
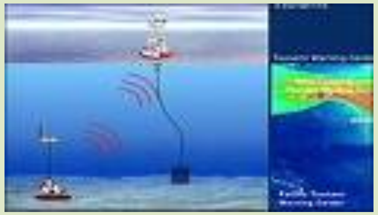
(Large-scale) scientific experiments
High energy particle physics
(Radio-) Telescopes



Remote process control
Accelerator control
(Tele-) Biomedicine
Robotics
Automotive
Electronic microscopes

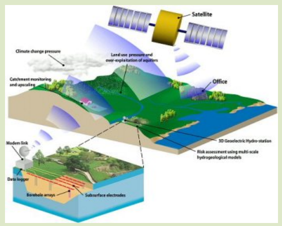




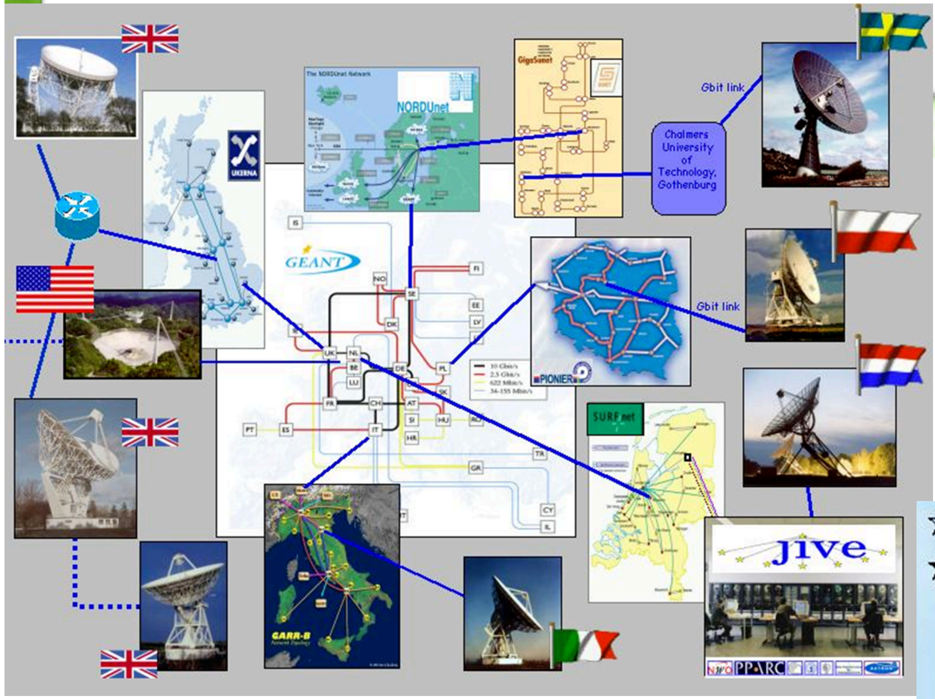




Widely Sparse Instrumentation
Power Grids
Monitoring of the territory
Monitoring of the sea
Geo-hazard prediction
Distributed laboratories
Transportation monitoring
Sensor network



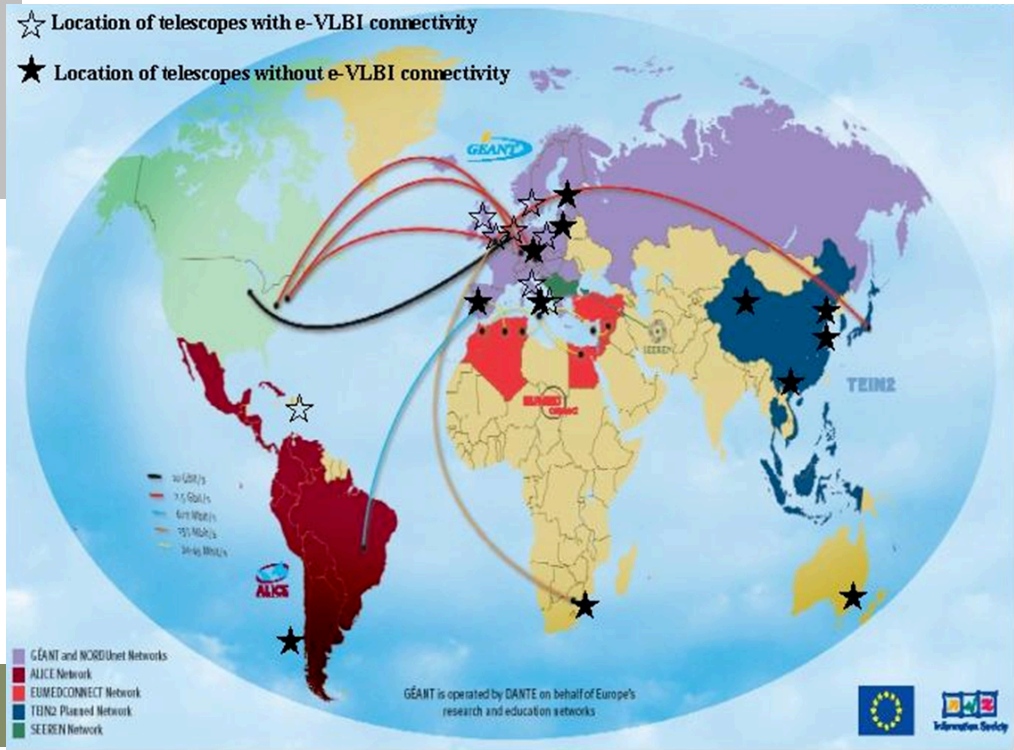



eScience Applications – Some examples



*e*VLBI (JIVE, The Netherlands)

Use of the network for data transfer from distributed radio-telescopes to a correlator



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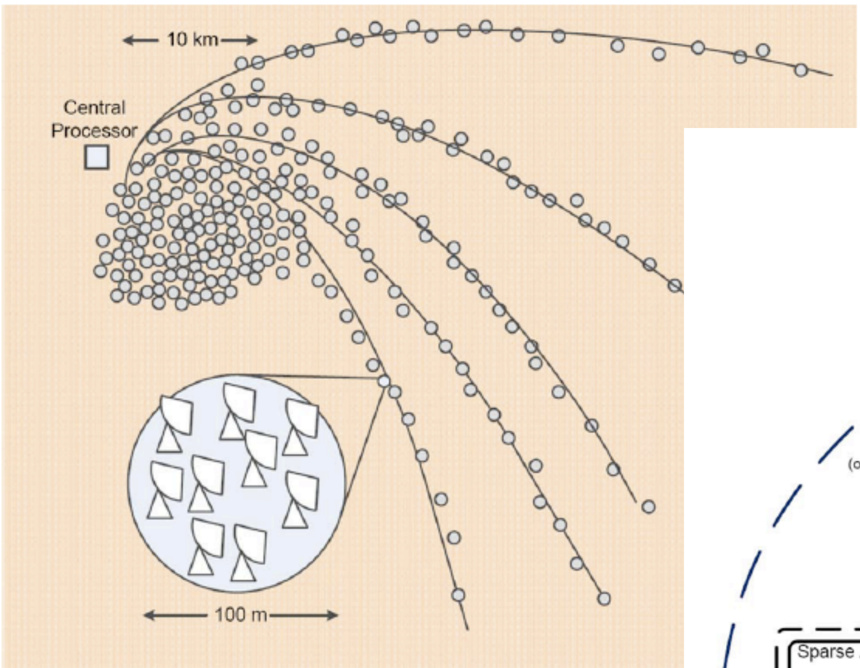
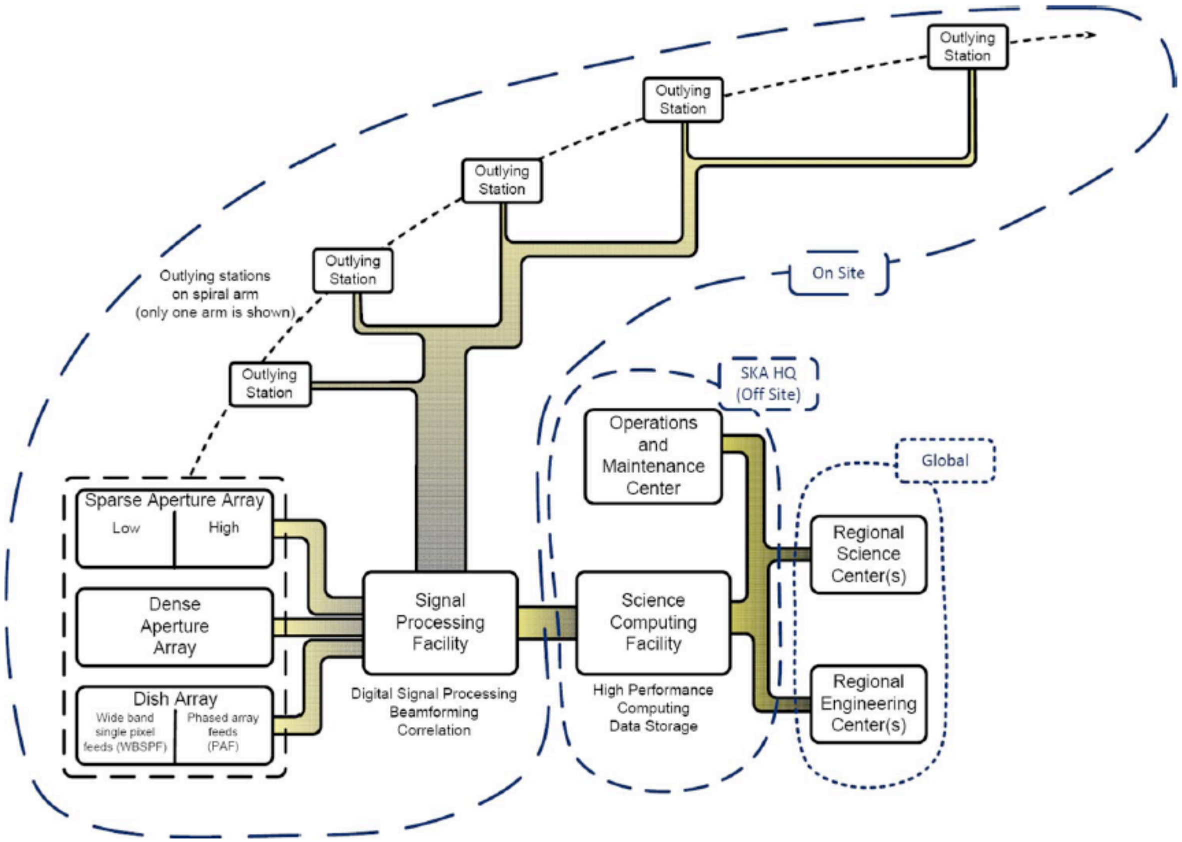
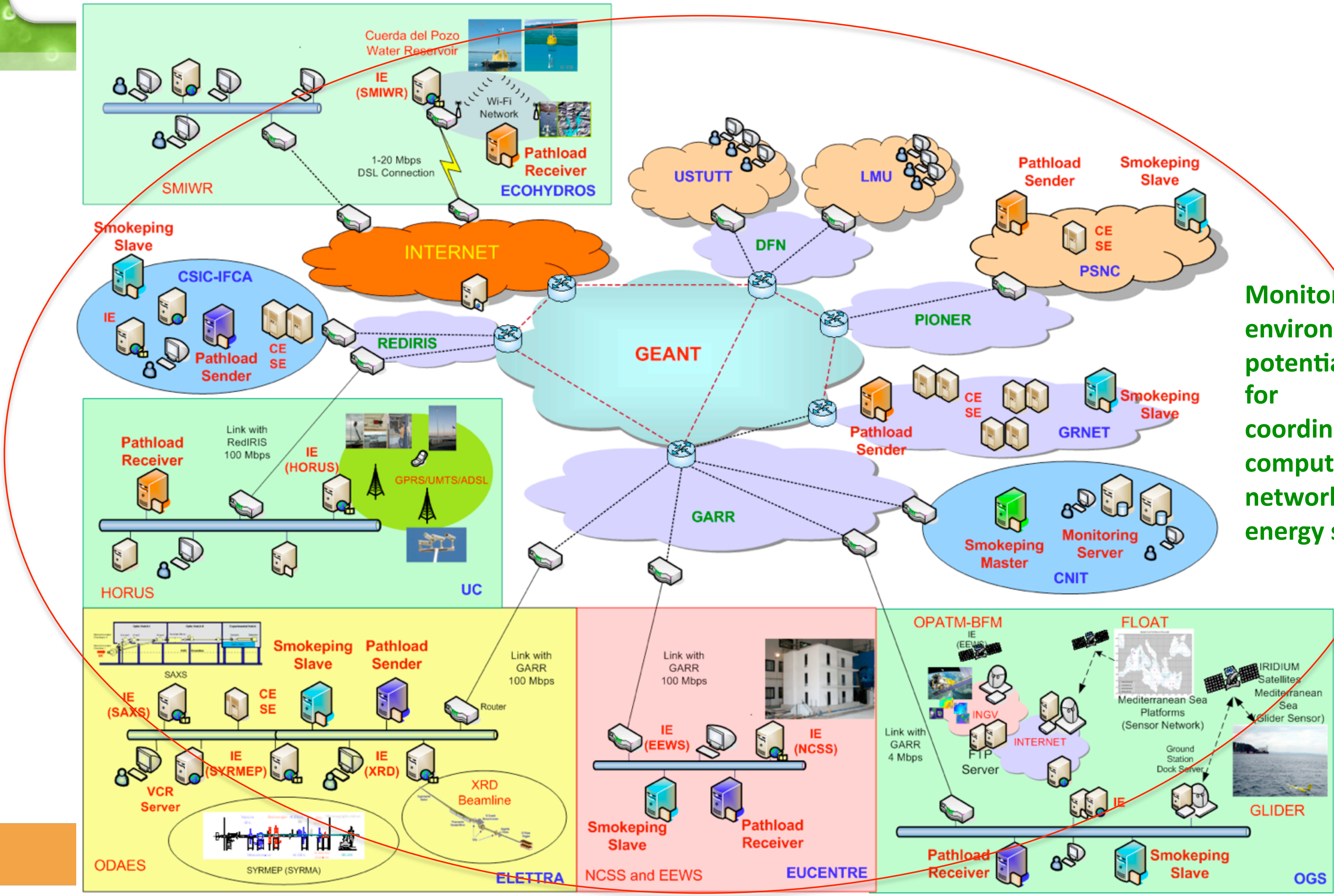


The Square Kilometre Array (**SKA**)

P. E. Dewdney, P. J. Hall, R. T. Schilizzi, T. J. L. W. Lazio, “The Square Kilometre Array,” *Proc. IEEE*, vol. 97, no. 8, pp. 1482-1496, Aug. 2009.



eScience Applications – A networking configuration example (DORII project)



Monitored environment, potential area for coordinatated computation/ networking energy saving

net

Ongoing Projects in the Wired Networking Environment

- **ECONET** (low Energy COnsumption NETworks) – EU FP7 Integrated Project (IP)
- **TREND** (Towards Real Energy-efficient Network Design) – EU FP7 Network of Excellence (NoE)
- **EFFICIENT** (Energy eFFIcient teChnologIEs for the Networks of Tomorrow) – Italian National Project (PRIN 2008)

Ongoing Projects

- **Goals**: re-thinking and re-designing network equipment towards more energy-sustainable and eco-friendly technologies and perspectives.
  - The overall idea is to introduce novel green network-specific paradigms and concepts enabling the reduction of energy requirements of wired network equipment by 50% in the short/mid-term (and by 80% in the long run) with respect to the business-as-usual scenario.
  - To this end, the main challenge is to design, develop and test novel technologies, integrated control criteria and mechanisms for network equipment allowing energy saving by dynamically adapting the device capacities and consumptions to current traffic loads and user requirements.

Ongoing Projects

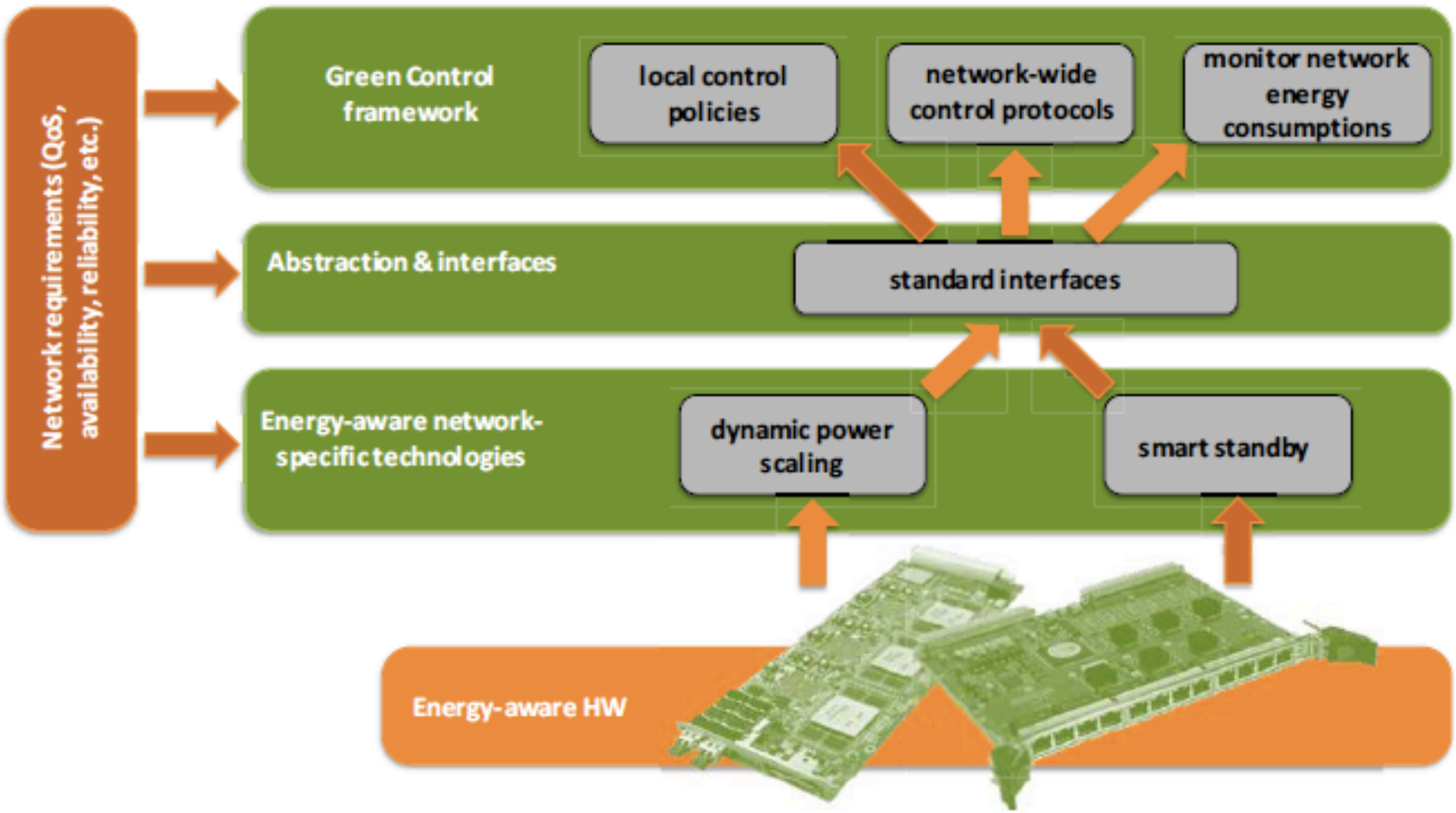
ECO net

Coordinator: **CONSORZIO NAZIONALE INTERUNIVERSITARIO PER LE TELECOMUNICAZIONI, ITALY**

Organisations	
VALTION TEKNILLINEN TUTKIMUSKESKUS	FINLAND
POLITECHNIKA WARSZAWSKA	POLAND
NAUKOWA I AKADEMICKA SIEC KOMPUTEROWA	POLAND
ERICSSON TELECOMUNICAZIONI	ITALY
ALCATEL-LUCENT ITALIA S.P.A.	ITALY
TELECOM ITALIA S.P.A	ITALY
INFOCOM S.R.L.	ITALY
LIGHTCOMM S.R.L.	ITALY
MELLANOX TECHNOLOGIES LTD - MLNX	ISRAEL
ETHERNITY NETWORKS LTD	ISRAEL
DUBLIN CITY UNIVERSITY	IRELAND
NETVISOR INFORMATIKAI ES KOMMUNIKACIOS ZARTKORUEN MUKODO RESZVENYTARSASAG	HUNGARY
LANTIQ DEUTSCHLAND GMBH	GERMANY
GREEK RESEARCH AND TECHNOLOGY NETWORK S.A.	GREECE

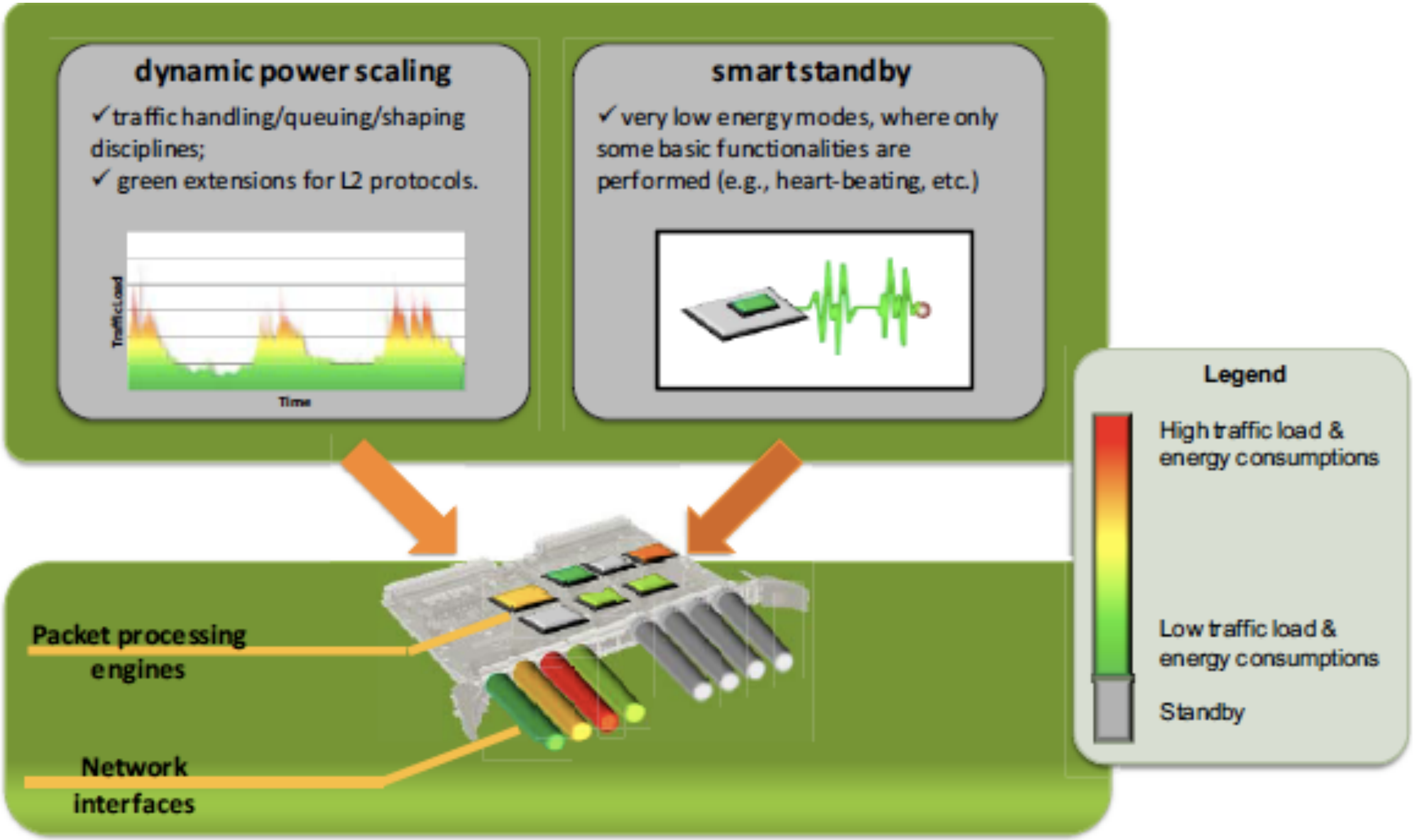
Ongoing Projects

ECO net



Ongoing Projects

ECO net



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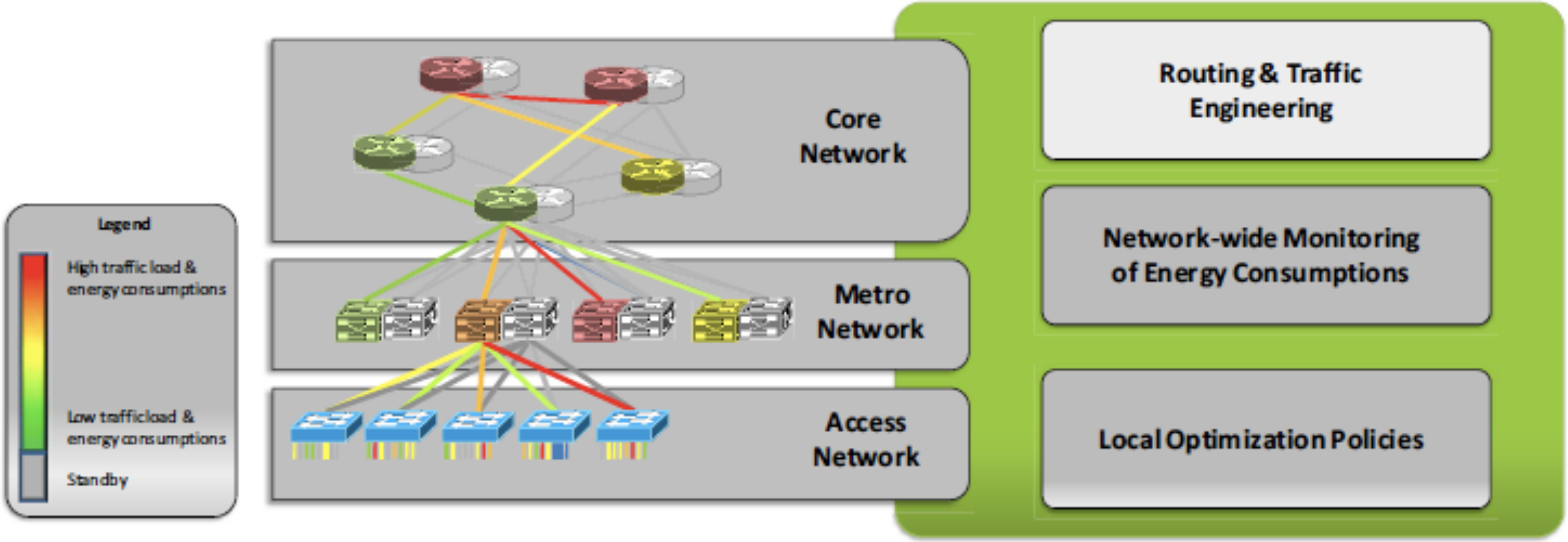
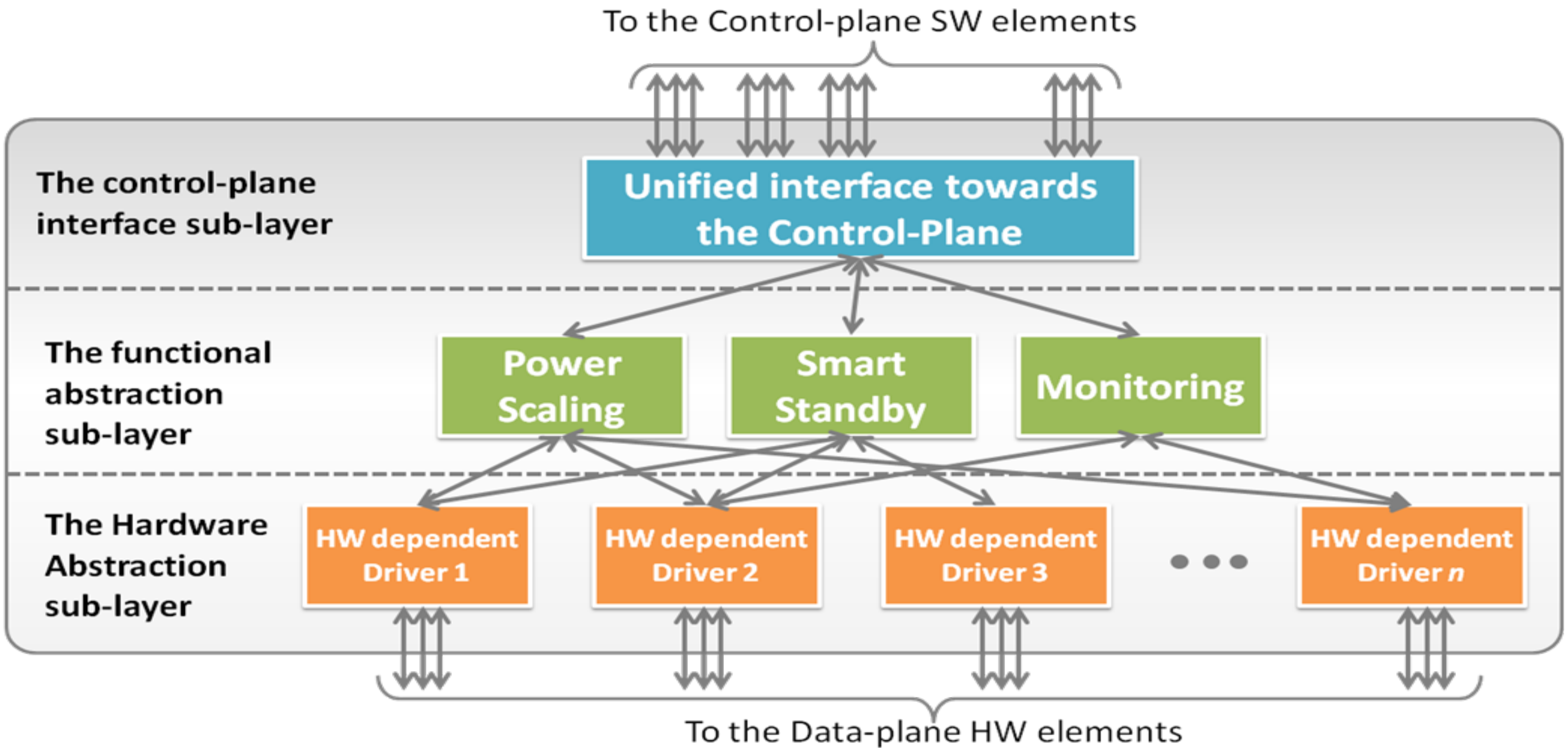
ECOnet



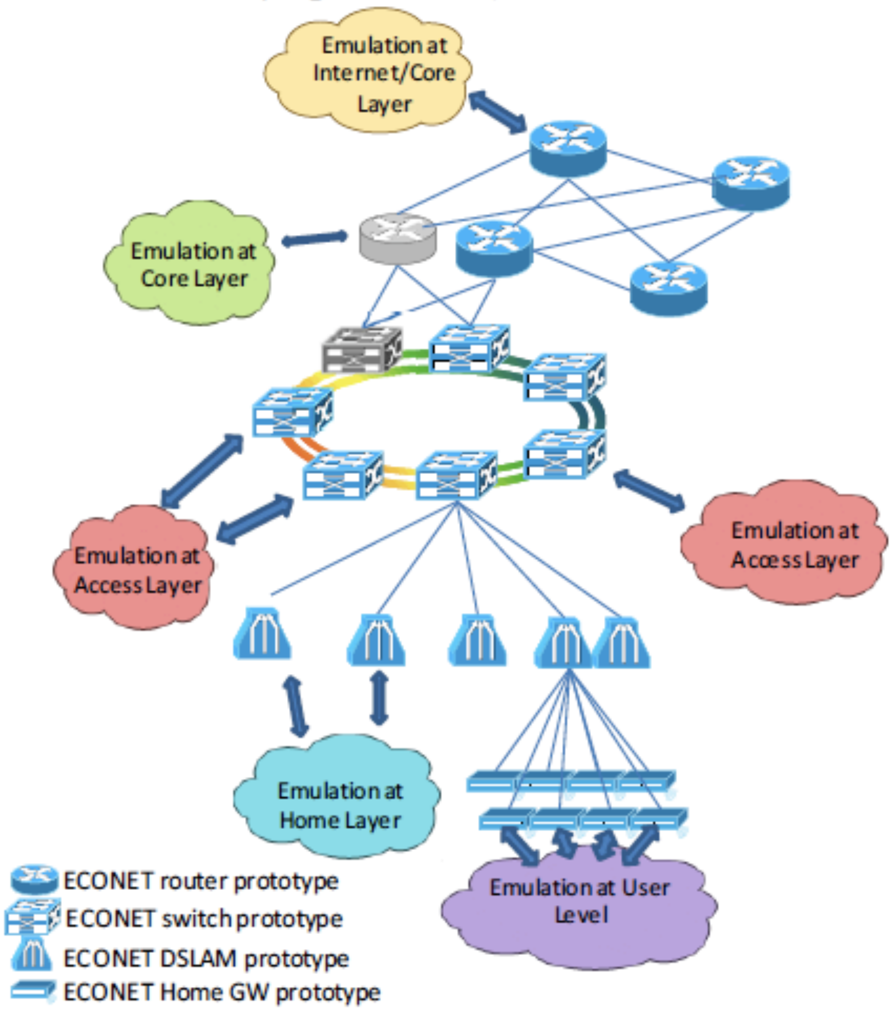
Ongoing Projects



Green Abstraction Layer

Ongoing Projects

ECONET Testbed
@ TELIT Test Plant



TREND

- **Goals**: integrating the activities of major European players to quantitatively asses the energy demand of current and future telecom infrastructures, and to design energy-efficient, scalable and sustainable future networks, considering both the backbone, and the wireless and wired access segments
  - collecting data to assess the power consumption of terminals, devices and infrastructures, to quantify the current energy needs and their expected evolution and scaling laws
  - identifying energy-friendly technologies, devices, protocols and architectures, and evaluating how they can be introduced in operational networks
  - defining new energy-aware network design criteria, balancing the attention to optimal performance and resource allocation with the minimization of energy requirements
  - experimentally proving the effectiveness of the proposed approaches

Ongoing Projects

TREND

Coordinator: **POLITECNICO DI TORINO, ITALY**

Organisations	
HUAWEI TECHNOLOGIES DUESSELDORF GMBH	GERMANY
INTERDISCIPLINARY INSTITUTE FOR BROADBAND TECHNOLOGY	BELGIUM
TELEFONICA INVESTIGACION Y DESARROLLO SA	SPAIN
FASTWEB SPA	ITALY
CONSORZIO NAZIONALE INTERUNIVERSITARIO PER LE TELECOMUNICAZIONI	ITALY
PANEPISTIMIO THESSALIAS (UNIVERSITY OF THESSALY)	GREECE
ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE	SWITZERLAND
TECHNISCHE UNIVERSITAT BERLIN	GERMANY
ALCATEL - LUCENT BELL LABS FRANCE	FRANCE
FRANCE TELECOM SA	FRANCE
UNIVERSIDAD CARLOS III DE MADRID	SPAIN

A few words about research challenges…

- Modelling green devices and networks
  - For two purposes
    - Control and optimization (fluid models, performance bounds, closed-loop strategies [but which timing?], parametric optimization)
    - Performance analysis (queueing models with vacations and setup times at the device level; traffic engineering [L2/L3] within the network), indications on scalability
- Experimental activity on test sites
  - Real equipment
  - Network emulation

A few words about research challenges…

- Wired/wireless network integration
  - Energy-aware traffic engineering to take into account the presence of wireless network operator’s base stations
  - Energy-aware backhaul network for wireless traffic transport
- Data centre/network integration
  - Impact of content delivery
  - Very large transfers/data-intensive computation (eScience)
- Integration of energy-aware network optimization with energy sources and the Smart Grid