Styria, Austria

Energy-oriented Internet

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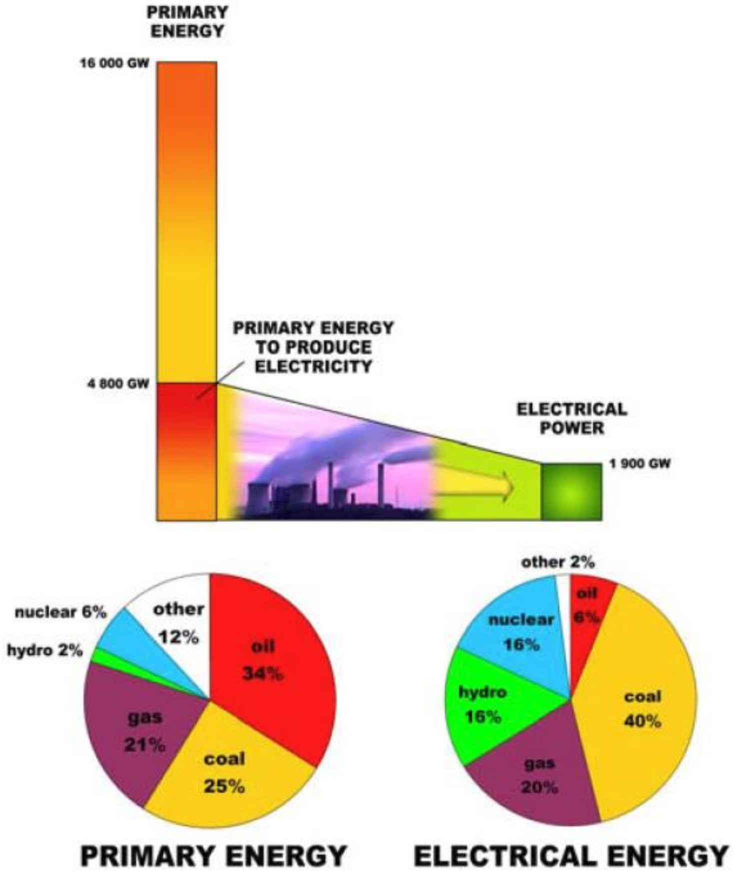
Outline

- The Energy problem
- The Energy problem in ICT
- The Energy-oriented Internet paradigm:
  - Energy efficiency
  - Energy awareness
  - Energy-oriented infrastructures

The Energy Problem

- Human's activity has severe impacts on the environment
  - Resources exploitation: Energy production/consumption require the resources exploitation of the earth
  - Climate changes: GreenHouse Gas (GHG) emissions produces climate changes, global warming & dimming, and pollution
- Parameters to measure this impact
  - Human ecological footprint
  - Carbon footprint



The Energy Problem

- Human ecological footprint
  - Measures the humanity's demand on the biosphere [1] [2]
- Carbon footprint 
  - Measures the total set of GHG emissions
- Three dimensions to handle
  - Energy consumption (Wh)
  - GHG emissions (kg CO_2)
  - Energy Cost (€)

1. Living Planet Report 2014, The biennial report, WWF, Global Footprint Network, Zoological Society of London
2. www.footprintnetwork.org
3. http://www.bbc.com/news/magazine-33133712

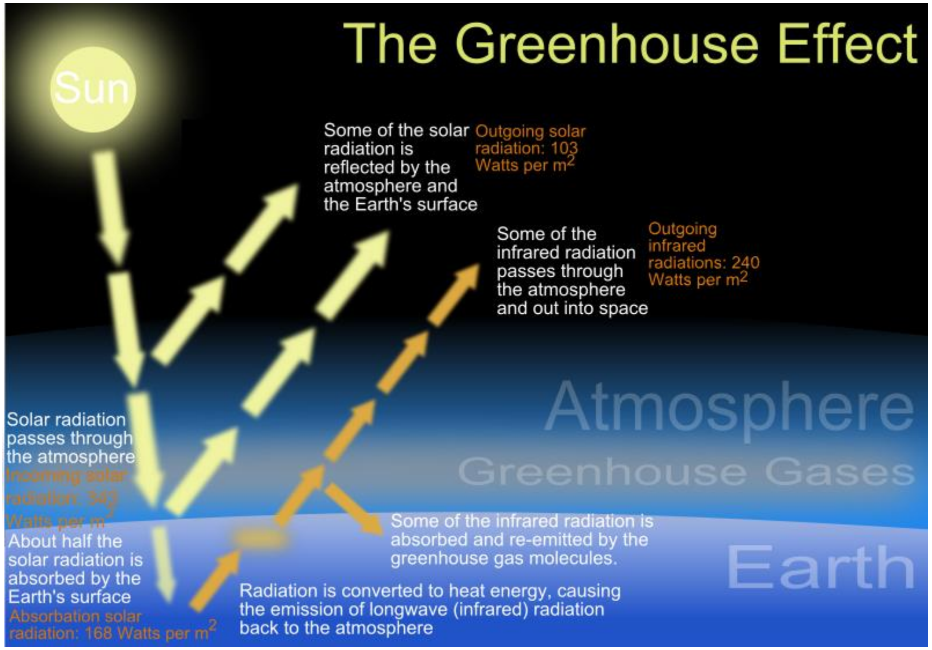
Human ecological footprint

- The worldwide human ecological footprint is in average 1.5 planet Earths
  - In average we are consuming the ecological resources at 1.5 times the rate the earth is able to restore them
  - United States average: 4.7 planet Earths [3]
  - Europe average: 2,6 planet Earths
    - *Belgium (highest): 4.3 planet Earths*
    - *Romania (lowest): 1.4 planet Earths*
    - *Sweden: 3.7 planet Earths*

1. Living Planet Report 2014, The biennial report, WWF, Global Footprint Network, Zoological Society of London
2. www.footprintnetwork.org
3. http://www.bbc.com/news/magazine-33133712

The GreenHouse Effect

- Major contributors to the GH effect:
  - water vapor 36–72%
  - carbon dioxide CO_2 9–26%
  - methane 4–9%
  - ozone 3–7%
  - nitrous oxide ~1%
  - chlorofluorocarbons ~ 1%



- Global Warming Potential (GWP) CO_2 equivalent (CO2e)

Greenhouse gas	Global Warming Potential (CO2e)
Carbon dioxide (CO_2)	1
Methane (CH_4)	25
Nitrous oxide (N_2O)	298
Sulfur hexafluoride (SF_6)	22800
HFCs	124 - 14800
PFCs	7390 - 12200

GLOBAL WARMING POTENTIAL OF MAIN GREENHOUSE GASSES

The Energy Problem

- Straightforward reasoning:
  - We can reduce earth resources exploitation and the GHG emission effect (mainly the global warming) by simply saving energy
  - How can we save energy?
    - *Reducing the energy consumption is an illusion… so then, how?*

      → By increasing energy efficiency
    - *How can we increase the energy efficiency?*
    - *... but, really reduces earth's resource exploitation and GHG emissions?*

Rebound Effect

Increassing energy efficiency...

really reduces earth's resource exploitation and GHG emissions?

Rebound effect

increased energy efficiency

⇓

overall reduction of costs

⇓

increases the demand

⇓

energy consumption increases

⇓

Negative impact exceeds the gains obtained by increasing the energy efficiency

⇓

Green energy sources:

Anything times zero is always zero

Systemic approach:

Not just trying individual energy savings, but assessing the full life cycle (LCA)

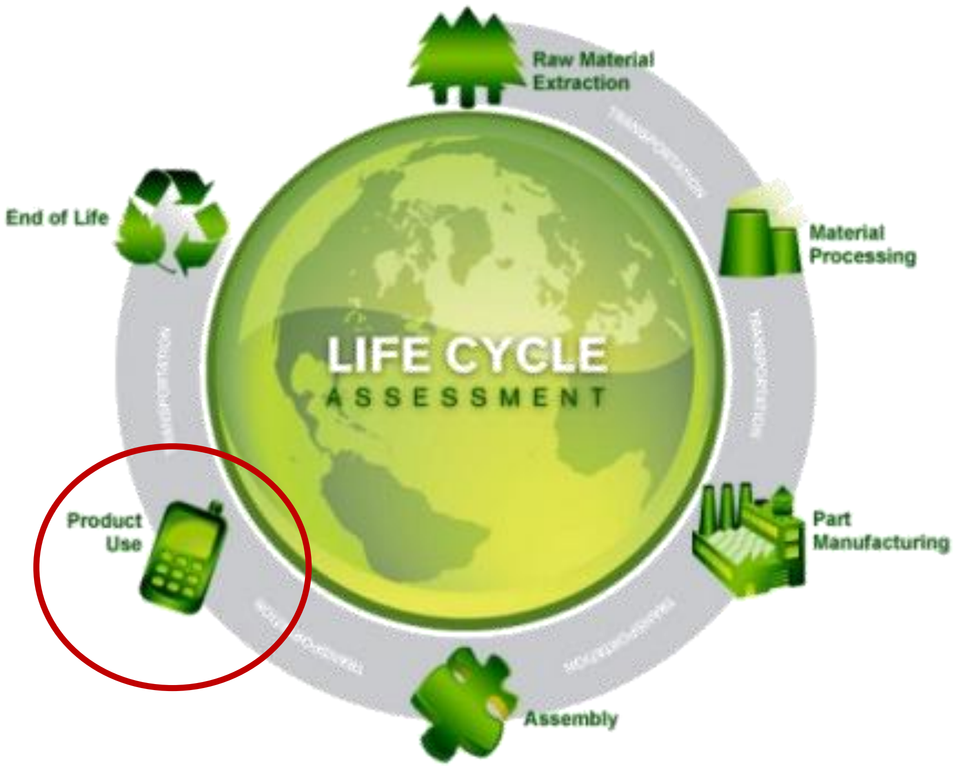
Energy sources

- Renewable energy sources
  - Solar
    - *Thermal + photovoltaic*
  - Aeolian
  - Hydropower & Tidal
  - Geothermic
  - Biomass
    - *CO_2 emissions*
  - Hydrogen
    - *Vector for storing energy*

- Fossil fuels
  - Oil, carbon, gas
- Nuclear
  - Fission (make energy by dividing heavy atoms cores)
  - Fusion (make much more energy than fission by merging light atoms; still uncontrolled)

Life Cycle Assessment

- Assess/reduce direct and indirect impacts of the life cycle of a product, not only that of its use



The Energy Problem in ICT

The Energy Problem in ICT

- The ICT (Information and Communications Technologies):
  - **Consumes 7% - 12%[1] worldwide produced electrical energy**
    - *240 GW [1] (mean value, including construction & use phases, the whole live cycle), which is equivalent of more than 200 modern nuclear power reactors*
  - **Emits 2 - 3% world's GHG**
    - *20% comes from **manufacturing** [2]*
    - *80% comes from the **use of equipment** [2]*

1. Barath Raghavan, Justin Ma, "The Energy and Emergy of the Internet", Proceedings of the 10th ACM Workshop on Hot Topics in Networks (HotNets-X), Cambridge, Massachusetts, Nov. 2011
2. SMART 2020: Enabling the low carbon economy in the information age, *The climate group*, 2008.

The Energy Problem in ICT

- ICT **consumes** as much energy as Railways System and **emits** as much GHG as Aviation industry

- In Italy, Telecom Italia, and in France, France Telecom, are the second largest consumers of electricity after the National Railway systems (2 TWh/year)
- In the UK, British Telecom is the largest single power consumer

BSC MareNostrum

"It is not the most powerful supercomputer in the world, but it is the most beautiful"
(Fortune, Sept. 2006)

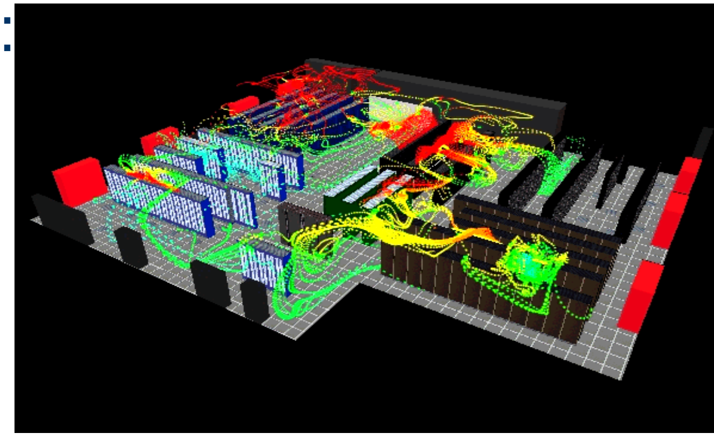
Source: Jordi Torres, "Green Computing: the next wave in computing", Ed. UPCommons, Technical University of Catalonia (UPC). February 2010. Ref. http://hdl.handle.net/2099.3/33669

The Energy Problem in ICT

- The ICT presents a «vicious cycle»:
  - Watts ⇒ Useful Work

    produces ⇒ Heat

    requires ⇒ Cooling

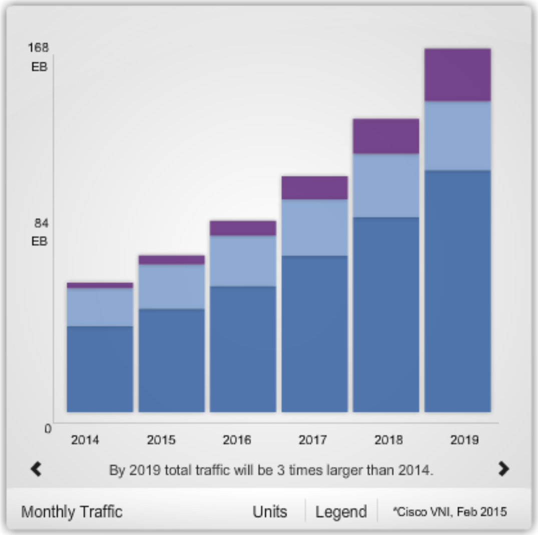


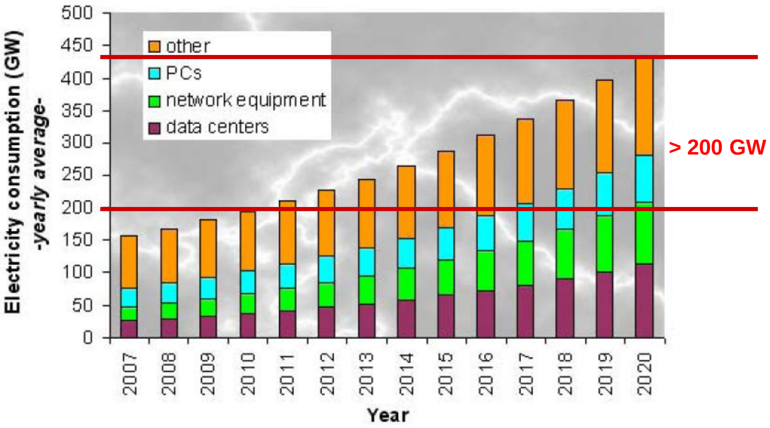
- ICT then, may consume up to two times energy:
  1. Powering devices
  2. Cooling (HVAC, Heating Ventilation and Air Conditioning) + UPS (Uninterruptible Power Supply)
  - Power Usage Effectiveness (PUE): ~ 2[1], but it can be reduced

1. The Green Grid, "The Green Grid Data Center Power Efficiency Metrics: PUE and DCiE," Technical Committee White Paper, 2008.

The Energy Problem in ICT

- How this is evolving (from to 2014 to 2020):
  - In 2018, the **number of users connected** to the Internet reached **3,8 billions** (more that a half of the population)[3] [4] [5][6]
  - **In 2020 the monthly traffic was expected to reach 170 *ExaBytes***[2]
    - *(1 ExaByte = 10^6 TB)*
    - ***Reality:*** *Data volume of global consumer IP traffic from 2017 to 202*
- In ten years, the **power consumption** has doubled[7]
- **Good news:** Production of green energy is increasing ☺



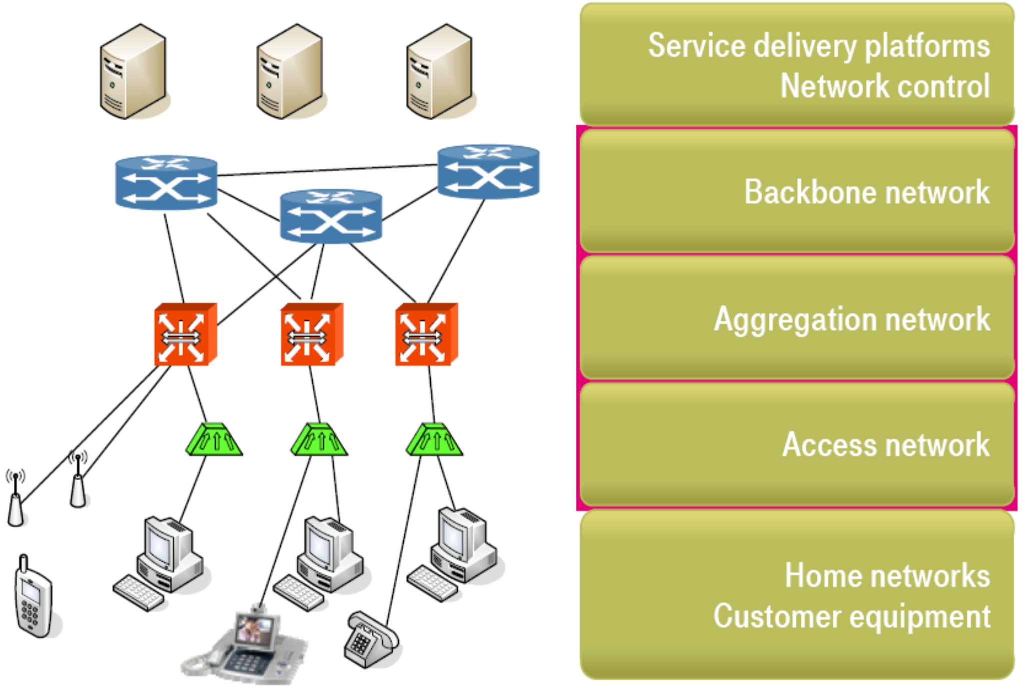


Electricity consumption forecasts for 2007-2020 of ICT equipment during use.

1. Barath Raghavan, Justin Ma, "The Energy and Emergy of the Internet", Proceedings of the 10th ACM Workshop on Hot Topics in Networks (HotNets-X), Cambridge, Massachusetts, Nov. 2011
2. Cisco visual networking index [online]. Available: http://www.cisco.com/en/US/netsol/ns827/networking_solutions_sub_solution.html.
3. Internet world stats [online]. Available: http://www.internetworldstats.com/emarketing.htm.
4. Etforecasts [online]. Available: http://www.etforecasts.com/products/ES_intusersv2.htm.
5. http://www.gsma.com/newsroom/press-release/half-worlds-population-connected-mobile-internet-2020-according-gsma/
6. http://www.neowin.net/news/microsoft-internet-users-will-double-to-4-billion-worldwide-by-2020
7. BONE project, 2009, "WP 21 Topical Project Green Optical Networks: Report on year 1 and updated plan for activities", NoE, FP7-ICT-2007-1 216863 *BONE project*, Dec. 2009.

The Energy Problem in the network infrastructures

- Energy is, then, a mandatory constraint to design, manufacture, operate and manage networks
  - **The Energy-oriented Internet Paradigm**
- Multilayer approach, we can actuate on the
  - Application
  - System/Middleware
  - Networking
    - *Backbone*
    - *Aggregation*
    - *Access*



The Energy-oriented Internet paradigm

The Energy-oriented Internet paradigm

- **Energy-Efficiency**
  - Refers to **technological advances** to reduce the energy consumption without affecting the performance. The **do more for less paradigm**
  - Energy-efficient solutions are usually referred to as **eco-friendly solutions**

The Energy-oriented Internet paradigm

- **Energy-Awareness**
  - Refers to **intelligent technologies** able to adapt its behavior or performance to the **current working load**, and to the **quantity** and **quality of energy** that the equipment is expending
    - *Requires energy-feedback information, i.e., it implies* ***knowledge of the energy sources*** *(whether they are* ***dirty*** *or* ***green****) that supply the equipment*
  - Energy-aware solutions are usually referred to as **eco-aware solutions**

1. Sergio Ricciardi, Davide Careglio, Germán Santos-Boada, Josep Solé-Pareta, Ugo Fiore, Francesco Palmieri, "Towards an energy-aware Internet: modeling a Crosslayer Optimization approach", Telecommunication Systems Journal (Springer), ISSN: 1018-4864 (print version), ISSN: 1572-9451 (electronic version), DOI 0.1007/s11235-011-9645-7, published online 17 Sep. 2011, http://www.springerlink.com/content/9xh42725v0163ww1/.

The Energy-oriented Internet paradigm

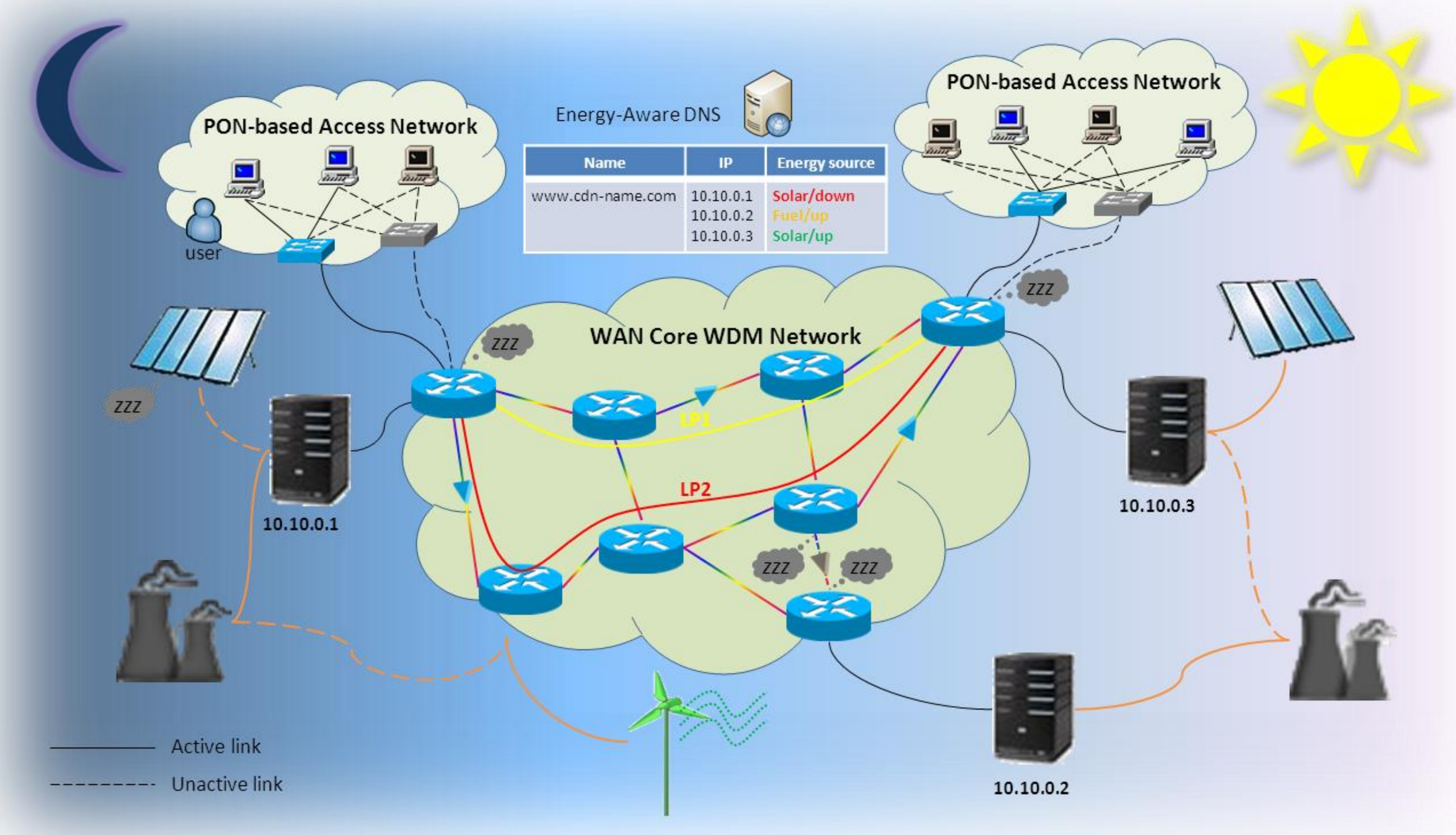
Energy-Oriented Infrastructures

- Refers to the combination of Energy-Efficiency and Energy-Awareness, with **green energy sources,** in a **sustainable and holistic[1] systemic approach**
  - *Implies smart grid power distribution, and the entire life cycle assessment (LCA)*

- Let us focus in Networking actuations

[1)] characterized by comprehension of the parts of something as intimately interconnected and explicable only by reference to the whole

Energy-oriented approach



Routing:

Follow-the-energy (sun, wind, tide) to minimize power consumption and/or GHG emissions
Follow-the-energy-cost (moon) to minimize the energy bill (cost of energy I lower at night)

Datacenter placements:

Near energy sources to reduce (1) dispersion, (2) cooling, (3) energy-costs

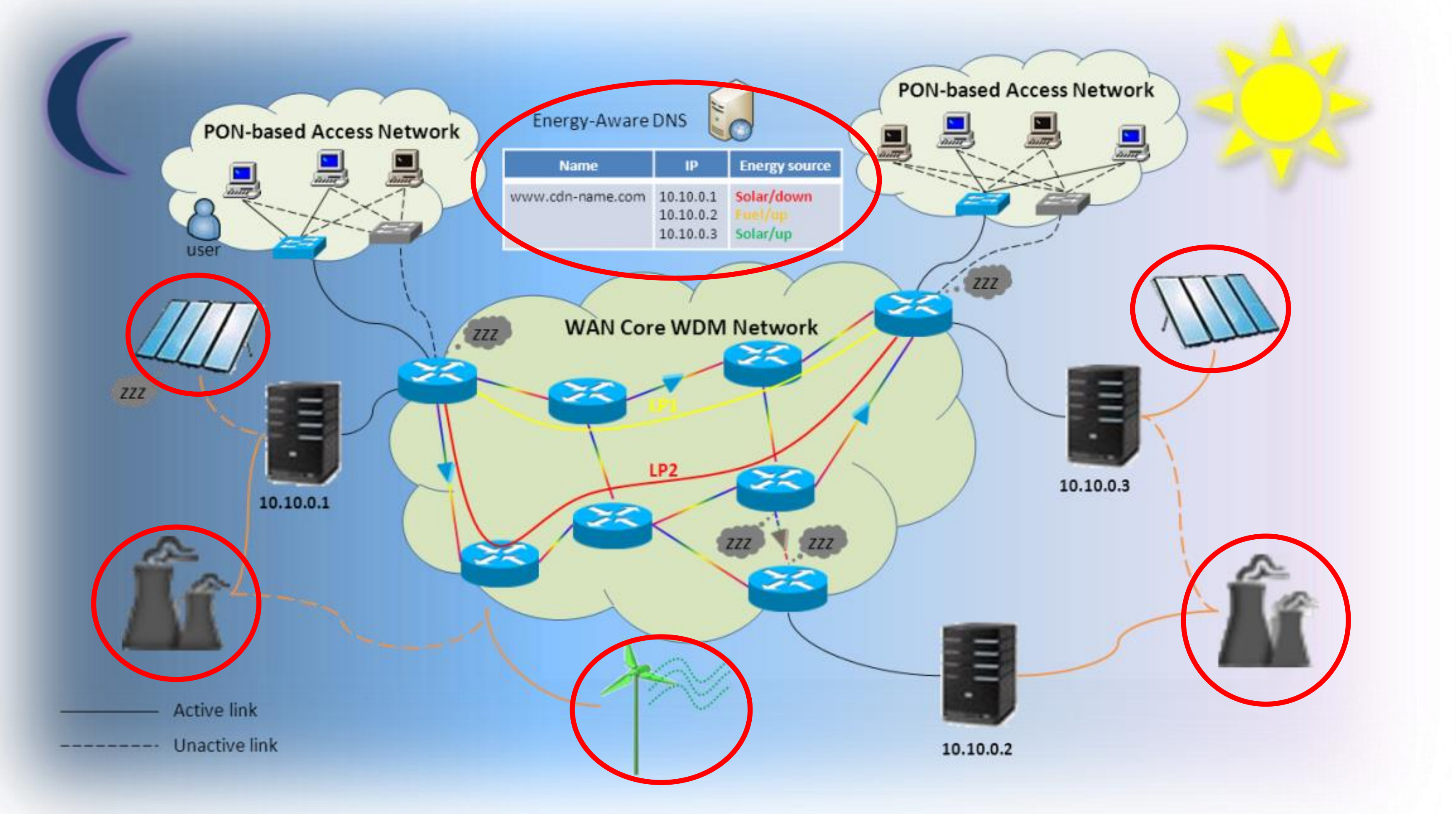
Requirements:

High performance communication network
Dynamical tasks allocation + sleep mode strategies & fully distributed scheduling paradigm

Energy-oriented approach

Can we make the network aware of the green energy sources (follow-the-energy)?

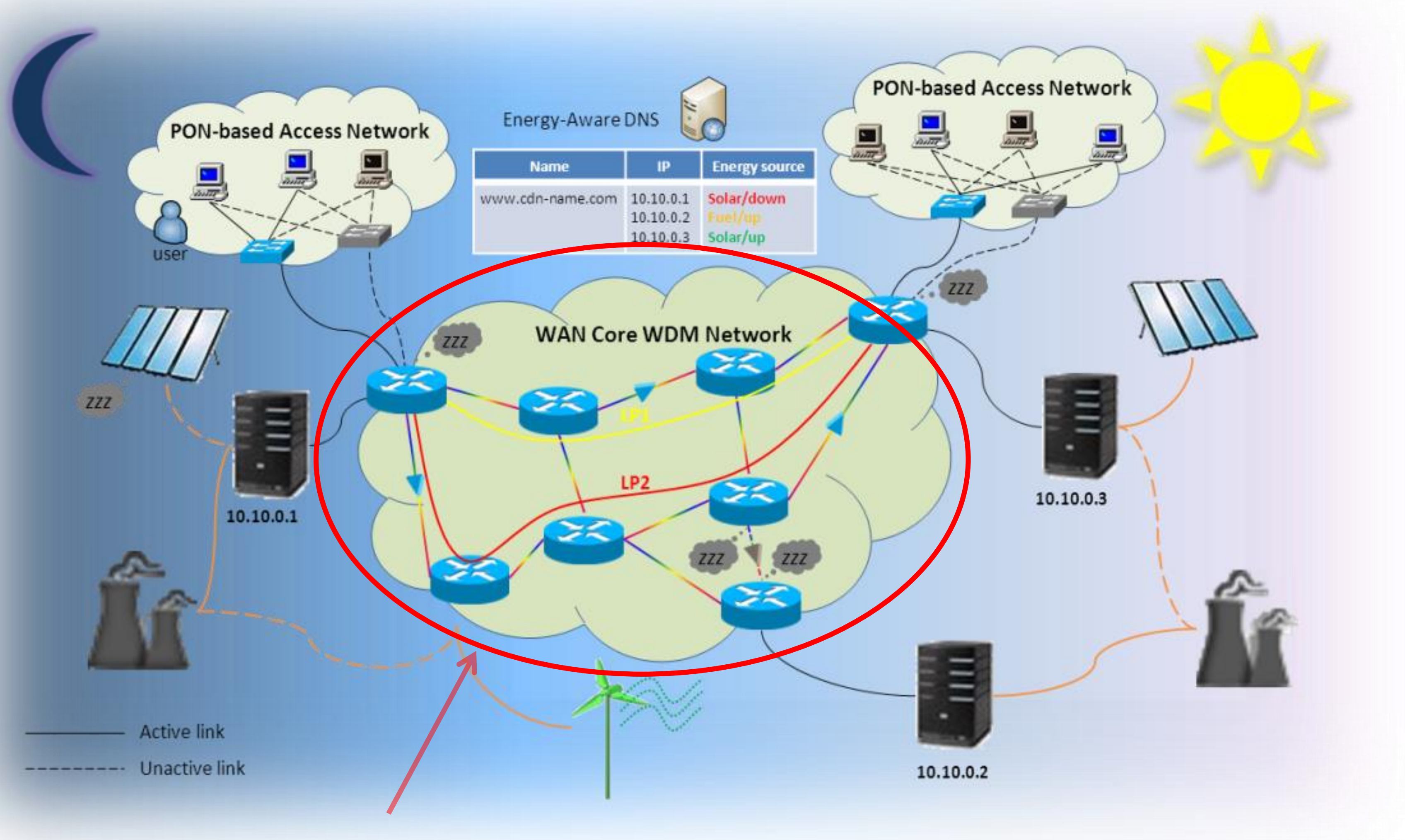
We can extend the OSPF-TE LSAs (Link State Advertisement) to carry information on the energy sources



Name	IP	Energy source
www.cdn-name.com	10.10.0.1	Solar/down
	10.10.0.2	Fuel/up
	10.10.0.3	Solar/up

Energy-oriented approach

Which path to choose for routing the connections in the *greenest* way?

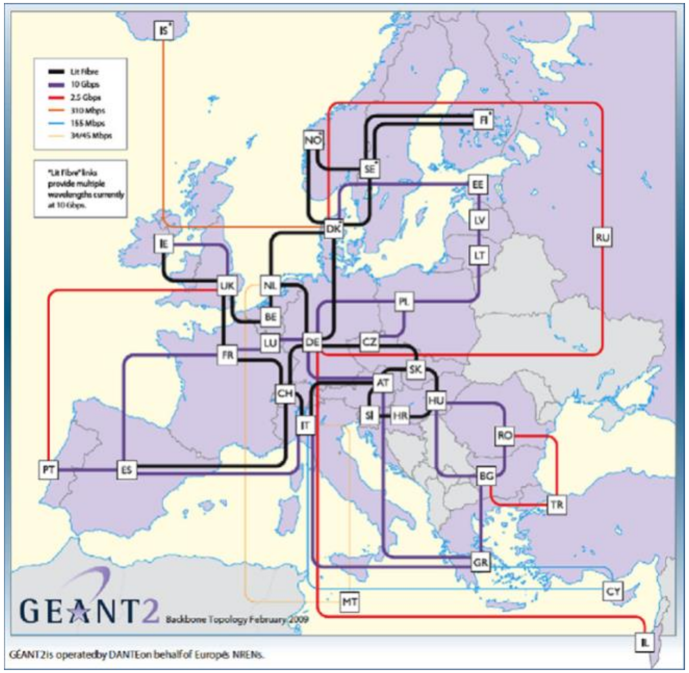


What next?

- Performance evaluation figures
  - Some results obtained from different Energy-aware Routing and Wavelengths Assignment algorithms applied to GÉANT 2
- The Energy-oriented Internet approach, illustrated
  - Energy-efficient **devices & architectures**
  - Energy-aware **algorithms & protocols**
  - Energy-oriented **infrastructures**

Energy-aware RWA Algorithms

- Based on these three orthogonal objectives:
  - **MinPower:** minimizing power consumption
  - **MinGas:** minimizing GHG emissions (energy-aware)
  - **MinCost:** minimizing costs (energy-unaware)
- Applied on the Pan European Network (GÉANT 2):

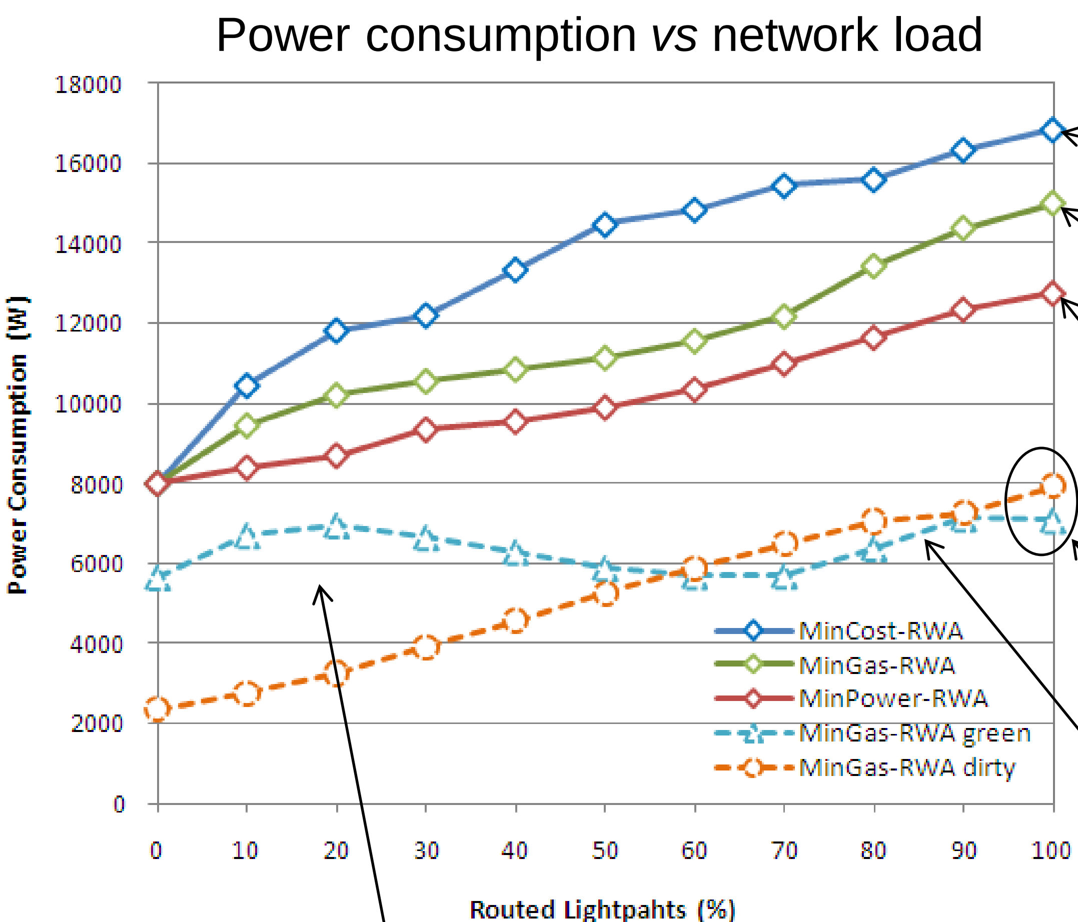


Source: Sergio Ricciardi, Davide Careglio, Francesco Palmieri, Ugo Fiore, Germán Santos-Boada, Josep Solé-Pareta, "Energy-Aware RWA for WDM Networks with Dual Power Sources", in Proceedings of 2011 IEEE International Conference on Communications (ICC 2011), Kyoto, Japan, June 5-9, 2011.

Energy-aware RWA Algorithms

- ILP Results of a energy-aware RWA on GÉAN-2:

Focus on the power consumption



MinCost-RWA is the most power consuming

MinGHG-RWA is in between

MinPower-RWA is the less power consuming

MinGHG-RWA decomposed in emitting (orange) and not emitting (blue) power consumptions

For low loads: *MinGHG-RWA* tends to use only green devices

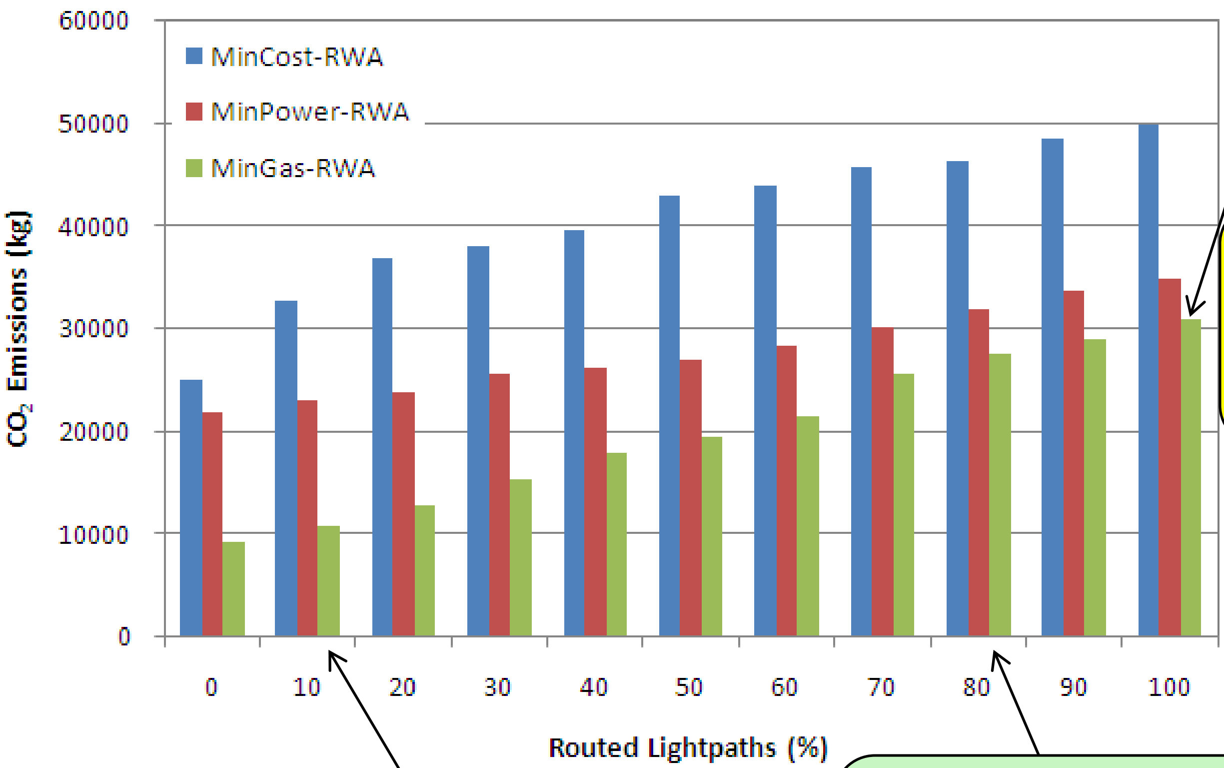
For high loads: *MinGHG-RWA* using GHG emitting devices is more probable

Energy-aware RWA Algorithms

- ILP (Integer Linear Programming) Results of a energy-aware RWA on GÉAN-2:

Focus on the CO_2 emissions

Emitted CO_2 *vs* network load



MinGHG-RWA is the less CO_2 emitting

Which strategy to use? Depends on the objective we want to minimize, the energy-bill, ecological footprint…

MinPower-RWA performs quite well as for GHG

For low loads: *MinGas-RWA* strategy achieves prominent CO_2 savings

For high loads: The difference between the *MinGas-RWA* and the *MinPower-RWA* strategies decreases (since it uses more dirty-powered nodes)

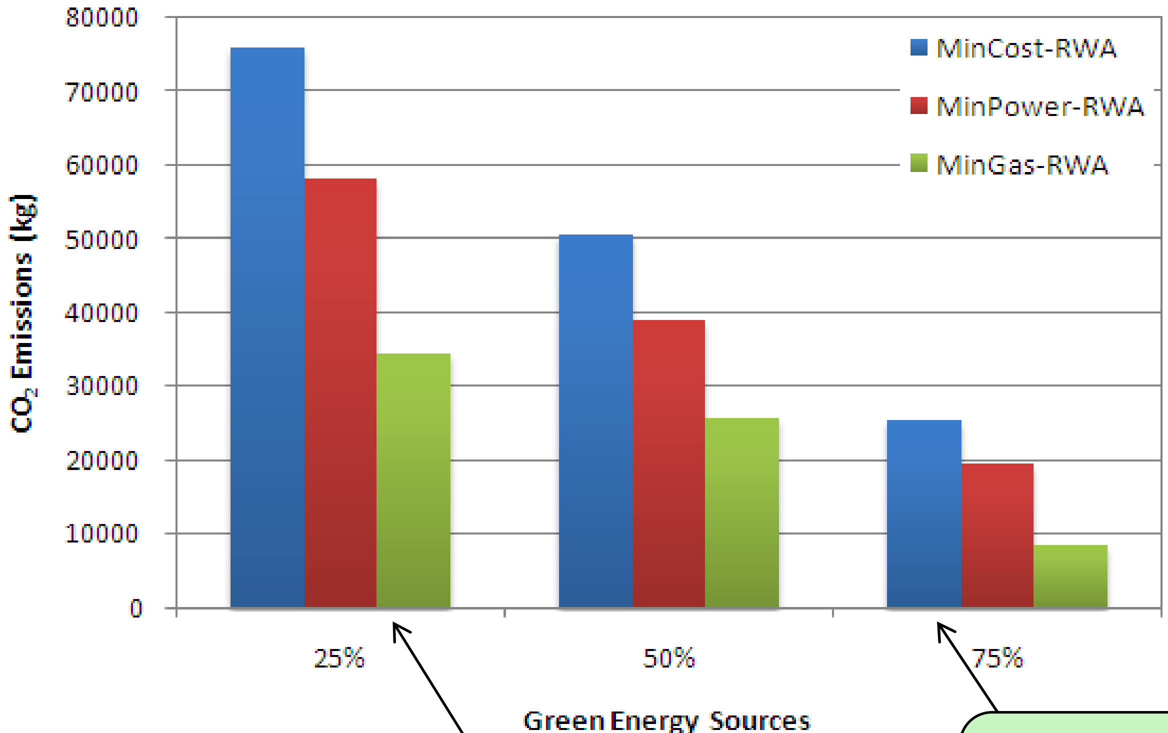
Source: Sergio Ricciardi, Davide Careglio, Francesco Palmieri, Ugo Fiore, Germán Sa
Sources", in Proceedings of 2011 IEEE International Conference on Communications (

Energy-aware RWA Algorithms

- ILP Results of a energy-aware RWA on GÉAN-2:

Average emitted CO_2 at different green power sources percentages (remaining power sources are fuel-based)

Focus on the energy sources



MinGas-RWA strategy, with as few as 25% of green energy sources, considerably reduces the overall network CO_2 emission

For low percentages: Energy-aware strategies are strongly advised to save CO_2

For high percentages: Good results in terms of CO_2 emissions also from energy-unaware strategies

Source: Sergio Ricciardi, Davide Careglio, Francesco Palmieri, Ugo Fiore, Germán Santos-Boada, Josep Solé-Pareta, "Energy-Aware RWA for WDM Networks with Dual Power Sources", in Proceedings of 2011 IEEE International Conference on Communications (ICC 2011), Kyoto, Japan, June 5-9, 2011.

Conclusions

- Performance evaluation figures
  - Some results obtained from different Energy-aware Routing and Wavelengths Assignment algorithms applied to GÉANT 2
- The Energy-oriented Internet approach, illustrated
  - Energy-efficient **devices & architectures**
    - *Low consuming devices*
    - *Enhanced architectures*
  - Energy-oriented **infrastructures**
    - *Sustainable systemic approach*
    - *Life Cycle Assessment*
    - *Smart Grid with green renewable energy sources*
  - Energy-aware **algorithms & protocols**
    - *Follow the sun, follow the moon (routing protocols)*
    - *Load (tasks) distribution (sleep mode algorithms)*

Selected References

1. Sergio Ricciardi, Francesco Palmieri, Ugo Fiore, Davide Careglio, Germán Santos-Boada, Josep Solé-Pareta, "Towards Energy-Oriented Telecommunication Networks", Handbook on Green Information and Communication Systems, Academic Press, Elsevier, chapter 19, pp. 491-512, ISBN 9780124158443, 2012.

2. Sergio Ricciardi, Francesco Palmieri, Jordi Torres-Viñals, Beniamino di Martino, Germán Santos-Boada, Josep Solé-Pareta, "Green Datacenter Infrastructures in the Cloud Computing Era", Handbook on Green Information and Communication Systems, Academic Press, Elsevier, chapter 10, pp. 267-293, ISBN 9780124158443, 2012.

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4. BONE project, 2009, "WP 21 Topical Project Green Optical Networks: Report on year 1 and updated plan for activities", NoE, FP7-ICT-2007-1 216863 *BONE project*, Dec. 2009

5. Living Planet Report 2010, The biennial report, WWF, Global Footprint Network, Zoological Society of London.

6. Barath Raghavan, Justin Ma, "The Energy and Emergy of the Internet", Proceedings of the 10th ACM Workshop on Hot Topics in Networks (HotNets-X), Cambridge, Massachusetts, Nov. 2011.

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The Energy Problem in the ICT

Energy-oriented Internet in a Carbon Constrained World

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