Politecnico di Milano

Advanced Network Technologies Laboratory

Why and How to Make the Internet Green

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  - Silvia Boiardi
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  - Edoardo Amaldi
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- Projects:

GreenTouch™

www.greentouch.org

MiWEBA

www.miweba.eu

Green ICT and ICT for Green

- The debate on climate change is fostering the development of new “green policies”
- Information and Communication Technology (ICT) plays a key role in this greening process
- Since the beginning, ICT technologies have been considered as part of the solution
- More recently, the awareness of the potential impact of the carbon emissions of the ICT sector itself has rapidly increased.

SMART GRID

ENERGY MANAGEMENT

GREEN ICT

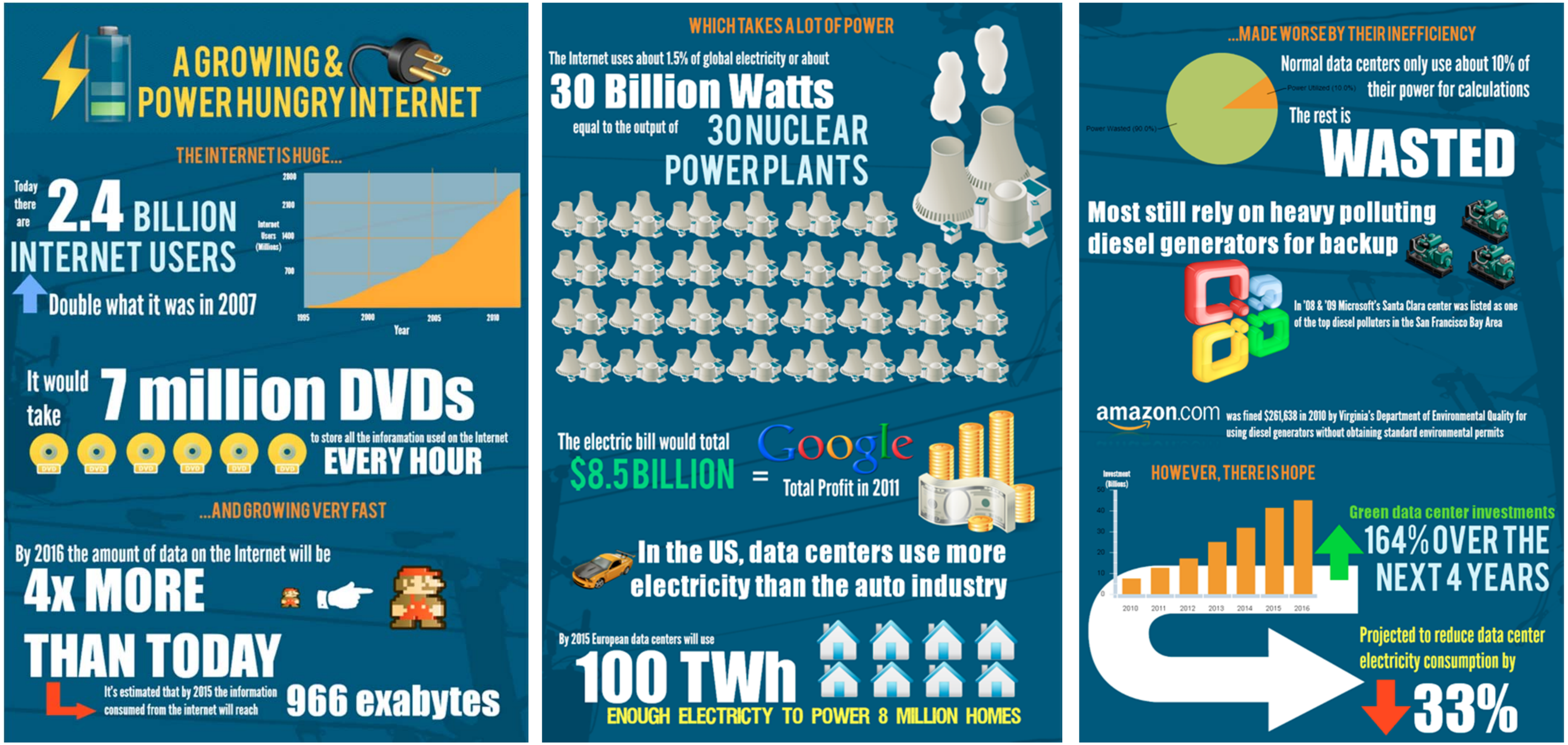
ICT consumption

- In 2007, the Internet was said to be responsible for 5.5% of the global energy consumption with an estimation of growth of 12% per year
- In 2007, the impact of ITC was estimated as 2% of total CO2 emissions
- The impact of datacenters will be multiplied by 3.4 in 2020
- The number of routers will go from 67 millions in 2002 to 898 millions in 2020
- The impact of the infrastructure will be more than doubled in 2020
- Large variance of consumption for the same services. The data from 8 large ISPs show a variation from 23Kwh/user to 109Kwh/user.

[Cook12] Gary Cook. How clean is your cloud? Greenpeace International, Amsterdam, The Netherlands, April 2012

[Smart2020] The Climate Group. SMART 2020: Enabling the low carbon economy in the information age. In 2010 State of Green Business, June 2008

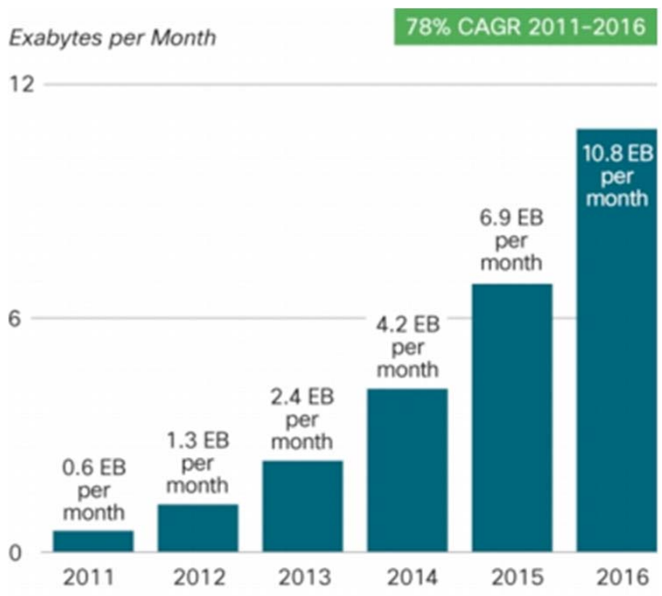
ICT consumption



Created by:
WirelessSatelliteInternet.org

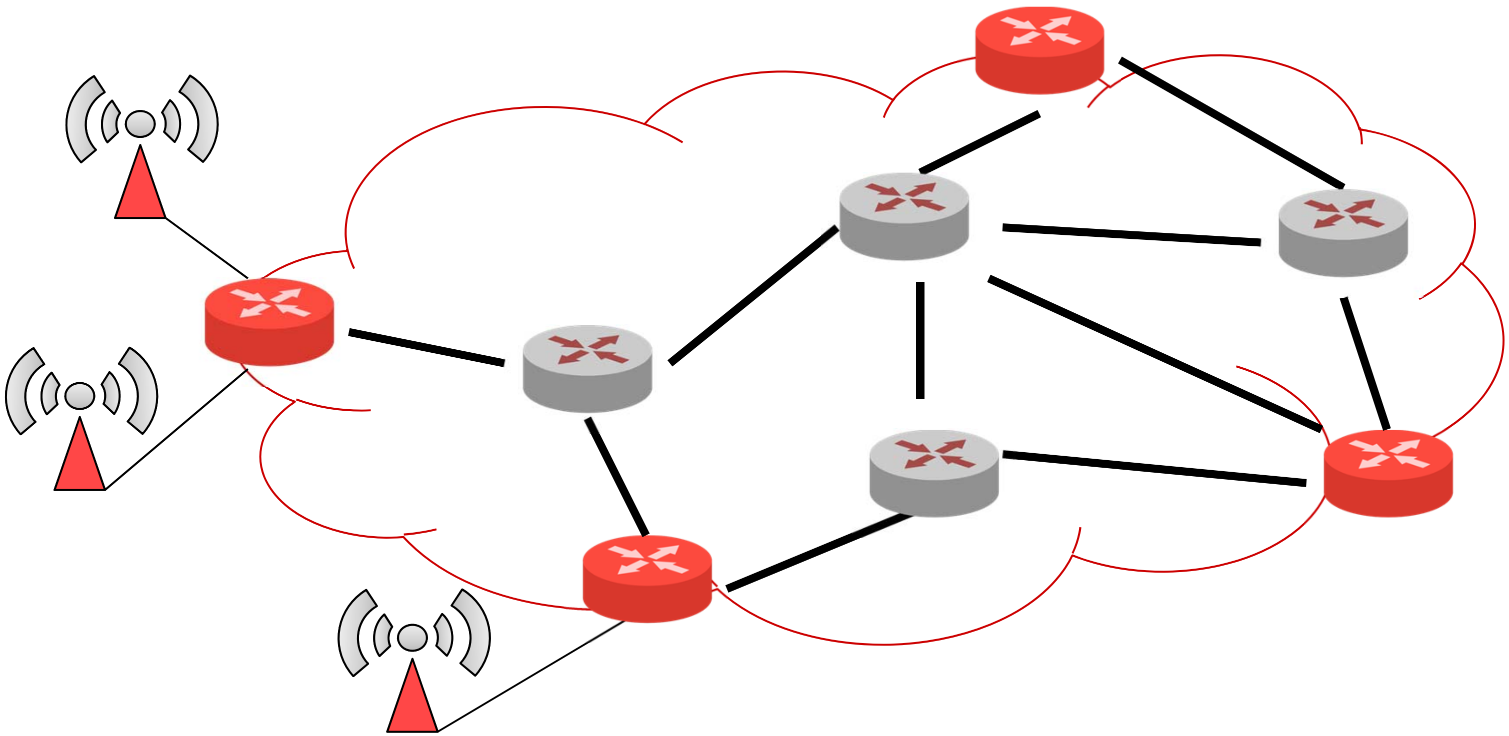
Network consumption

- Network contribution to ICT energy consumption is increasing
  - Traffic exponential growth
  - Technology improvements for better energy efficiency are slower than with computing devices (data centers)
- The energy cost for network operators is of the order of operational expenses (OPEX)



Network consumption

- Networks are made of nodes (devices)
- The network energy consumption is just the sum of the consumption of its nodes



Network consumption

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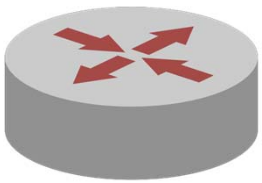
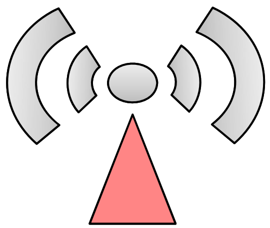


Routers
Switches

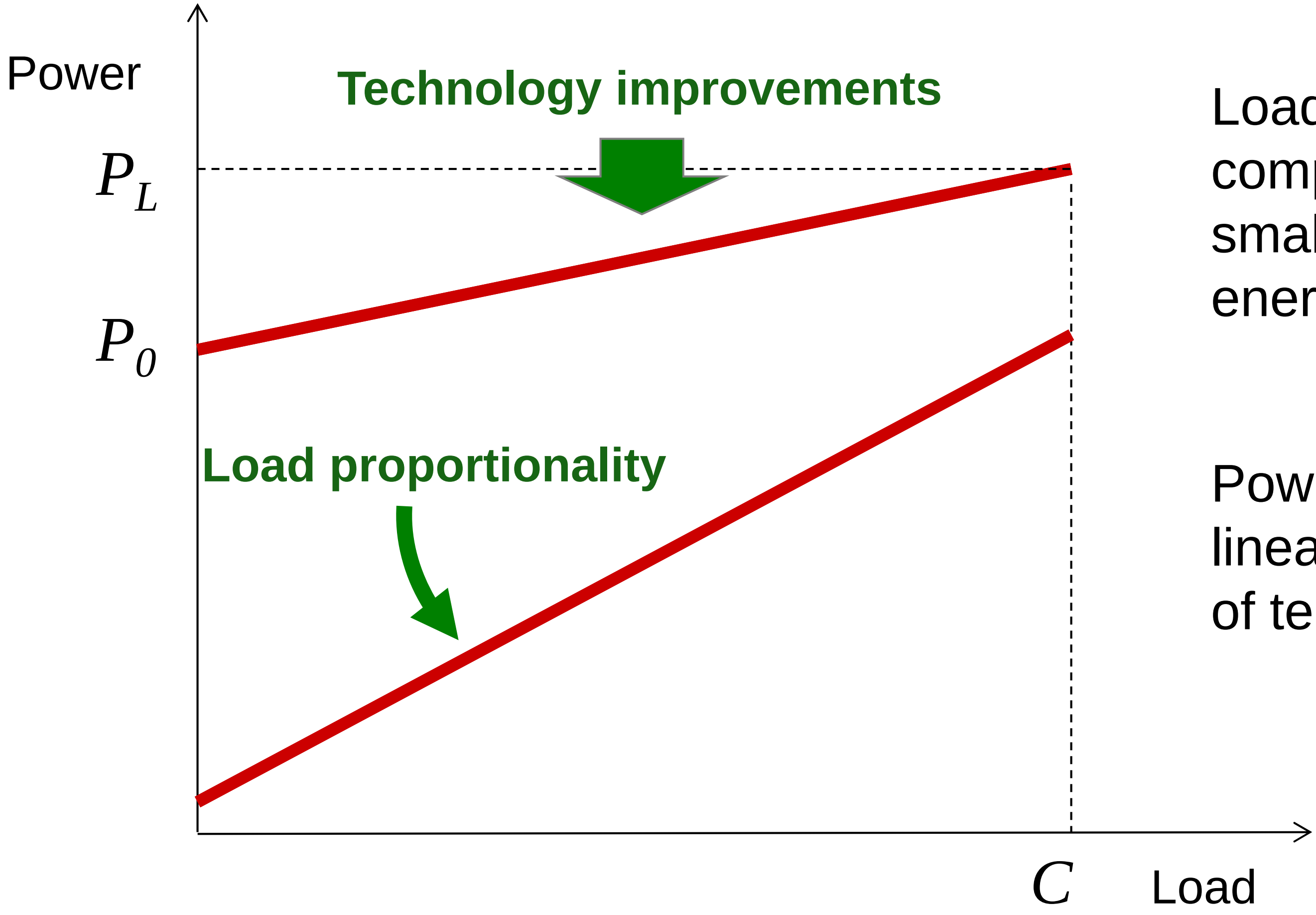


Base Stations
Access Points

- The consumption of a node varies according to the amount of traffic load (in bps)
- How? ...

Load proportionality?

Power profiles of network devices

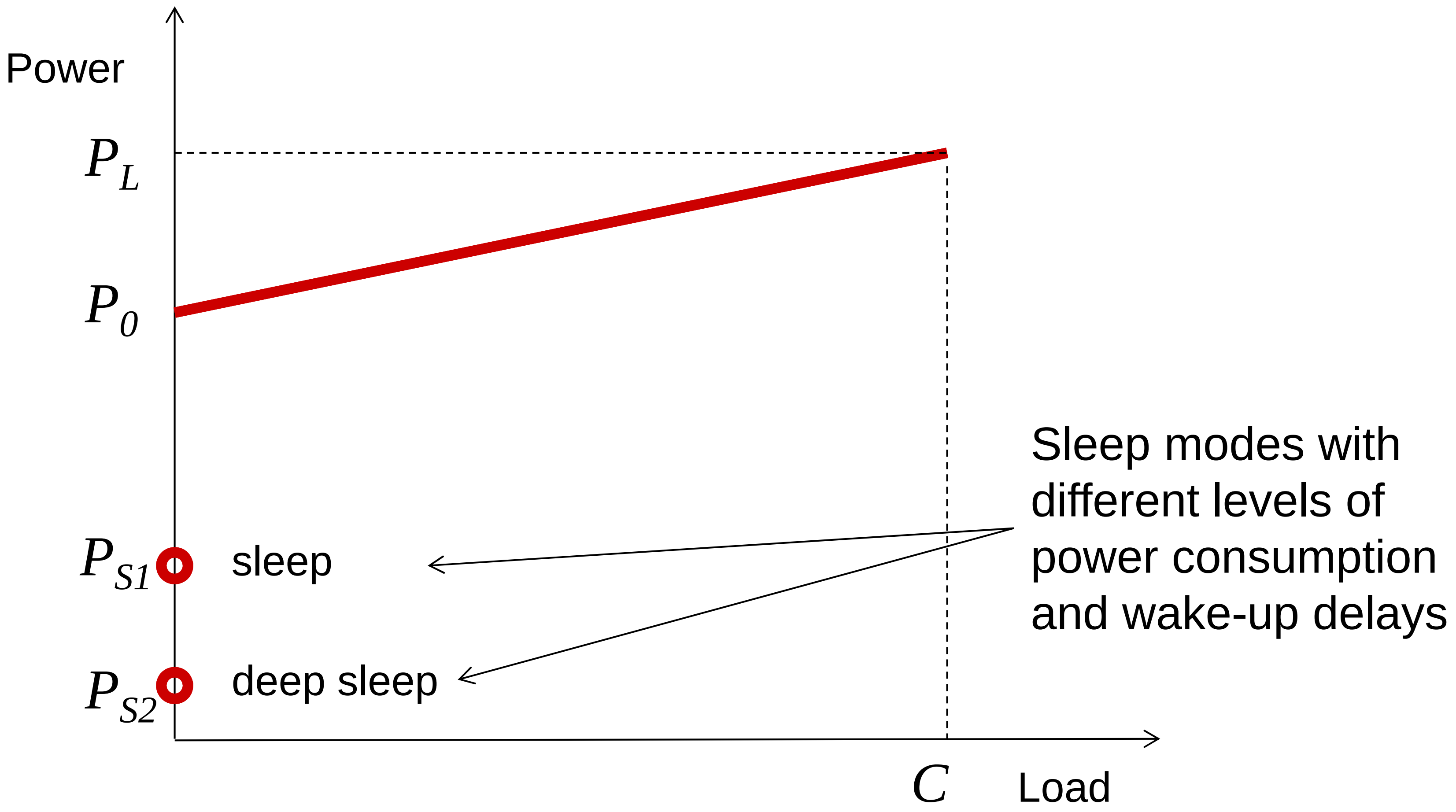


Load depend component usually a small fraction of the energy consumption

Power profiles mostly linear for a wide range of technologies

Load proportionality?

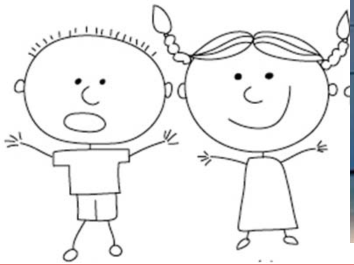
Power profiles of network devices

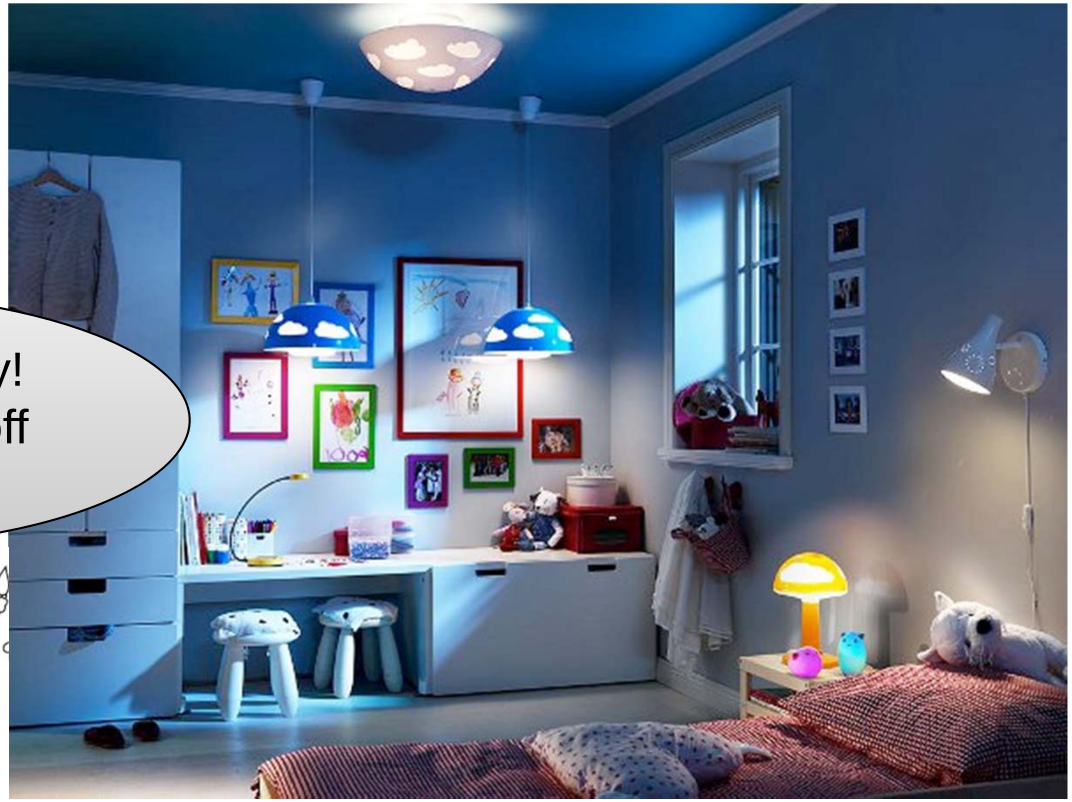


Load proportionality: Mum's rule

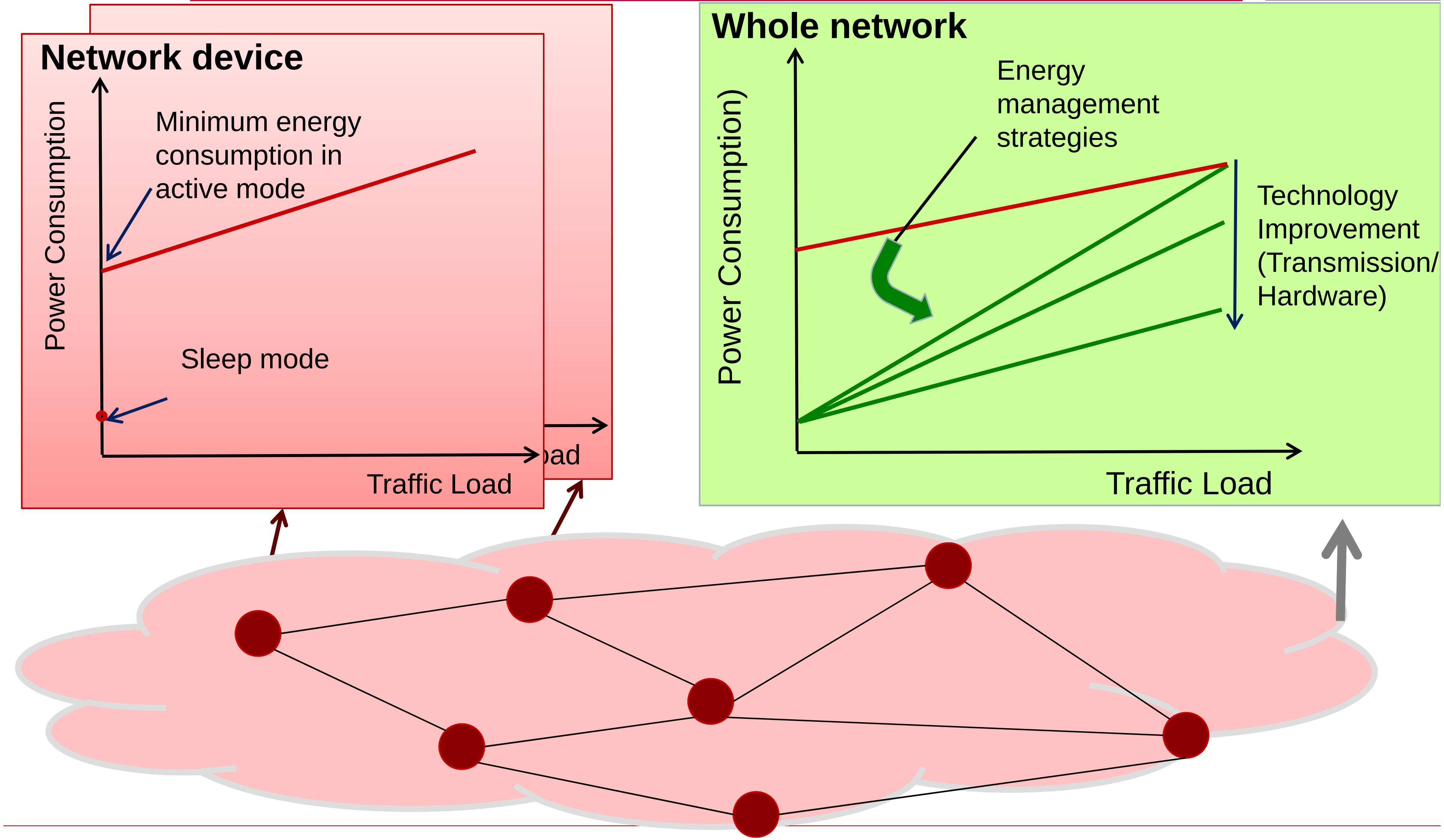
"Remember to turn off the light"

Kids, dinner is ready!
Remember to turn off
the light



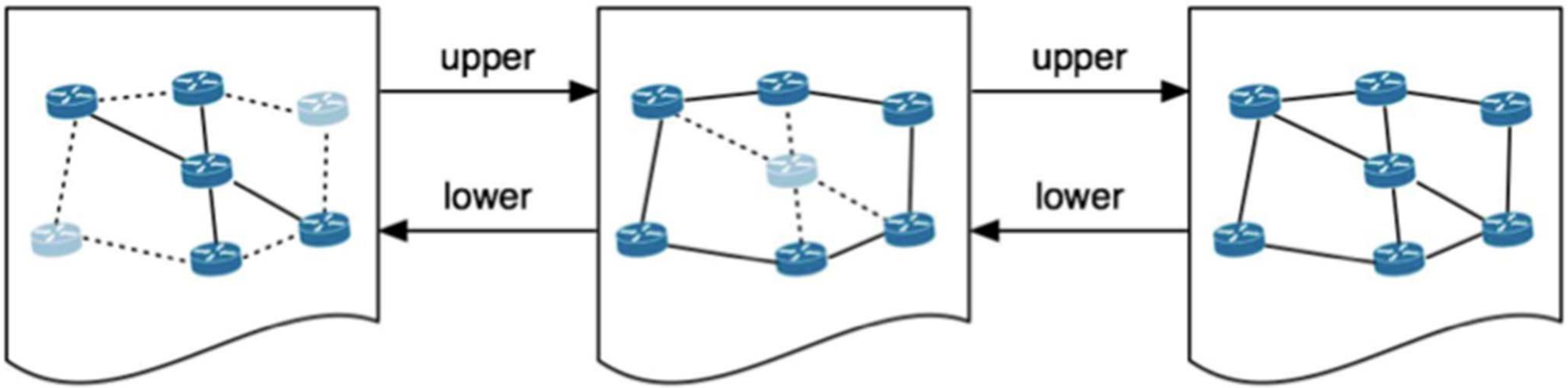


From node power profile to network profile



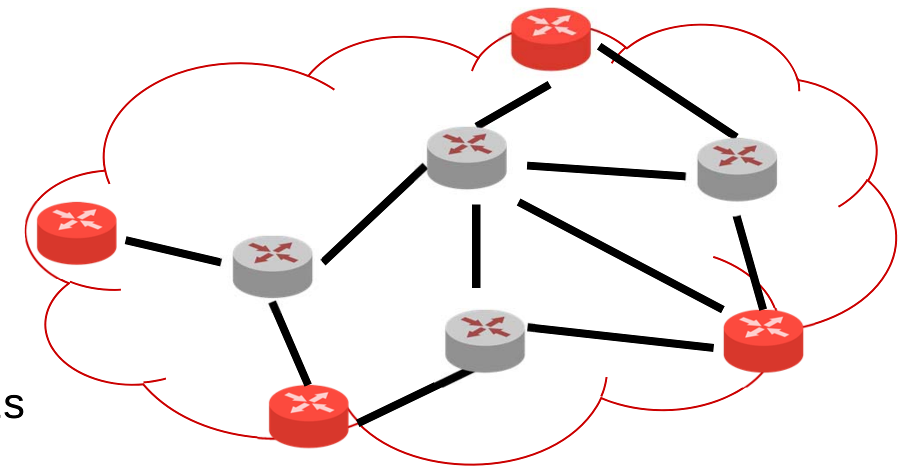
Energy management

- Energy management at system level selectively puts in sleep some of the network nodes and/or their interfaces to save energy
- Network capacity is modified to fit the traffic demand



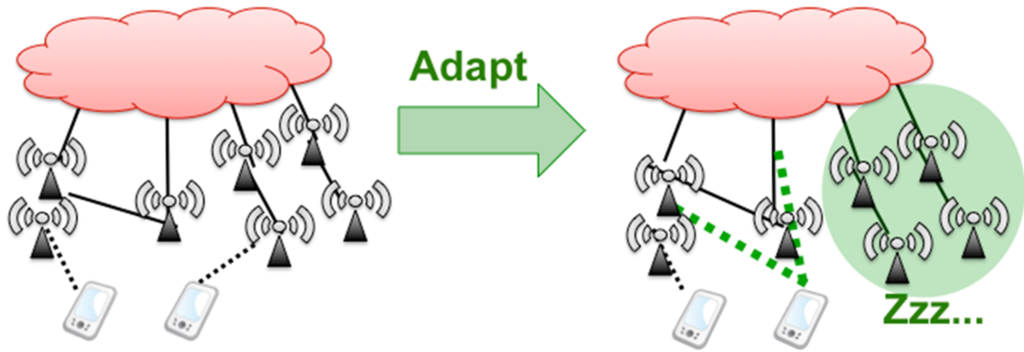
Energy management from an optimization point of view

- From an optimization point of view, it basically consists of a dynamic **network design** where network topology is re-optimized based on traffic patterns
- Classical network design problems:
  - Given:
    - traffic demands (pairs of source-destination with required traffic)
  - Decide:
    - Network topology
    - Link capacity
    - Node capacity
    - Routing
  - Subject to constraints:
    - Link and node load constraints



Energy management from an optimization point of view

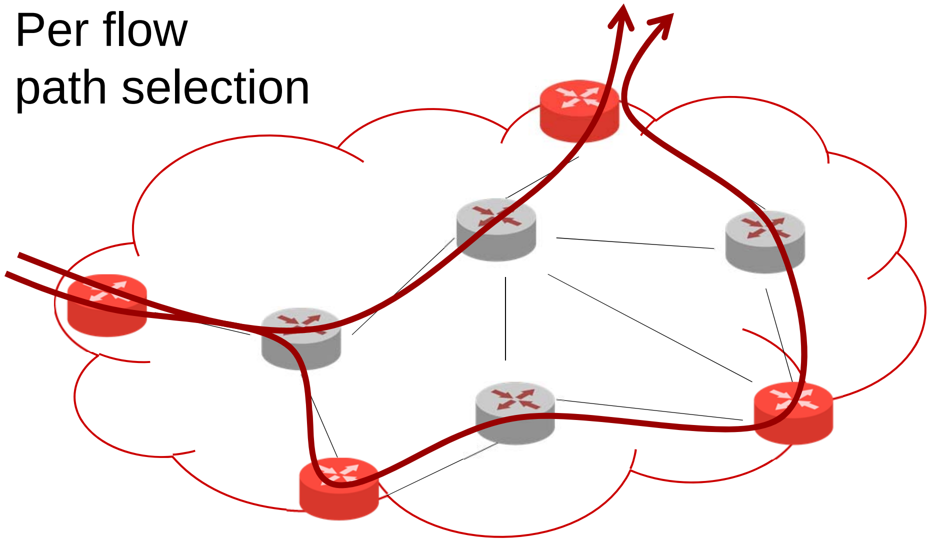
- Can we simply reuse the known results from network design models and algorithms?
- There are a number of issues that make the problems of energy management different:
  - Different traffic patterns cannot be optimized independently
  - Transition constraints; reconfiguration costs; design and operational issues; unexpected traffic variations; QoS vs energy tradeoff; resilience vs energy tradeoff; etc.



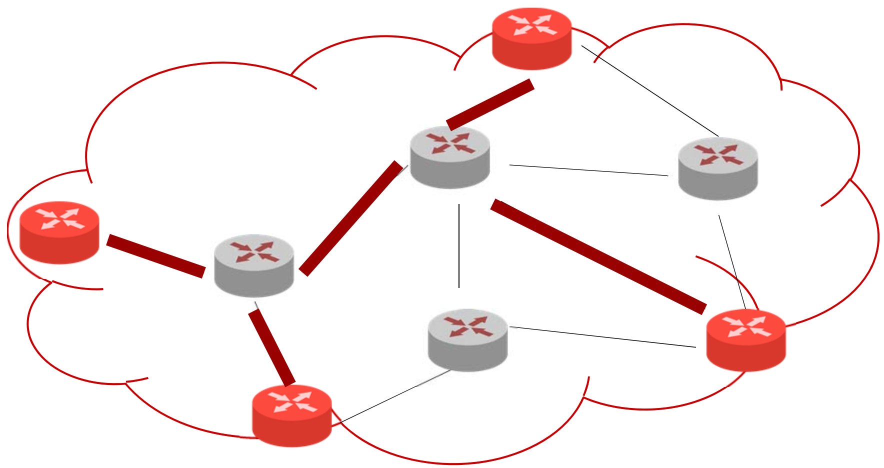
IP Networks

- Two possible approaches to IP routing:
  - Flow based (MPLS – Multi Protocol Label Switching)
  - Shortest Path routing (Open Shortest Path First)

Per flow path selection

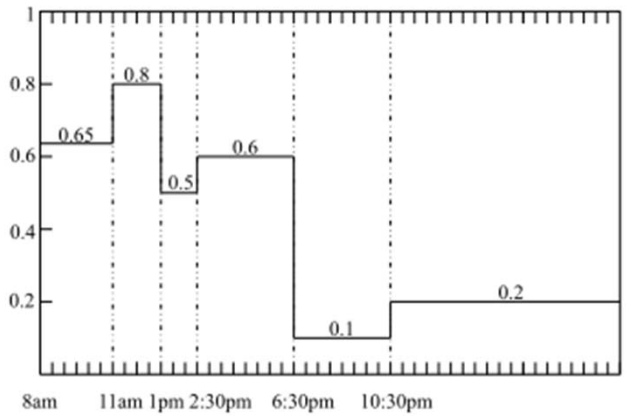


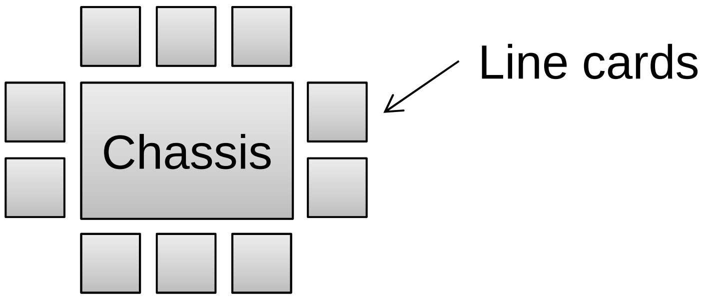
Link weigths w_i



MPLS: flow based management

- **Basic model**: network design with multi-commodity flows, cost minimization (energy)
- **Our approach**: multi-period optimization, on-off constraints, switch-on cost, router model with chassis and line cards, fixed and variable routing





[TON13] B. Addis, A. Capone, G. Carello, L.G. Gianoli, B. Sansò, "Energy Management through Optimized Routing and Device Powering for Greener Communication Networks”, ACM/IEEE Trans. on Networking, in press (available online), 2013.

MPLS: flow based management

Model structure

Objective function:
Sum of consumption in periods
+ transition consumption

Single period:

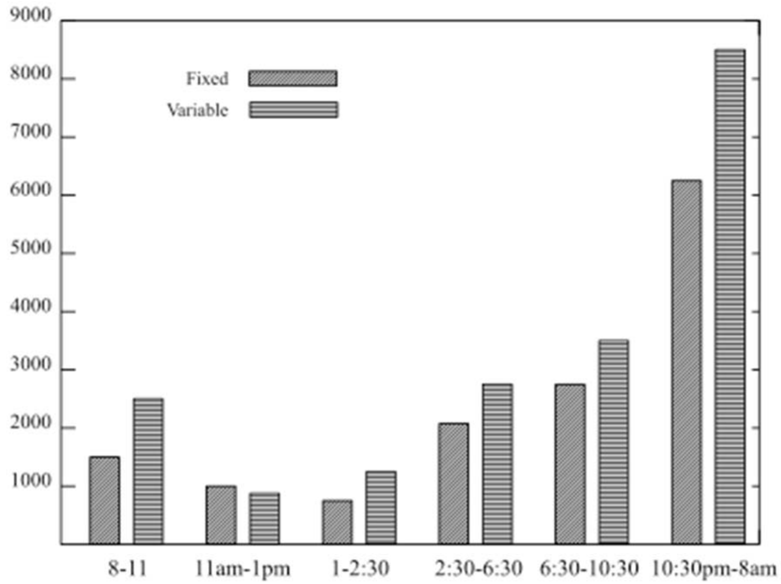
Single period:
Network design on a given topology
Single path routing
Capacity constraints/dimensioning on links (number of line cards active)

...

Transition constraints

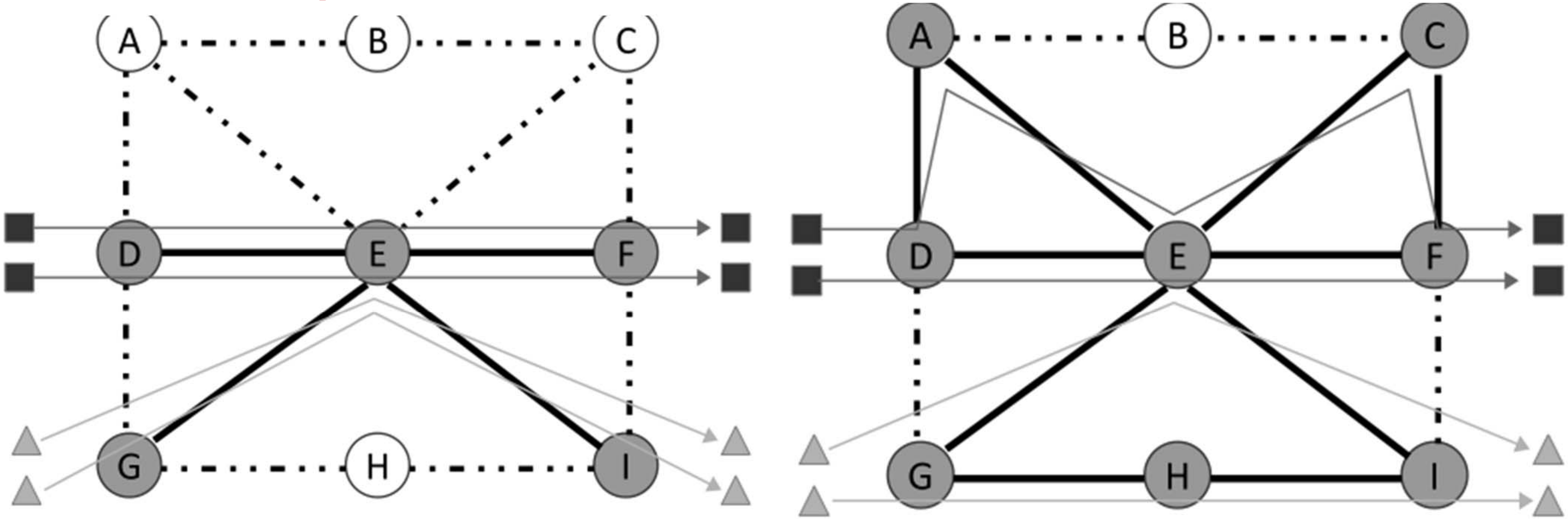
MPLS: flow based management

- Lesson learned
  - **Model:**
    - Modeling the problem less trivial it may appear
    - Complexity (MILP solvers) quite higher than classical network design
  - **Results:**
    - With well dimensioned networks energy savings in the order of 55% (expected higher savings in real ntw)
    - Heuristics (GRASP, single period) can achieve good performance (gap 5-7%) in reasonable time
    - Trade-off link utilization (QoS) and energy
    - On-line version with period-by-period optimization



MPLS: Protection and robustness

Non protected **Robust**



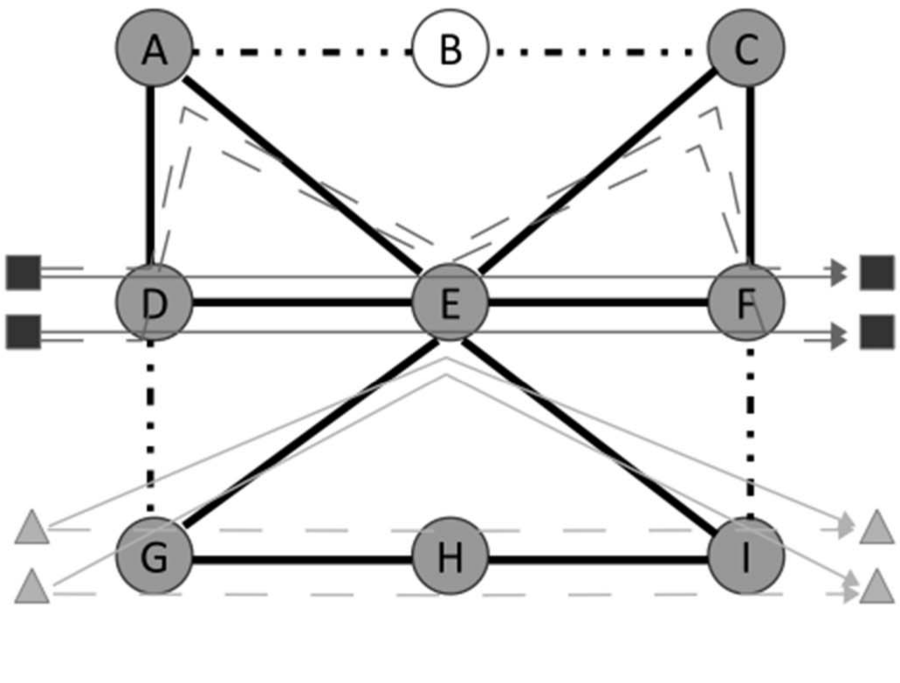
(a) Simple: 4 nodes and 10 links put to sleep

(b) Robust: 1 node and 4 links put to sleep

[SustainIT12] B. Addis, A. Capone, G. Carello, L.G. Gianoli, B. Sansò, Energy aware management of resilient networks with shared protection, SustainIT 2012
[ICNC13] B. Addis, A. Capone, G. Carello, L.G. Gianoli, B. Sansò, A robust optimization approach for energy-aware routing in MPLS networks, ICNC 2013.
[ComNet13b] B. Addis, A. Capone, G. Carello, L.G. Gianoli, B. Sansò, Robust Energy Management Green and Survivable IP Networks, Computer Networks, under review.

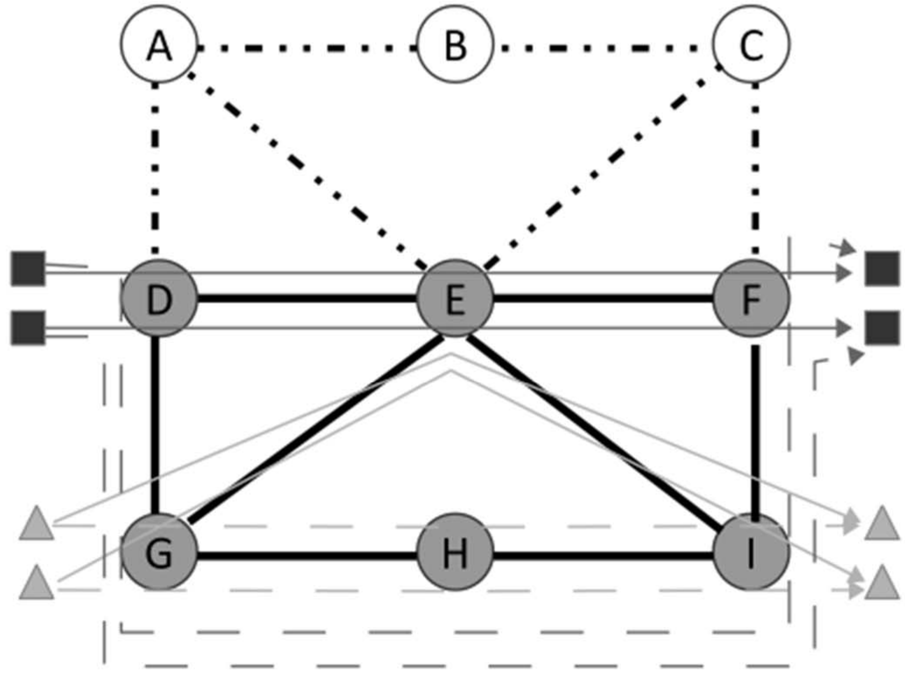
MPLS: Protection and robustness

Dedicate protection



(c) Dedicated prot: 1 node and 4 links put to sleep

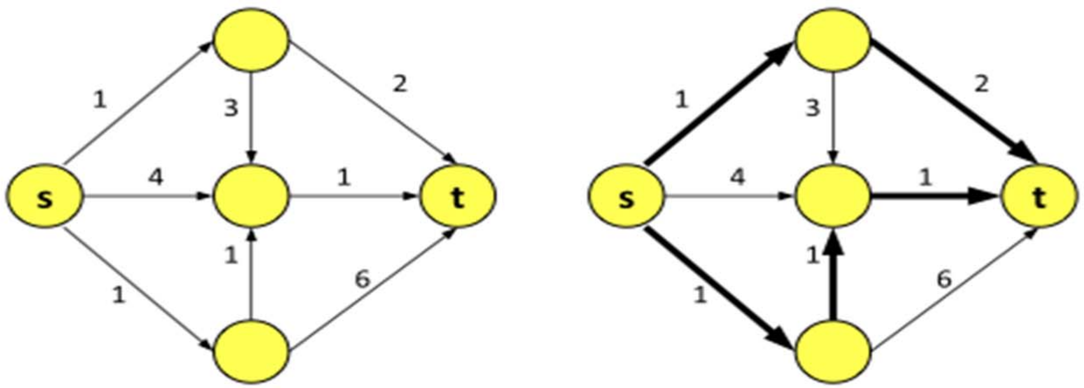
Shared protection



(d) Shared prot: 3 nodes and 6 links put to sleep

OSPF: weight optimization

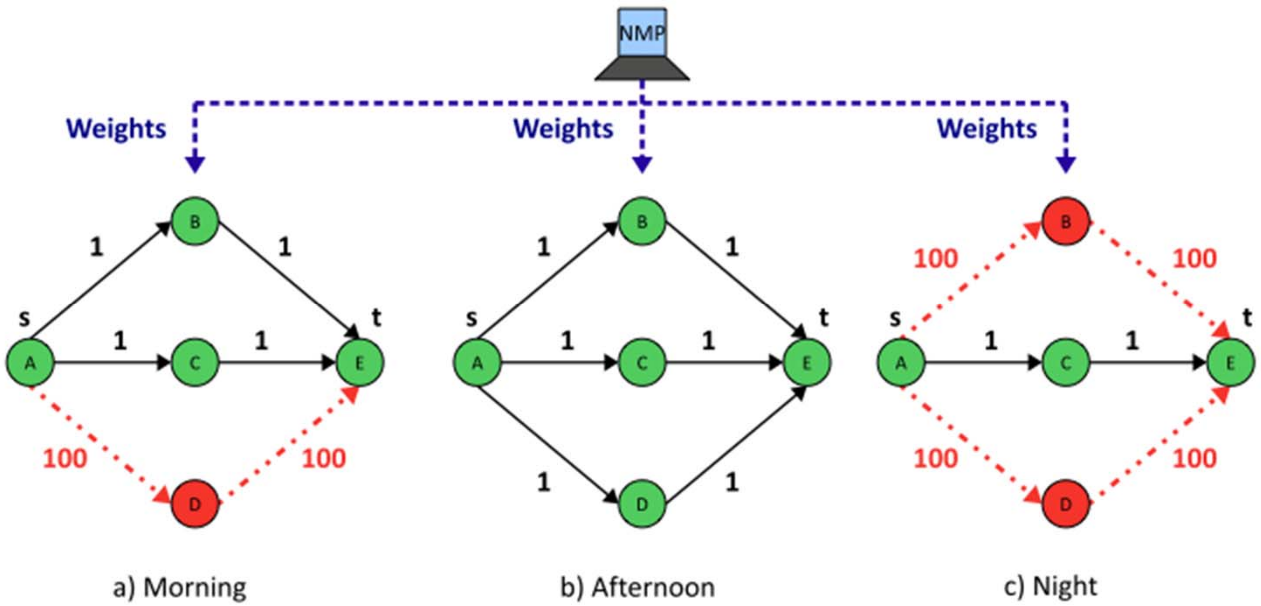
- IP networks operated with **Open Shortest Path First** (OSPF)
  - A **weight** assigned to each link
  - A demand d_{sd} routed along the **shortest paths** between nodes s and t
- Equal cost multi-path rule, **ECMP**
- **Traffic engineering** ⇒ Adjust the link weights



$d_{st} = 2$ 1 unit along each path

OSPF: weight optimization

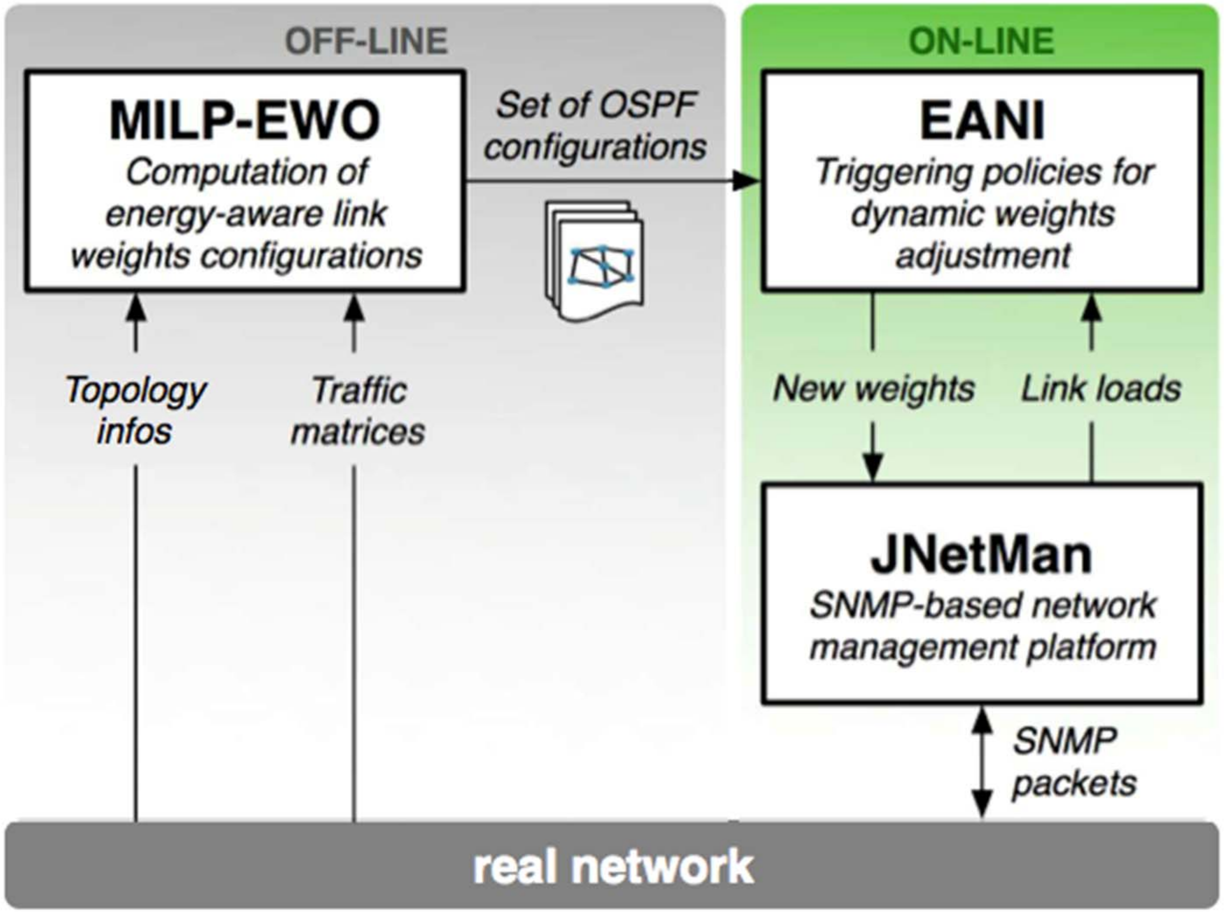
- **Models and algorithms**
  - Weight optimization for energy saving
  - MILP formulation and heuristics



[ComNet13a] E. Amaldi, A. Capone, L.G. Gianoli, “Energy-Aware IP Traffic Engineering with Shortest Path Routing”, Computer Networks, vol. 57, no. 6, April 2013, pp. 1503–1517.

OSPF: weight optimization

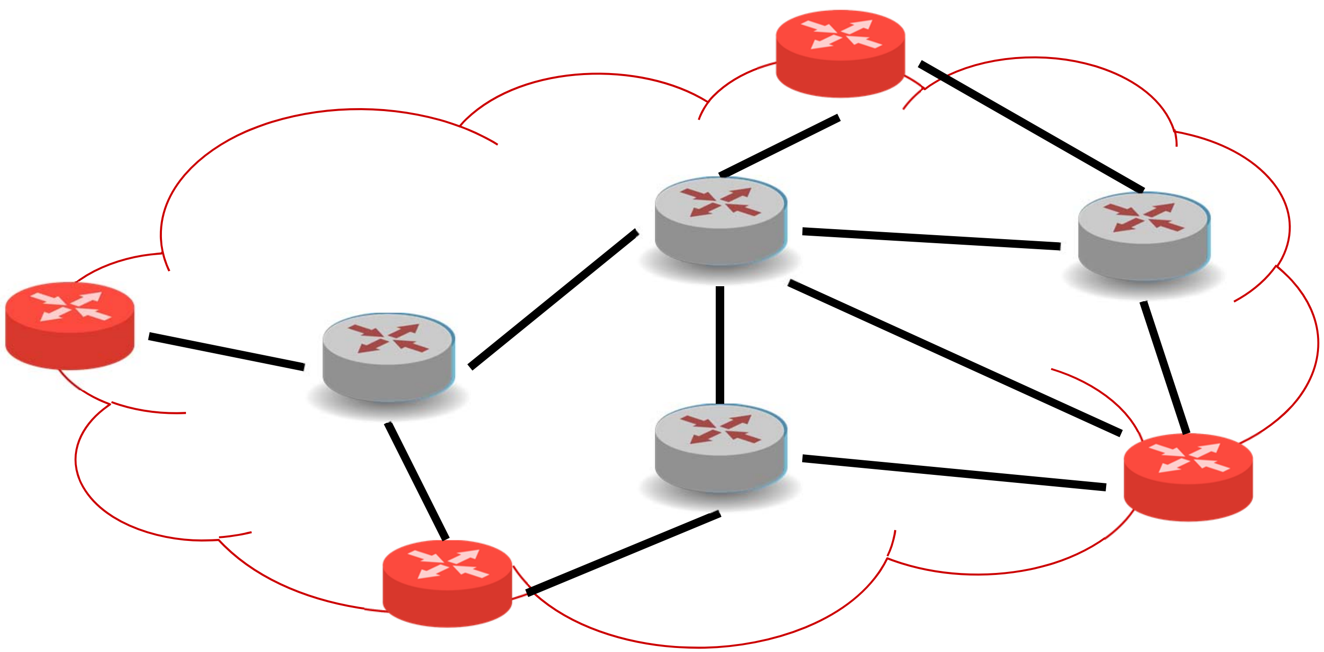
- Prototype implementation



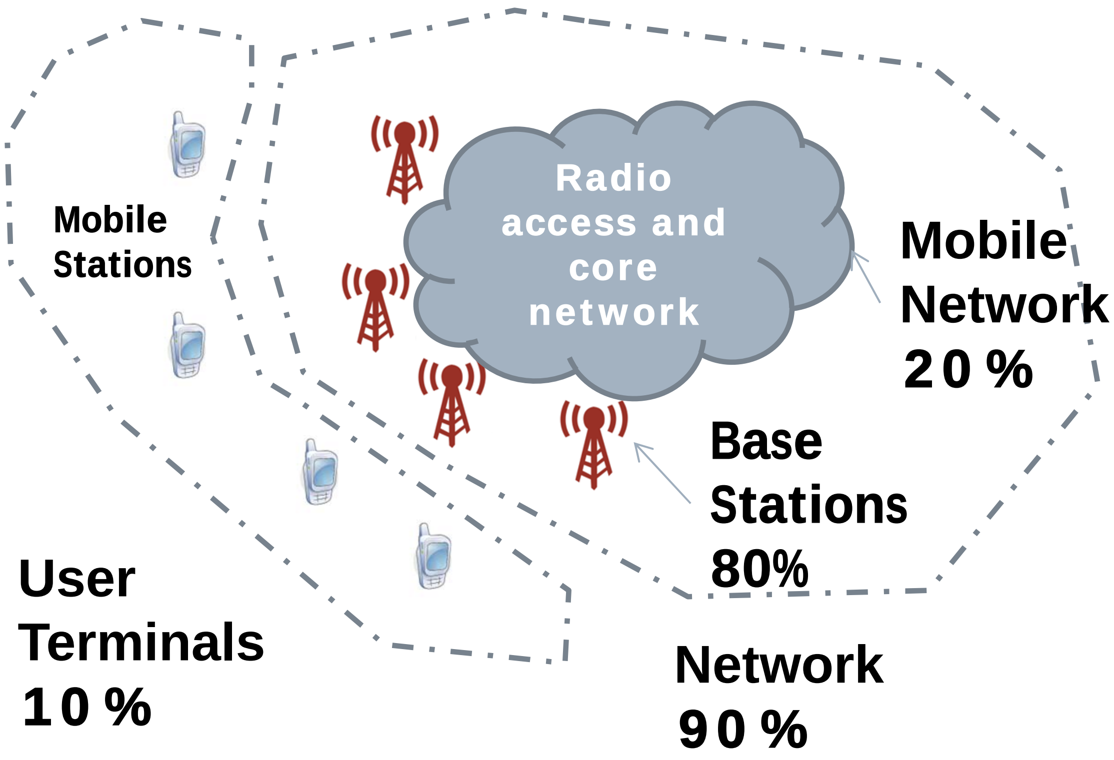
JNetMan:
New POLIMI open source project
www.jnetman.org

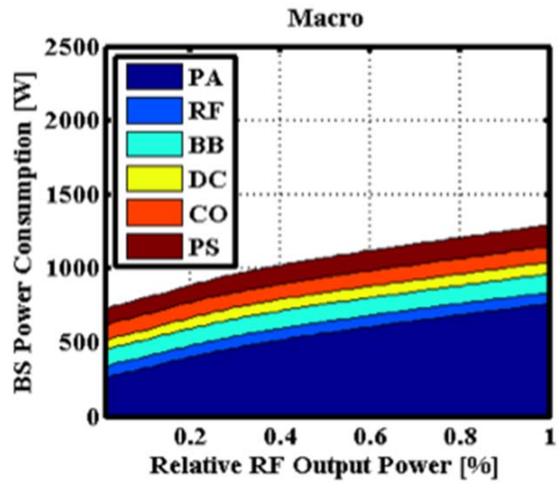
Load proportional?

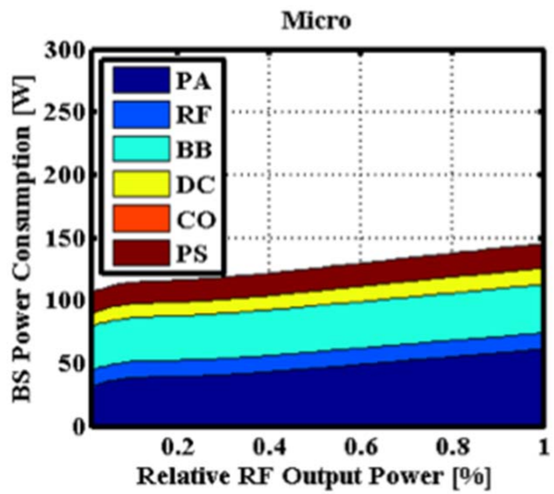
- **Minimum energy consumption due to always active network edges**
- Depending on technology a spanning tree always active may be necessary



What about wireless networks?

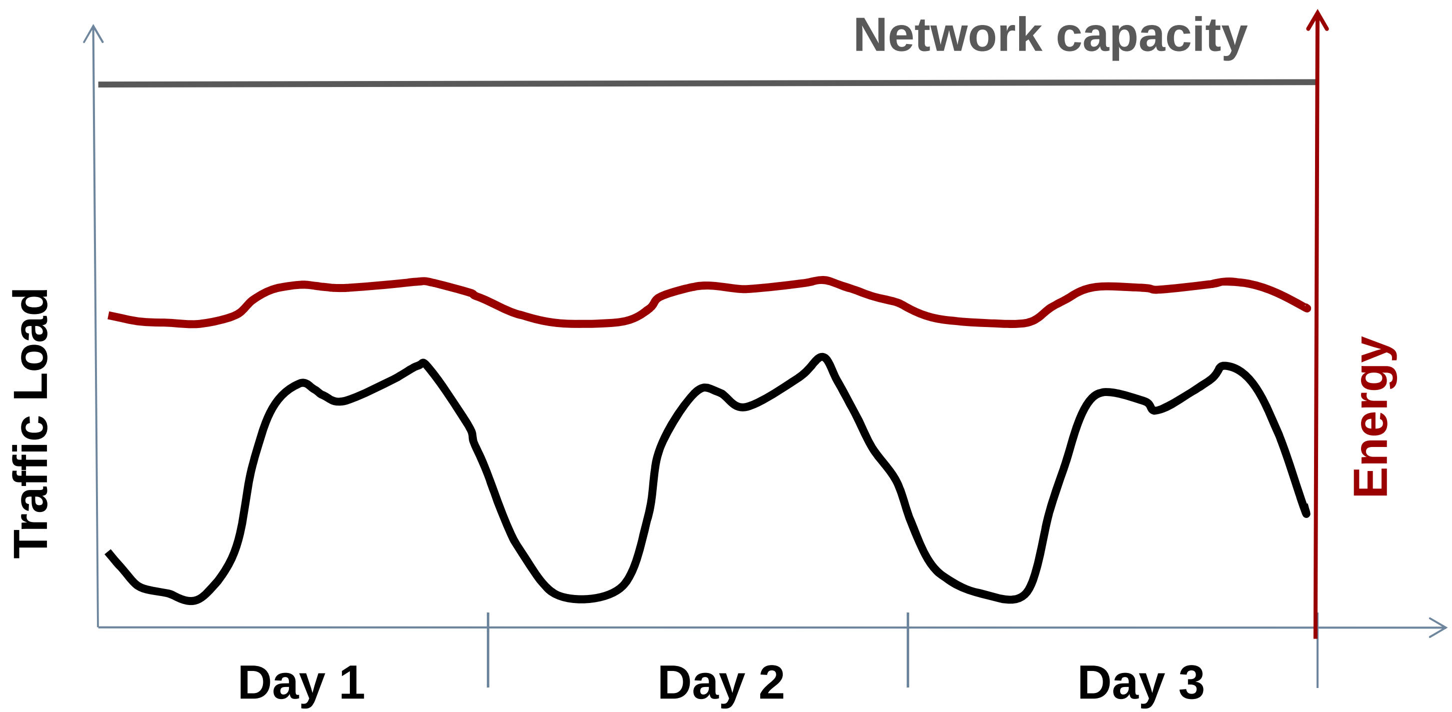






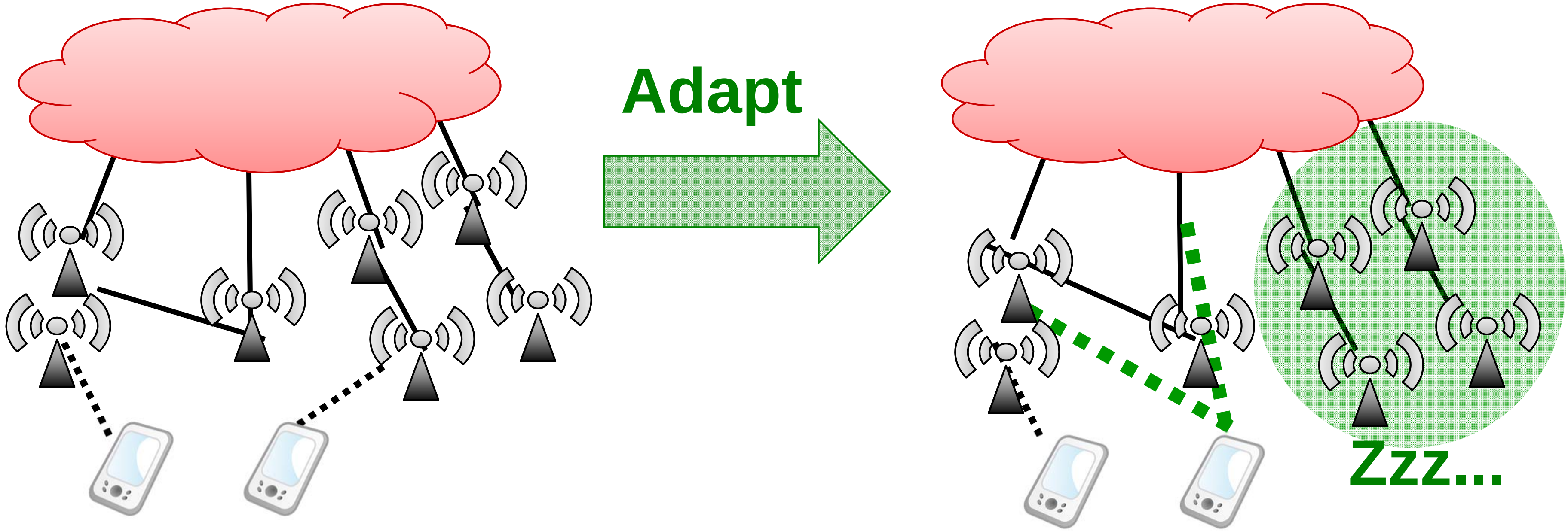
Source: EARTH project and GreenTouch

Wireless access: variable load & overprovisioning



- Wireless access networks are dimensioned for estimated peak demand using dense layers of cell coverage
- Large capacity overprovisioning (5-10x) to account for time and geographical variations

Wireless access: Energy Management

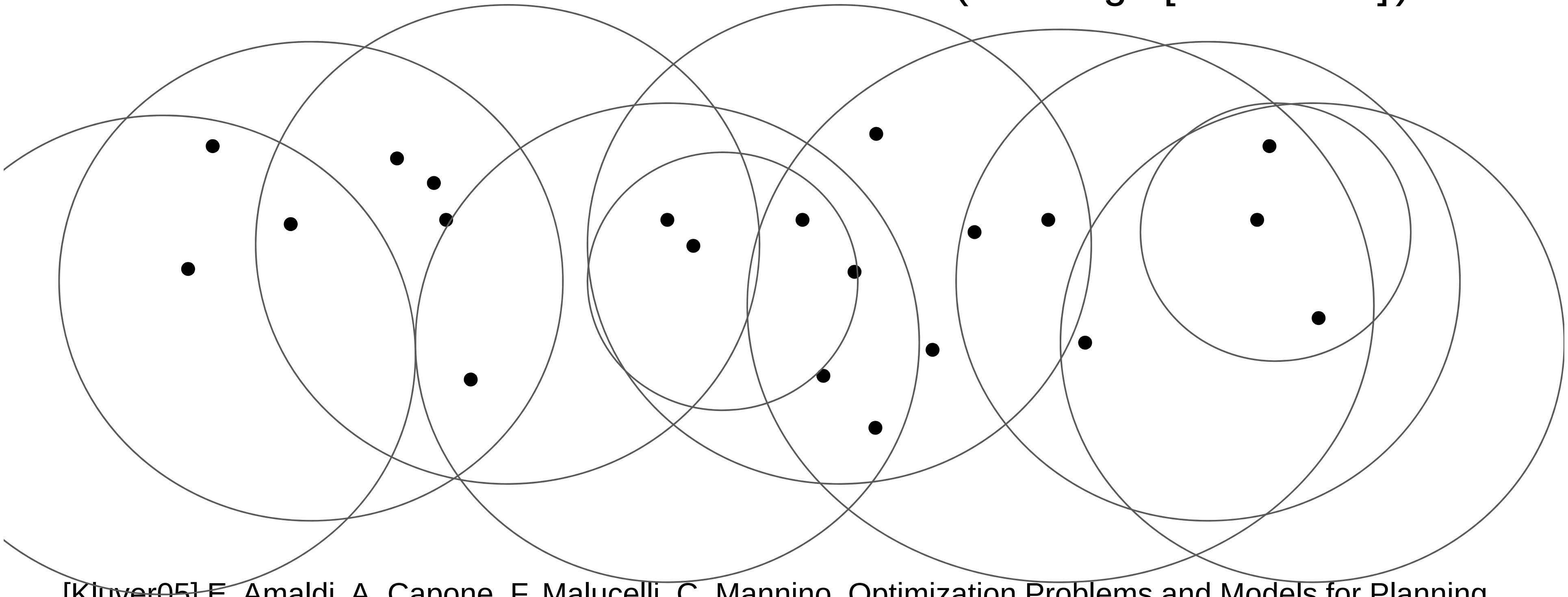


- Real-time network adaptation based on load requirements
- Support of sleep modes

[ComNet11] J. Lorincz, A. Capone, D. Begusic, “Optimized network management for energy savings of wireless access networks”, Computer Networks, vol. 55, no. 3, 21 February 2011.

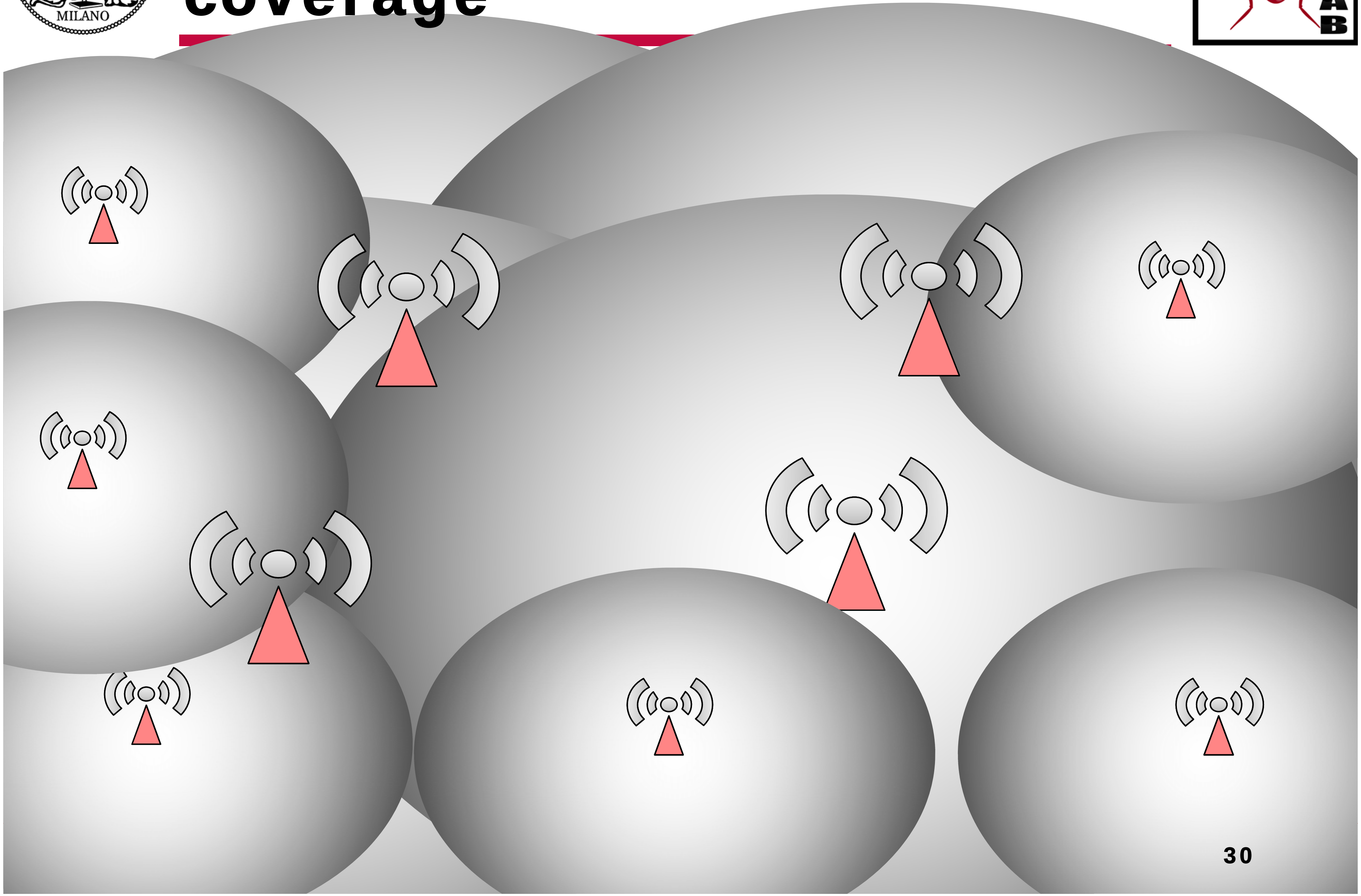
Wireless access: Energy Management

- **Modeling issues:**
  - The basic model is a radio planning problem
  - Several extensions of the set covering problems for the radio scenario available in the literature (see e.g. [Kluver05])



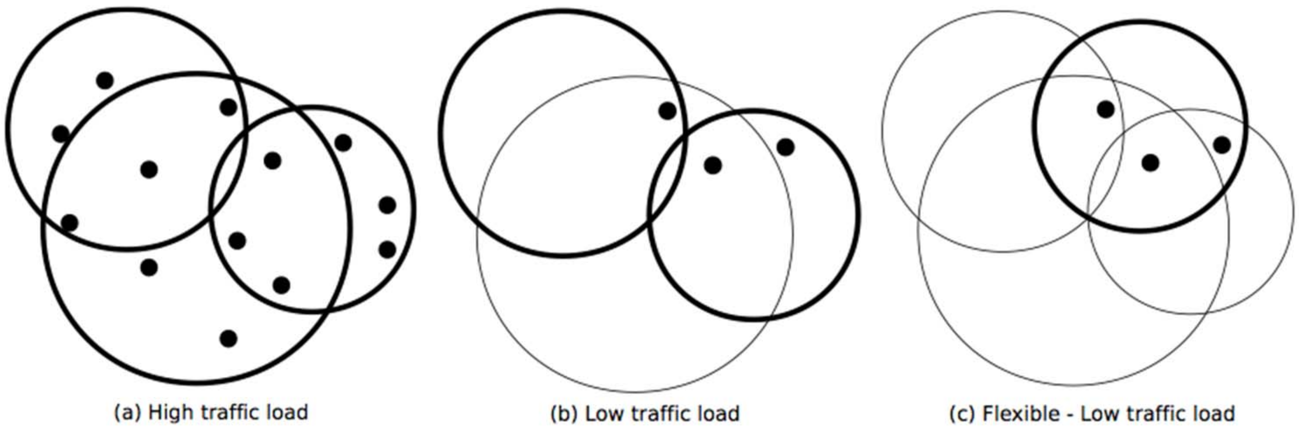
[Kluver05] E. Amaldi, A. Capone, F. Malucelli, C. Mannino, Optimization Problems and Models for Planning Cellular Networks, in Handbook of Optimization in Telecommunications, Kluver Academic Publishers, 2005.

Energy adaptation with full coverage



Wireless access: Energy aware network design

- If in addition to management we consider design, things get more interesting
- Not all network layouts are good to be managed according to traffic variations and save energy
- Spare capacity makes system more flexible and able to save energy



[ComNet13c] S. Boiardi, B. Sansò, A. Capone, “Radio Planning of Energy-Aware Cellular Networks”, Computer Networks, in press (available online), 2013.

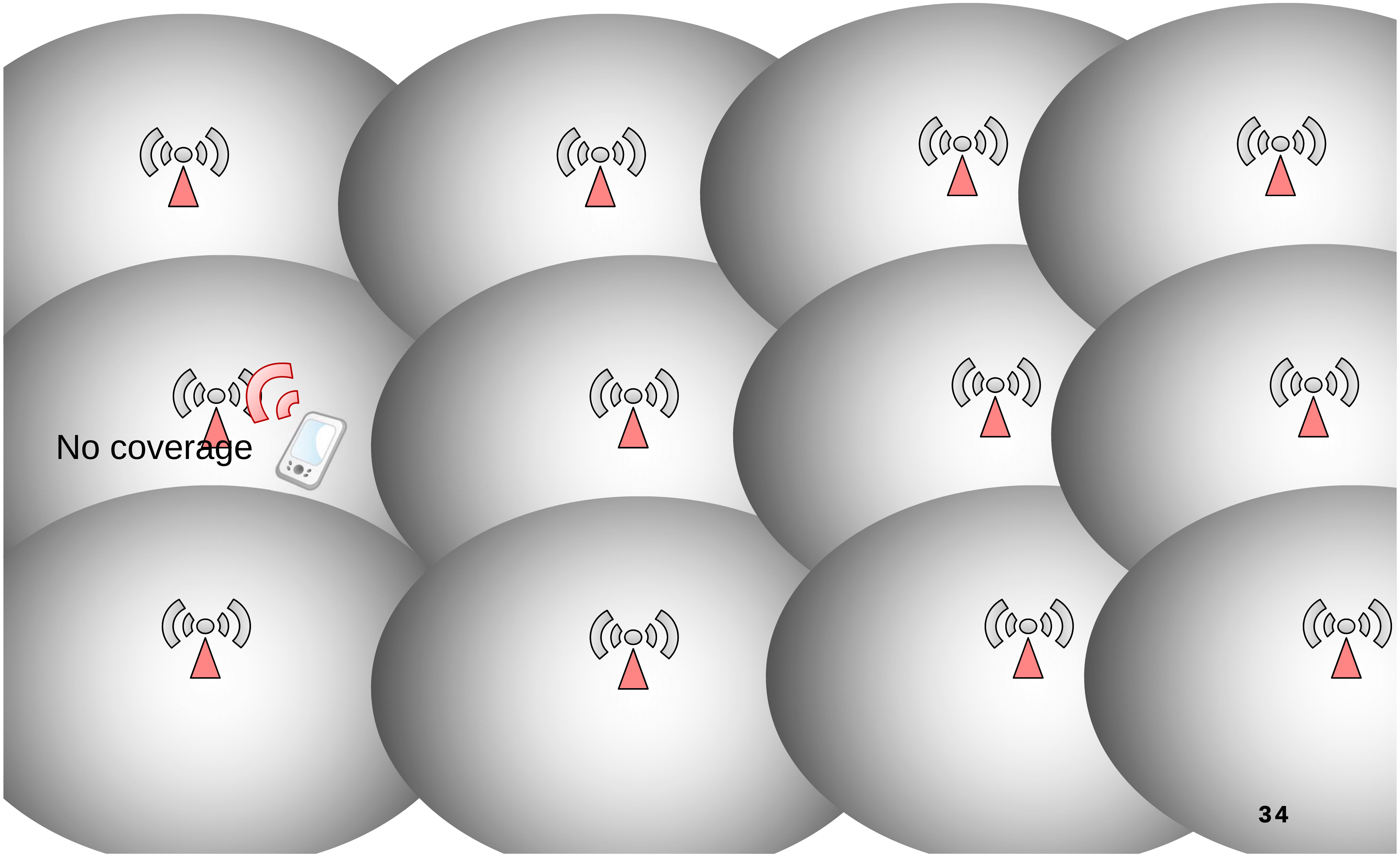
Load proportional?

- There are some limiting constraints of the traditional cellular architecture that prevent high energy savings
- Cellular networks require **full coverage** of the service area for supporting the **any-time everywhere service** paradigm
- Turning off some base stations is possible only if their areas are covered by some other base stations that are active
- **Large overlaps** among cells is required
- **Capacity over-provisioning** for flexibility allowance (CAPEX vs OPEX)

Limits of traditional cellular architectures

- It has been shown that with traditional cellular technologies **energy savings** in the range of **20%-40%** can be achieved
- Due to traffic increase an higher energy efficiency it is expected that in the future **micro and pico cellular layouts** will be preferred over traditional macro cellular ones
- This may even **reduce the savings** achievable with energy management since most of the base stations are essential for providing full coverage

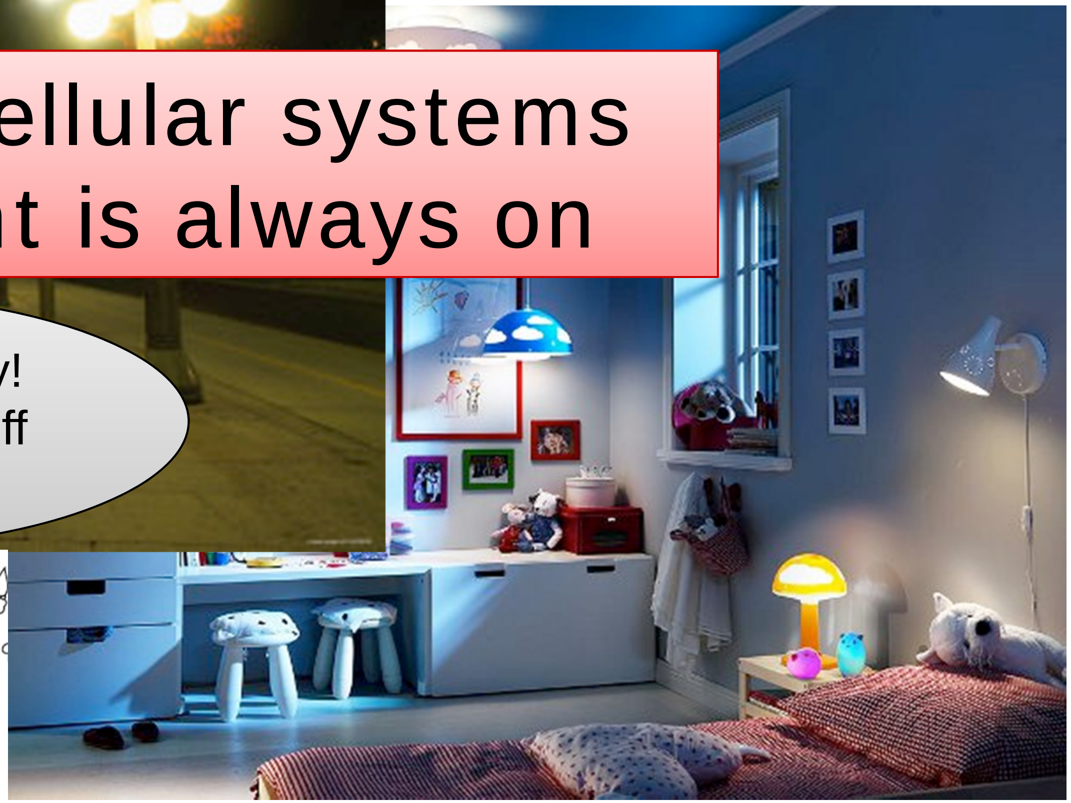
Micro-cellular coverages

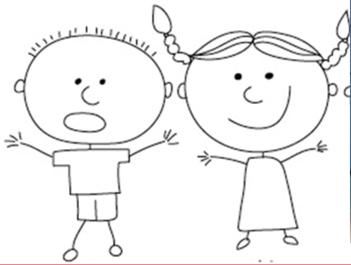


Mum’s rule applied to wireless networks

In cellular systems light is always on

Kids, dinner is ready!
Remember to turn off the light





Beyond cellular

- We need to go beyond the cellular paradigm that requires always-on full coverage
- And move towards an **"on demand" coverage** model
- While guaranteeing service availability everywhere and anytime

[WONS12] A. Capone, A. Fonseca dos Santos, I. Filippini, B. Gloss, Looking Beyond Green Cellular Networks, 9th Annual Conference on Wireless On-Demand Network Systems and Services (WONS)

[Sustainit12] A. Capone, I. Filippini, B. Gloss, U. Barth, Rethinking Cellular System Architecture for Breaking Current Energy Efficiency Limits, SustainIT 2012

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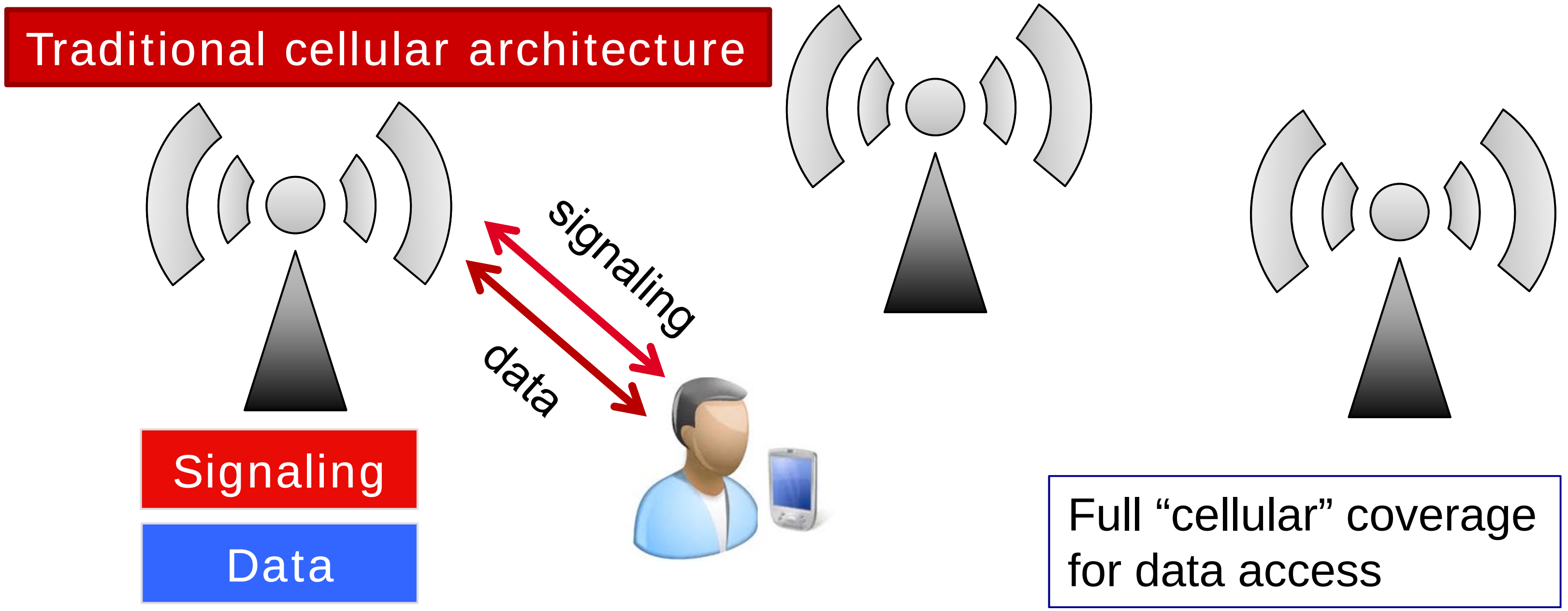
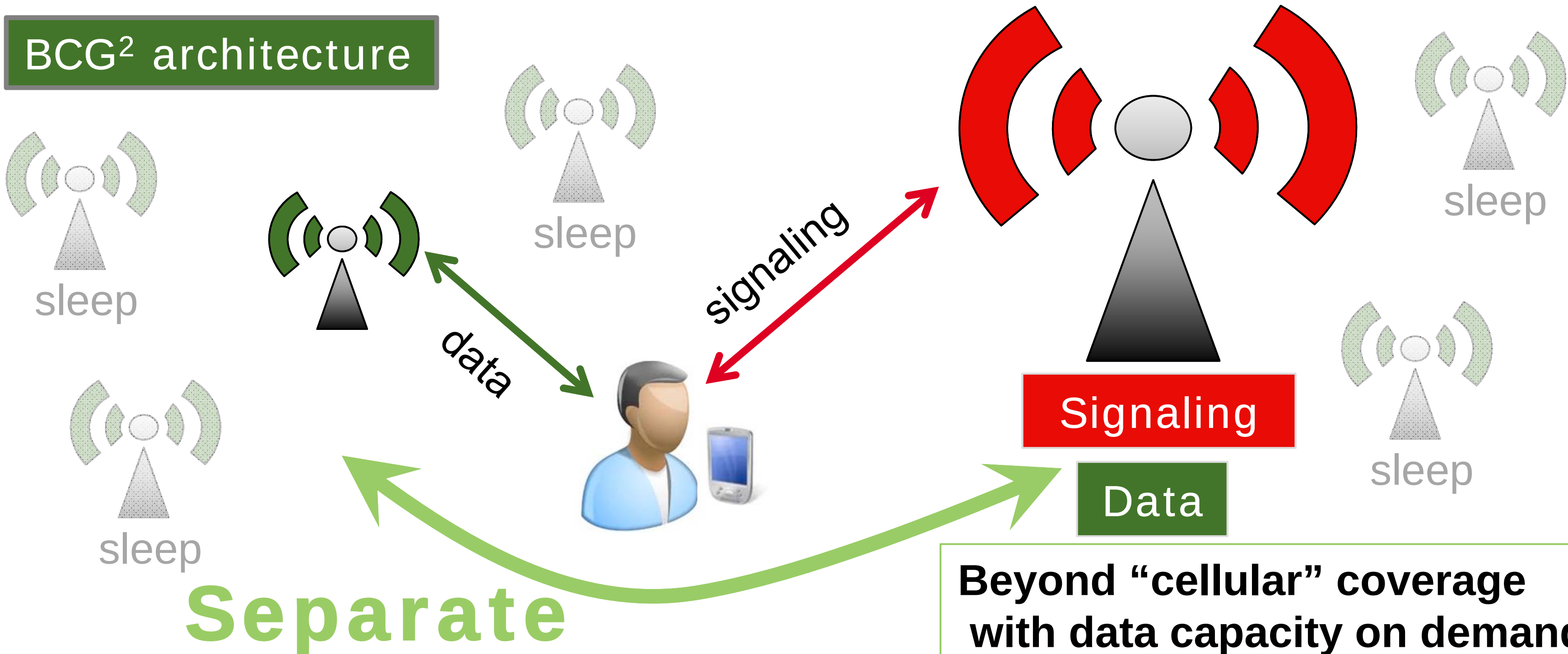
BCG²: Basic idea



Limitation of traditional cellular architecture:

- Continuous and full coverage for data access
- Limited flexibility for energy management
- High energy consumption also at low traffic load

BCG^2: Basic idea



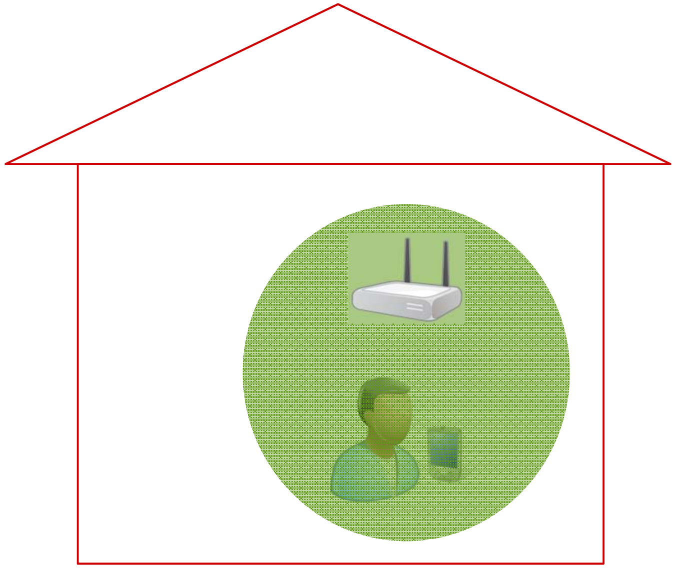
Beyond "cellular" coverage with data capacity on demand

Separation of signaling and data functions at the radio interface:

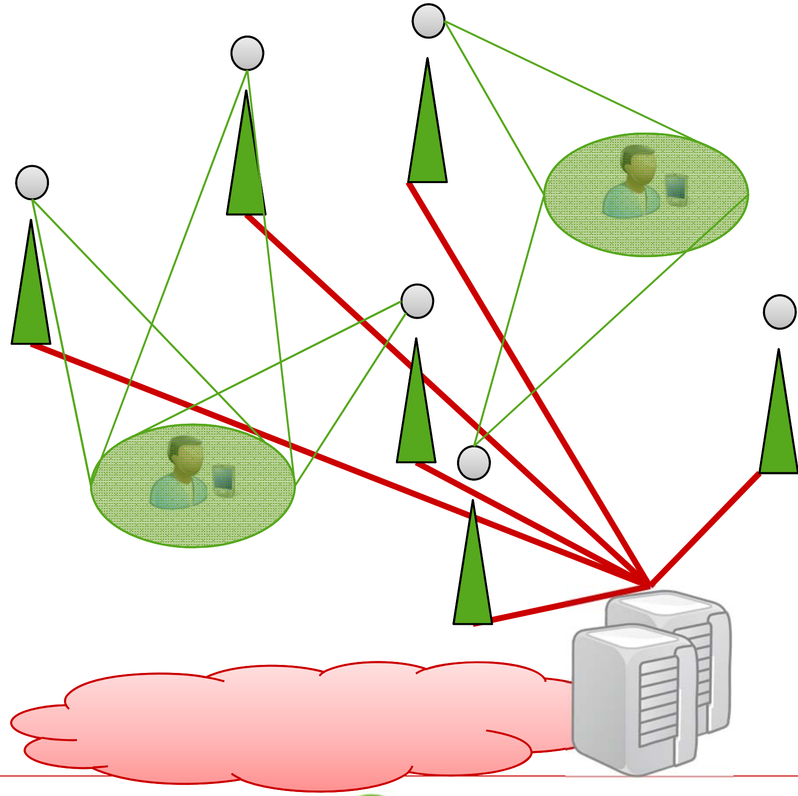
- Full Coverage and always available connectivity ensured by signaling base stations only
- Data access capacity provided by data base stations on demand

Long term view: Individual cells

- **Long term scenario**



1) From femto cells
to individual "**atto cells**"



2) Individual **virtual cells**
with centralized
processing and distributed
antennas

Conclusion

- Achieving **load proportional** energy consumption is the first step for **environmental sustainability** of the communication infrastructure and still an **open challenge**
- From a **modeling and optimization** point of view it offers the opportunity to revise classical **network design and management problems** under a new light
- From the analysis of the **fundamental limits of** current systems, ideas on brand **new architectures** may arise

Full list of references

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Thanks!

Questions

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