



---

# Research on energy-efficient networking in the TREND Network of Excellence

---

Fabio Neri (Politecnico di Torino, Italy)

neri@polito.it

iMinds 2010: Innovation, Incubation, Inspiration

16 December 2010, Ghent, Belgium





---

# Towards Real Energy-efficient Network Design

Grant agreement n. 257740  
THEME [ICT-2009.1.1]  
[The Network of the Future]

---

The aim of the TREND Network of Excellence (started September 2010, with duration 3 years) is to foster the **integration** of the EU research community in *green networking* with a long term perspective to consolidate the European leadership in the field

<http://www.fp7-trend.eu>



# Power consumption of ICT



- ❑ ICT is today responsible for 2% to 10% of the worldwide power consumption
- ❑ Some studies predict that 50% of the world electricity will be used by ICT in a few years: the new generations of Internet applications may require amounts of electricity that cannot be generated nor transported to major metropolitan areas
- ❑ This may end up limiting the penetration of broadband networking
  
- ❑ Energy-efficient networking has recently become a very fashionable research topic
- ❑ Too many buzzwords and too few data
- ❑ Need to understand which are the real possible gains, if any, of power awareness and power efficiency in networking

---

# Why a Network of Excellence?



- The European technical community can claim both a strong background in networking and a high level of environmental consciousness
- There exists a significant market potential for green networking equipment
- In the above framework, a NoE is the perfect instrument for promoting awareness and contributing to build a sound knowledge base in the scientific community
- TREND is a small NoE, with strong industrial participation and commitment, and a significant commitment on (joint) research activities

# Questions addressed by TREND



- *What is the real power consumption of ICT?*
- *In which sections of network infrastructures (home, access, core, data center) can energy-conscious approaches be more effective?*
- *Can optical technologies help in significantly reducing power consumption?*
- *Is the current Internet architecture, and TCP/IP in particular, energy friendly?*
- *What are the best engineering criteria and principles to actively support energy efficiency along the sequence of network design, planning, and operation?*
- *What kind of mutually beneficial incentives can be proposed to network operators, service providers, and users, in order to maximize energy efficiency?*

# TREND topics



## Energy efficiency in network infrastructures:

- ❑ Estimation of power consumption in ICT and collection of data
- ❑ Assessment of the fundamental energy-saving potential of network technologies and protocols
- ❑ Guidelines for policies and incentives to stimulate energy-efficiency in networks
- ❑ Redesign the home equipment for energy efficient communications
- ❑ Organizing the flying bits: saving energy on wireless access
- ❑ Power on/off strategies for energy saving and transparent connectivity
- ❑ Energy-efficient networking equipment
- ❑ Energy-efficient network design and control
- ❑ Energy-efficient service provisioning and content distribution
- ❑ Energy-efficient protection schemes
- ❑ Tools for power management and power management protocols

# TREND partners



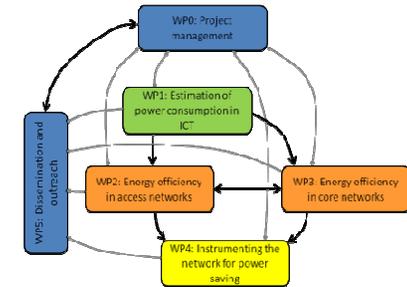
- (1) POLITECNICO DI TORINO
- (2) ALCATEL - LUCENT BELL LABS FRANCE
- (3) HUAWEI TECHNOLOGIES DUESSELDORF GmbH
- (4) TELEFONICA INVESTIGACION Y DESARROLLO SA
- (5) FRANCE TELECOM SA
- (6) FASTWEB SPA
- (7) UNIVERSIDAD CARLOS III DE MADRID
- (8) INTERDISCIPLINARY INSTITUTE FOR BROADBAND TECHNOLOGY
- (9) TECHNISCHE UNIVERSITAT BERLIN
- (10) ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE
- (11) CONSORZIO NAZIONALE INTERUNIVERSITARIO PER LE TELECOMUNICAZIONI
- (12) PANEPISTIMIO THESSALIAS (UNIVERSITY OF THESSALY)

# TREND organization



- 12 partners (2 manufacturers – 3 telecom operators – 7 university groups) + 7 Collaborating Institutions (participating to research and integration activities with no budget allocation), all with significant previous experience in the technical topics
- duration: 3 years
- estimated effort: 446 person-months
- project budget: 4.4 MEuro (34% for research, 35% for integration and structuring, 21% for spreading of excellence, 8% for project management)
- EC contribution: 3.0 MEuro

# TREND organization



- 6 workpackages:

- WP1: Assessment of power consumption in ICT
- WP2: Energy efficiency in access and home networks
- WP3: Energy efficiency in core networks
- WP4: Instrumenting the network for power saving
- WP5: Dissemination and outreach
- WP6: Project organization and management

- Integration enablers:

- Integrated Research Actions and Joint Experimental Activities
- mobility and joint publications
- joint education and dissemination



---

## Part 2: An interesting question

*«Is circuit switching more energy-friendly than packet switching?»*

---



---

# Packet versus circuit switching

- Is circuit switching to be preferred to packet switching in terms of energy efficiency?
- Interesting questions/research issues arise in the domains of:
  - Transmission
  - Switching
  - Networking

---

# Packet vs circuit: Transmission (I)

- Packet switching requires more information overheads (packet headers) hence more power
- Continuous-mode versus burst-mode operation of transmission lines:
  - Current physical layers are mainly continuous-mode: line always active; idle bits/cells transmitted between useful information
  - Even Ethernet has evolved to continuous-mode
  - Burst-mode operation: no power between packets; new synchronization and receiver adaptation at every packet

---

# Packet vs circuit: Transmission (II)

- Burst-mode operation can save significant power with typical link loads. But burst-mode operation:
  - Is more complex and power costly
  - Has more synchronization issues
- Hybrid continuous-/burst-mode operation is an interesting option
  - Similar to powering off idle continuous-mode lines
  - Fast resynchronization of waking-up lines is necessary
- Is burst-mode operation applicable to circuit switching? Idle detection techniques (which are application dependent) should be devised ...

---

## Packet vs circuit: Transmission (III)

- Digital operation: take decisions on every bit at the receiver (*Is this signal a '0' or a '1'?*)
- Is digital operation on every link along the source-destination path necessary?
- Analog operation (*amplify and forward the received signal waveforms*) is less power-hungry
- What about network management and security?

---

# Packet vs circuit: Switching (I)

Packet switching not easy to define:

*“distributed, progressive, header-based resource allocation, with storing and discarding of data units”*

Current circuit switching devices consume less power than packet switching devices

---

## Packet vs circuit: Switching (II)

- Packet switching was not conceived for energy efficiency
- Issues related to power consumption
  - Large buffers are needed to solve contentions in a distributed fashion
  - Header processing and routing/forwarding operations are needlessly repeated on all packets belonging to the same flow
  - The switching fabrics must be reconfigured at rates that depend on line rates and on packet sizes, not on Quality of Service requirements

---

## Packet vs circuit: Switching (III)

- TCP/IP was not conceived for energy efficiency
- Issues related to power consumption
  - The stateless IP paradigm asks for independency between datagrams belonging to the same flow, hence causes needlessly repeated switching operations
  - TCP generates acknowledgement packets
- But TCP/IP is very difficult to modify ...

---

# Packet vs circuit: Switching (IV)

- Other interesting questions for pkt switching:
  - Packet sizes:
    - Larger packets require smaller switching rates (less power) but larger buffers (more power)
  - Synchronous vs. asynchronous switch operation:
    - Segmentation/reassembly of variable-size packets into fixed-size switched data units has power costs
    - Independent clock domains for different subsystems in switching devices require more adaptation buffers but less energy costs for clock distribution
- Packet switching easily permits dynamic voltage (hence power?) scaling

---

# Packet vs circuit: Networking (I)

- Centralized resource allocation schemes and traffic schedulers avoid distributed contention resolution:
  - Less need for buffering in switches
  - Less intelligence in switches
  - More signaling traffic
  - Does it scale?
- Fast circuit switching (e.g., one circuit per web page) appears as a good solution
- Will the Internet become the control plane of an analog circuit-switched WDM network?

## Packet vs circuit: Networking (II)

- Switching vs multiplexing: given the bandwidth abundance of optical fibers, and the flexibility permitted by wavelength agility, contention resolution and traffic grooming can be avoided in most switching devices
- For example: two packets/flows competing for the same link are immediately forwarded on different (wavelength) circuits, and not buffered and transmitted at different times
- Extreme case: one end-to-end lightpath (i.e., one optical circuit) for every information flow → no packet switching

---

# Packet vs circuit: Networking (III)

- Buffering vs discarding packets: retransmissions have large power costs, and require extra buffering at edge nodes
- Should we look for lossless packet transport schemes (e.g., flow controlled FiberChannel)?
- Shared media are not energy-efficient:
  - useless load on receivers
  - coordination overheads (e.g., packet collisions, or token circulation)

---

# Packet versus circuit switching: Summary

- Interesting questions/research issues arise in transmission, switching and networking domains
- Do we still have to design networks for optimal bandwidth utilization, or rather minimize the amount of switching/power?
- Are we stepping back from packet to (some) circuit switching, and from digital to (some) analog operation?

---

## Part 3: A specific research activity ...

- Optical fibers offer bandwidth abundance
- Packet switching permits to efficiently use bandwidth by efficiently grooming information
- Can we trade bandwidth efficiency for energy?
- How much multiplexing and how much switching?

A. Bianco, E. Bonetto, D. Cuda, G.A. Gavilanes Castillo, M. Mellia, F. Neri, “Energy-Efficient Design of Wavelength-Routing Networks,” 35<sup>th</sup> European Conference on Optical Communication (ECOC 2010), Torino, Italy, Sept. 2009

---

# WDM networks

- Wavelength Division Multiplexing (WDM) networks transparently carry several information-bearing signals in optical fibers
- Wavelength Routing (WR) networks (also called Wavelength Switched Optical Networks - WSON)
  - Are the most used paradigm in WDM networks
  - Lightpaths (optical circuits) are routed over WDM fiber links thanks to (transparent, but slow) optical cross-connects, which operate in the optical domain
  - Optical cross-connects are less energy hungry than packet switches and routers
  - A sequence of one or more lightpaths is traversed from source to destination; electronic switching/grooming is performed at nodes terminating lightpaths

# WR network design

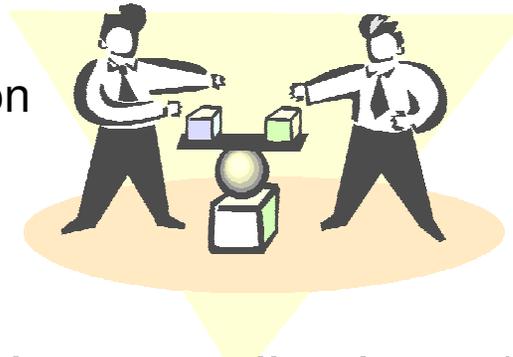
- The design of Wavelength Routed networks is usually separated into two sub-problems:
  - ❖ Logical Topology Design (LTD)
  - ❖ Routing and Wavelength Assignment (RWA)

*Given a traffic matrix, find a set of lightpaths (optical circuits) satisfying the traffic requests and optimizing a given target function (regardless of the physical topology)*

# PA-Logical Topology Design

- LTD: given the traffic matrix, find the best (in terms of cost/performance) lightpath set
- Power-Aware LTD (PA-LTD) target:
  - find the best trade-off between the utilization of electronic (for switching) and optical resources (for transmission)
  - Minimizing the total power consumption

Power due to  
optical transmission



Power due to  
electronic switching

- Power consumption contributions (for a given bitrate  $Rb$ )
  - $P^{SW}$ : electronic switches for grooming, add and drop traffic
  - $P^{TX}$ : optical transceivers for electro-optical conversion and transmission

---

# Logical topologies

- When  $P^{TX} \approx P^{SW}$ , PA-LTD (OPEX based) and traditional (CAPEX based) LTD find similar solutions, since they simply minimize the number of transceivers
- For  $P^{TX} < P^{SW}$ , the best topologies have more transmission and less switching, i.e., a larger number of lightpaths and of optical transceivers
- PA-LTD looks for the best compromise between the number of transceivers and the amount of traffic switched electronically (or between the amount of multiplexing and the amount of switching)

---

## Our PA-LTD

Each node is equipped with an electronic switch and a set of optical transceivers

- Transceivers (lightpaths) have a fixed capacity (10 Gbps) and consume a fixed nominal power ( $P^{TX} = 8W$ )
- Traffic is switched electronically at the edges of a lightpath, and the power cost of switching depends linearly on the amount of traffic

The parameter  $\nu^O$  (“efficiency of optics”) equals the ratio between optical transmission power and electronic switching power (at the same bitrate)

$$P^{SW} = \nu^O P^{TX}$$

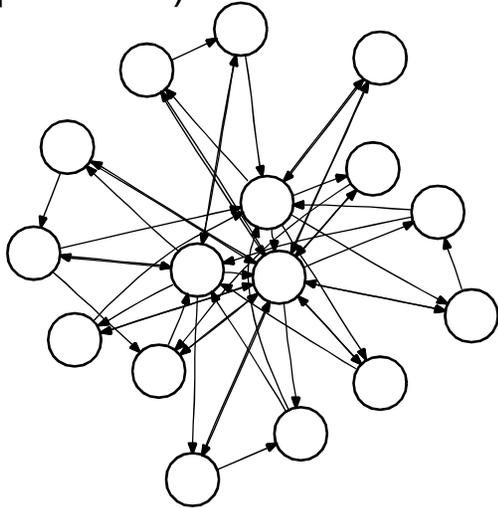
---

## Our PA-LTD

- PA-LTD was formulated as a Mixed Integer Linear Programming (MILP) problem
- We solved it using the CPLEX optimization environment
- We compared PA-LTD against an LTD model with CAPEX minimization as a target (CA-LTD)
- The impact of PA-LTD over CAPEX and OPEX was analyzed
- We characterized the logical topologies obtained for different power consumption scenarios of electronic switching vs. optical transmission

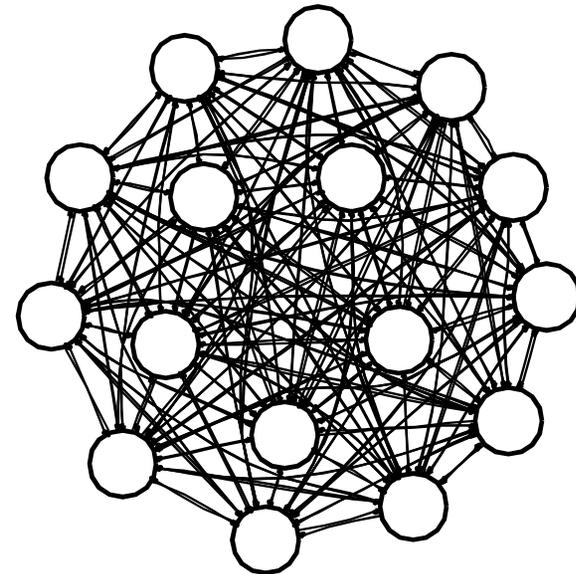
# Transmission vs. switching

Depending on the power consumption of switching with respect to transmission, the logical topology can be partially connected to minimize the number of transceivers (equivalent to cost-optimized) ...



**Partial mesh:**  
forward traffic  
on most of the nodes

But for less power-efficient switches, more links become convenient (cost- and power- optimized solutions differ)



**Full mesh:**  
no traffic  
forwarding

# Test scenarios

- We considered uniform traffic matrices with different traffic loads:  $\lambda_{0.1}$ ,  $\lambda_{0.2}$ , and  $\lambda_{0.5}$ , corresponding to 1, 2 and 5 Gb/s per node
- The optics efficiency ( $\nu^0$ ) can change as new technologies become available

+Laser  
+Modulator  
+Driver  
+Control  
+Receiver  
+CDR

*Generic  
optical  
transceiver  
~8Watt  
@ 10 Gb/s*



*Commercial  
tunable optical  
transceiver*

- **CAPEX**

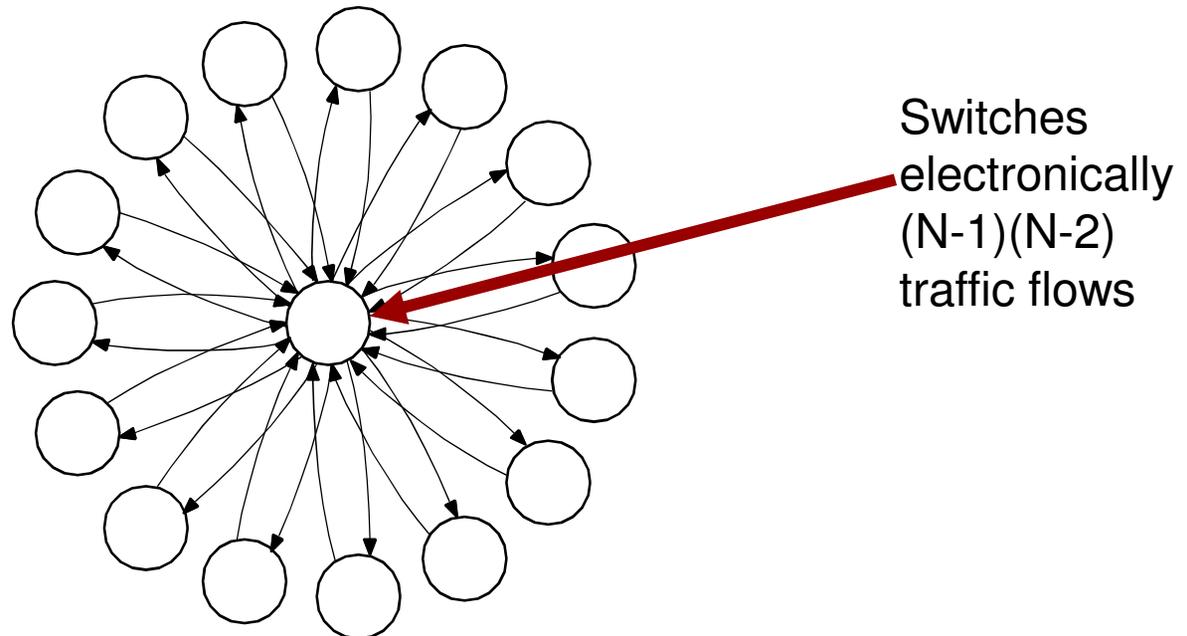
- In this first study, only the cost of all transceivers is considered
- One transceiver at 10Gbps costs ~100 \$

- **OPEX**

- Energy consumption is considered as the main contribution
- Energy cost is set at 0.2 \$/kWh

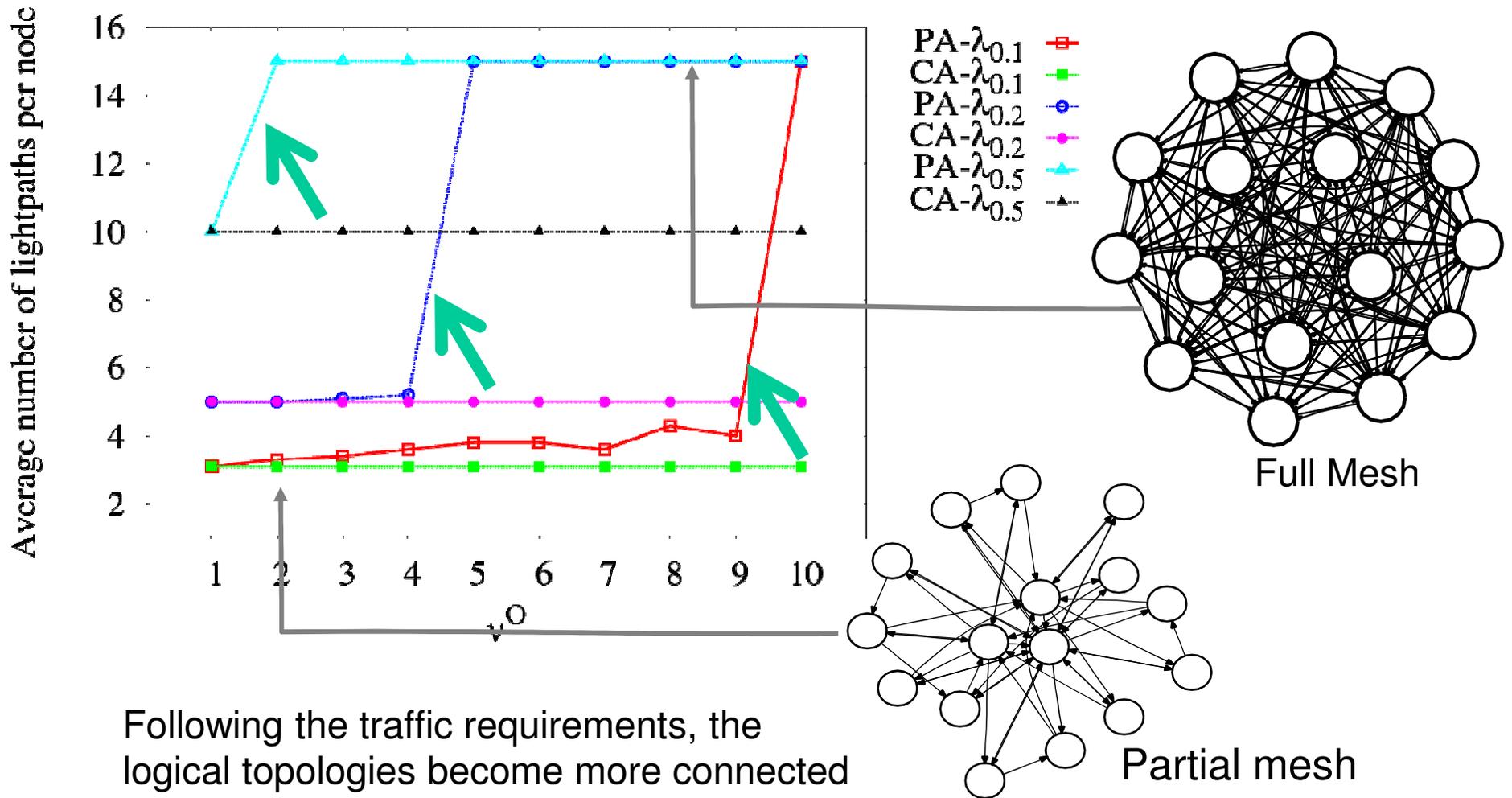
## In a low-traffic scenario

- All the traffic from every node can be transmitted by a single lightpath ...

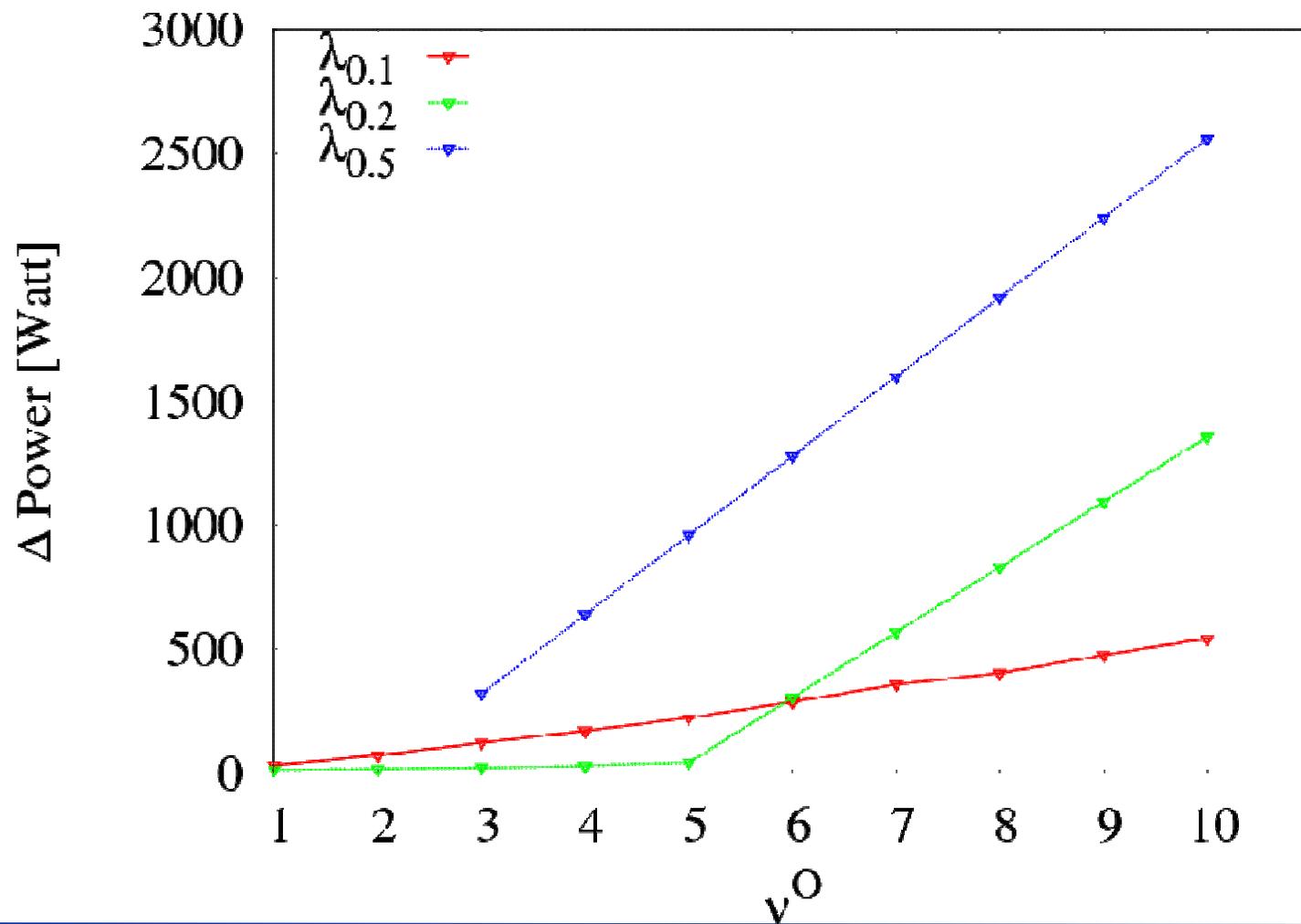


... and electronic switching is concentrated in a single node

# For a network with 16 nodes

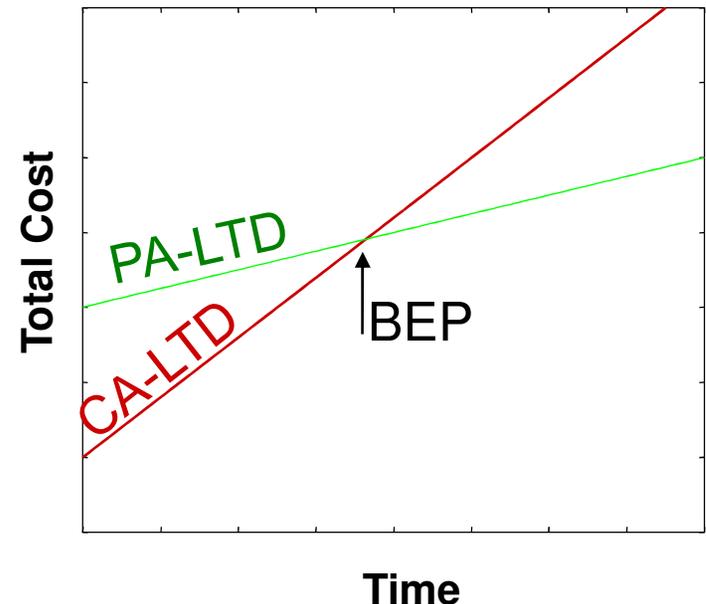


# Power advantage of PA-LTD

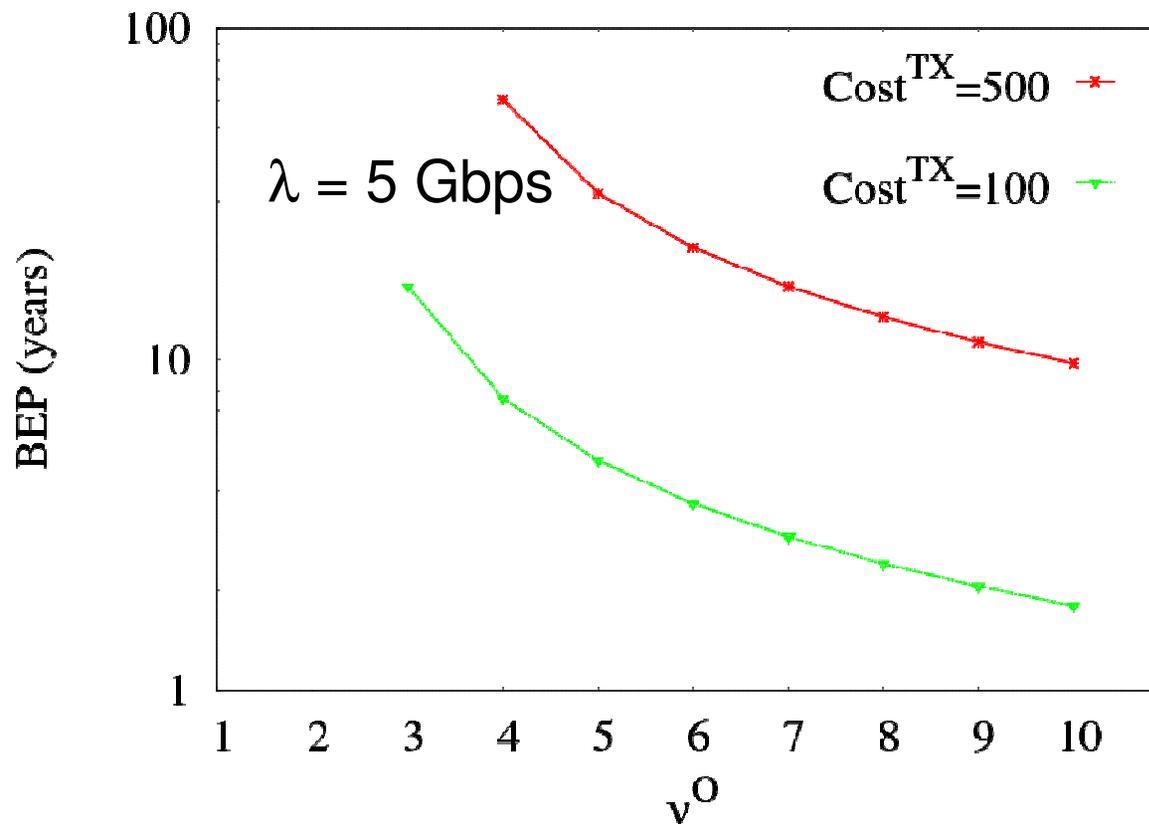


# Economical analysis

- For  $P^{TX} < P^{SW}$ , lower power consumption means higher costs (due to the larger number of transceivers), but also money savings by energy efficiency
- PA-LTD finds results having usually larger CAPEXs than CA-LTD results
- It is possible to recover the difference due to a smaller OPEX
- Break-Even Point (BEP):
  - Time required to start having an economical advantage for a PA-LTD solution respect to the CA-LTD one



# Break Even Point



As transceiver's cost reduces, the BEP time becomes shorter

---

# Conclusions

- Power saving can be a driver for a deeper penetration of optical technologies in networking beyond point-to-point transmission
- Results suggest that a “more multiplexing, less switching” (or a “more circuit switching, less packet switching”) evolution of network architectures may be convenient
- Is circuit switching coming back in the network core?



---

# Towards Real Energy-efficient Network Design

Grant agreement n. 257740  
THEME [ICT-2009.1.1]  
[The Network of the Future]

---

More information coming soon at:

<http://www.fp7-trend.eu>

Contact:

[fabio.neri@polito.it](mailto:fabio.neri@polito.it)

