

Energy saving in IP over WDM backbone networks



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Outline

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- **Introduction**
 - Energy consumption in telecommunication networks
 - Reference network scenario and power consumption model
- **Energy minimization at the IP network layer**
 - Virtual topology design
 - Dynamic link switch off
- **Energy minimization at the WDM optical network layer**
 - Power Aware Routing and Wavelength Assignment
- **Conclusion**

The Need of “Green Networking”

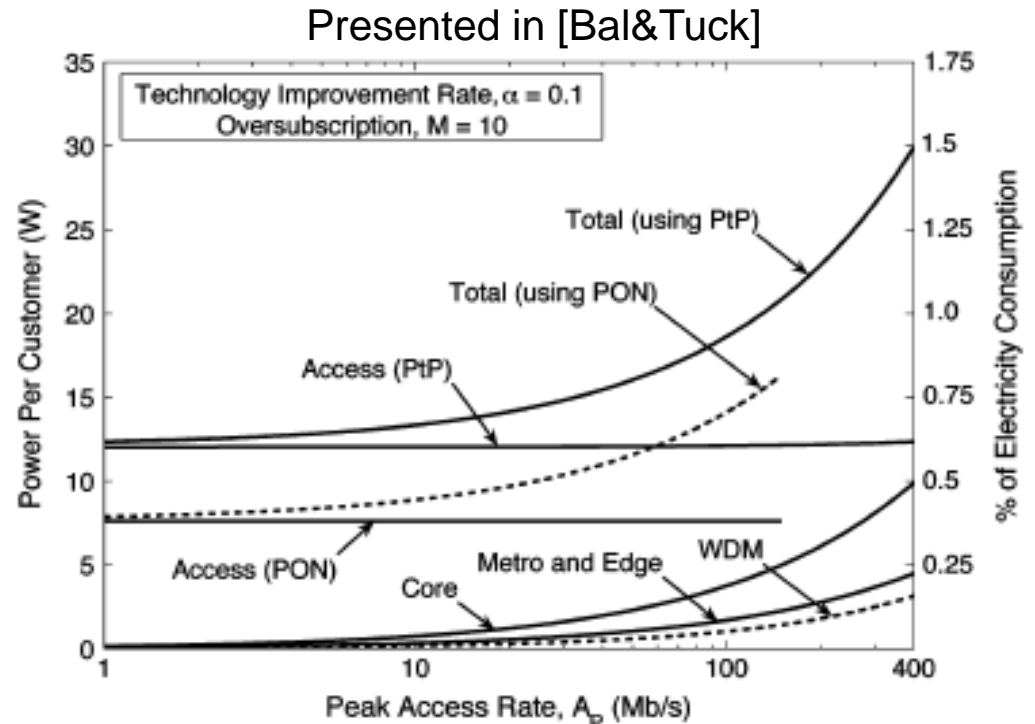
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- The energy consumption is expected to be the actual bottleneck of the Internet in coming years
 - Traffic grows more than the energy needed to transfer it over the Internet decreases [Bal&Tuck]
 - Currently 2% of the total electricity consumption – expected to grow up to 5-6% in 2020
 - Electronic packet switches (IP routers) consumes several MW for aggregated capacity of few tens Tbits/s [Alek]
- Benefits of energy saving:
 - Drastic cost reduction: 1% of 3TW-h → 3-4 million €
 - Lower environmental impact (GHG emission)
 - Rapid development of the Internet where energetic resources are scarce

Energy Consumption in TLC Networks

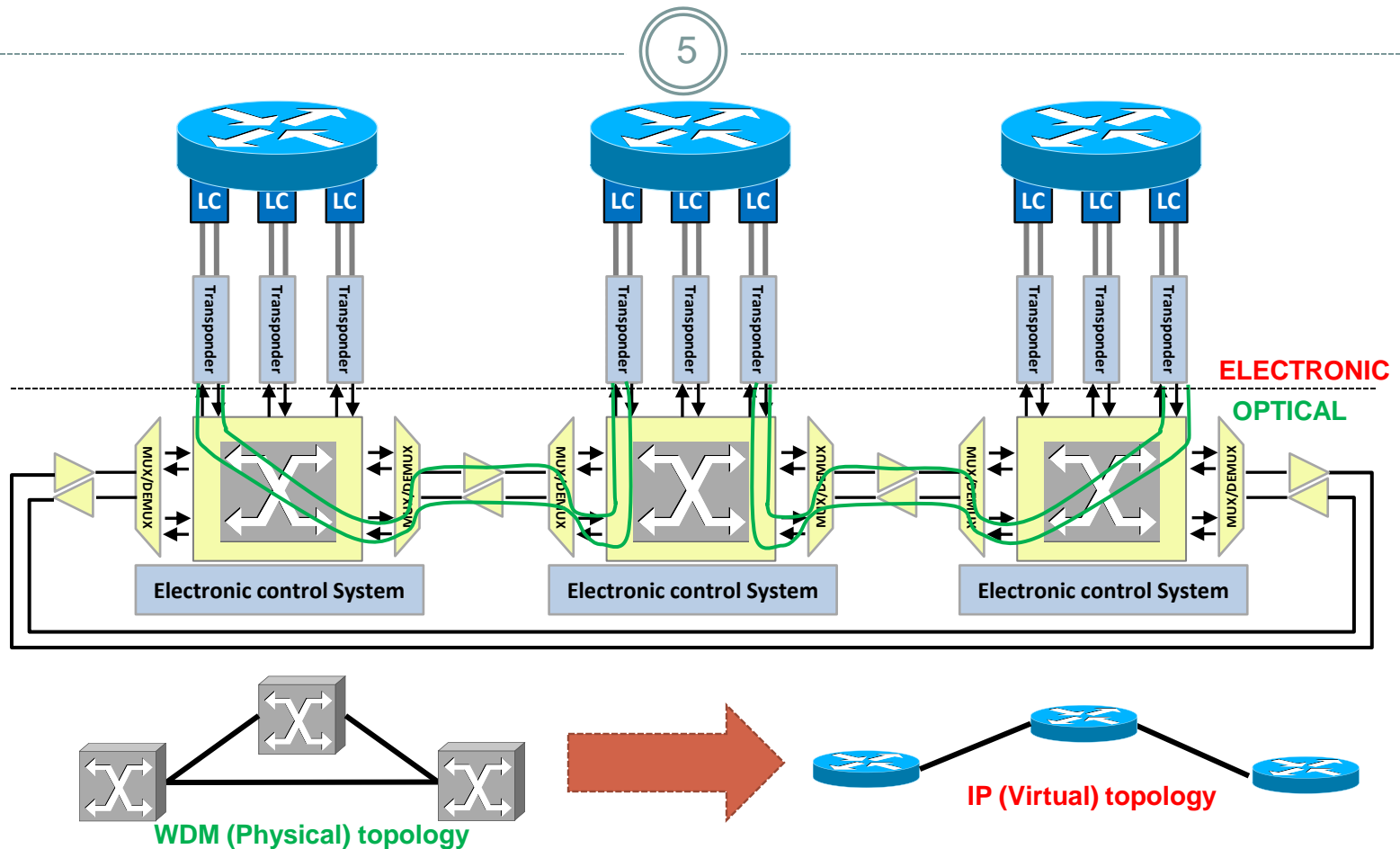
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- As the access rate grows:
 - The power consumption of the access section remains almost constant
 - The power consumption of the core section rapidly grows
 - The power consumption of WDM links becomes non-negligible



Improving the energy efficiency of core networks

IP over WDM Network Architecture

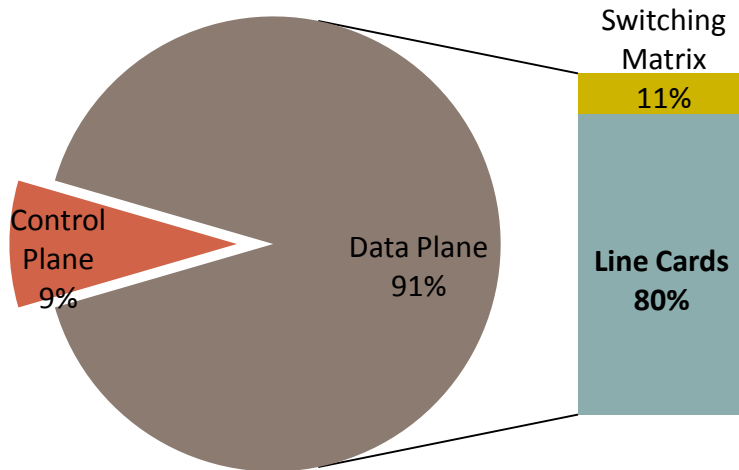


Any IP topology is possible regardless of the physical topology

Power Consumption of IP over WDM Networks

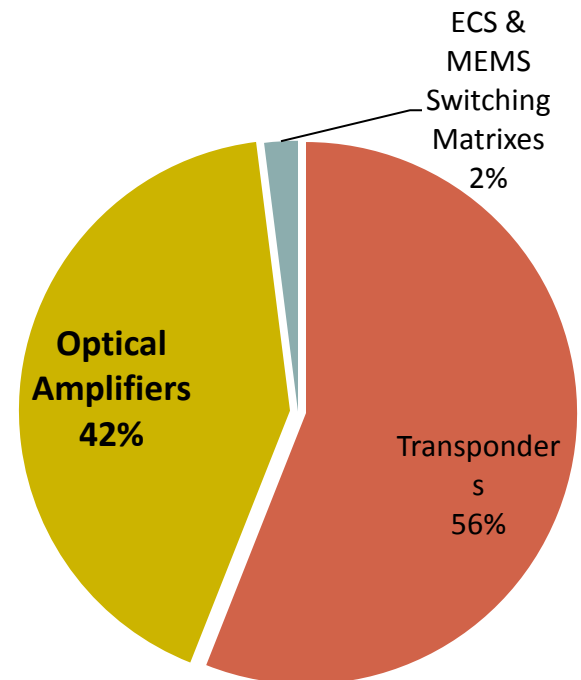
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IP Layer



Minimize the number of line cards

WDM Layer



Minimize the number of optical amplifiers kept active

Energy Saving Strategies

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Opportunities

Networks are designed without considering the energy consumption

The traffic changes during a day but all network devices are always active

Strategies	IP Layer	<u>Energy-Minimized Virtual Topology Design (EM-VTD)</u>	<u>Dynamic link switch-off</u>
	WDM Layer	Static Energy-Minimized Routing and Wavelength Assignment (EM-RWA)	<u>Dynamic EM-RWA or dynamic fiber switch-off</u>

○ Faced problems

Energy Minimized Virtual Topology Design

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**SOLUTION PROPOSED TO PERFORM AN ENERGY
EFFICIENT DESIGN OF THE IP LAYER TOPOLOGY
CONSIDERING THE PEAK TRAFFIC DEMAND**

“Start-Single Hop and Reroute (Start-SH&ReR)” Algorithm

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- **Objective:** designing the virtual topology (IP topology) minimizing the number of deployed line cards
- **Basic Operation**
 - Starting phase: constructs an IP link for each traffic flow
 - ✦ Equivalent to the single-hop lightpath bypass strategy
 - Rerouting phase: tries to eliminate unnecessary links
 - ✦ Uses a particular cost function inside the routing algorithm
- A. Coiro, T. Squarcia, M. Listanti, A. Valenti and F. Matera, “*Energy Minimized Virtual Topology Design and Traffic Routing*”, **submitted to IET Optoelectronics**

Start-SH&ReR: Performance Evaluation

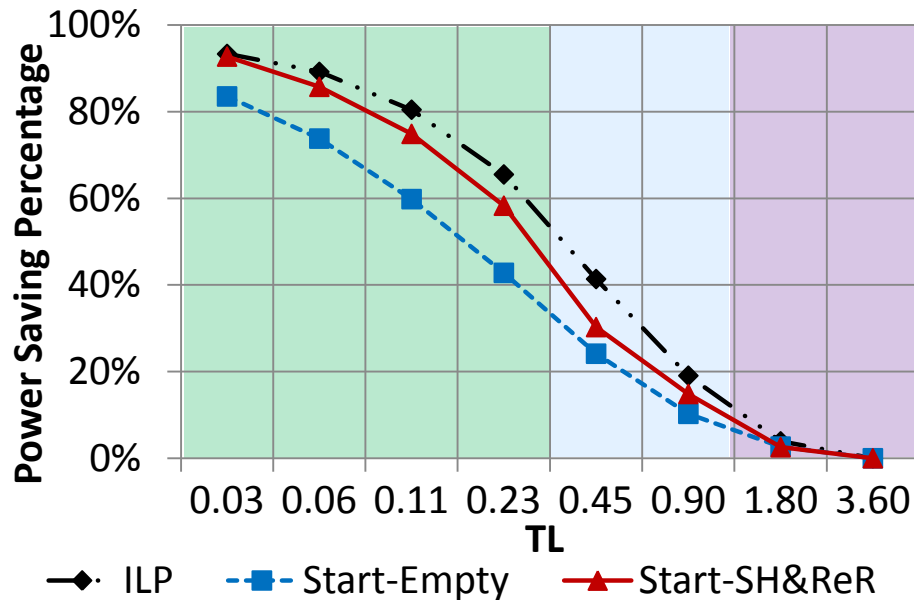
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- Heuristic algorithm proposed in [Shen&Tuck] (Start-empty)
- Single-Hop bypass strategy (considered as an upper bound)
- Optimal solution given by the ILP formulation
 - Used to define the energy efficiency $\eta^i = PC^{Opt}/PC^i$
 - ✦ PC^{Opt} : Optimal solution; PC^i Power consumption of algorithm “i”
- Results expressed Vs. the ratio
TL=AvgTrafficFlow/LineCard_Capacity

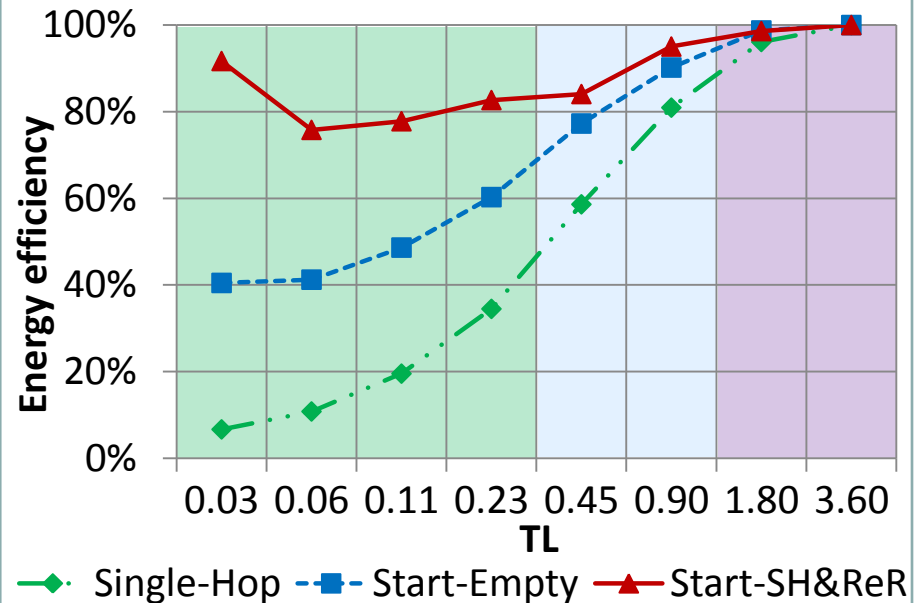
Start-SH&ReR: Results

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Power saving with respect to Single-Hop



Energy efficiency



Medium-low TL: Start-SH&ReR saves much more energy than Start-Empty

High TL: little performance difference between Start-Empty and Start-SH&ReR

Very high TL: even the Single-Hop strategy performs very well

Dynamic Link Switch-Off

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**SOLUTION PROPOSED TO REDUCE THE ENERGY
CONSUMED AT THE IP LAYER IN PRESENCE OF VARIABLE
TRAFFIC**

Distributed and Adaptive Interface Switch-off for Internet Energy Saving (DAISIES)

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- **MPLS-TE**
 - Fully knowledge of link state (link load)
 - Decoupling of the IP (logical) and MPLS topologies
- **Distributed**
 - Each node takes part at the energy saving mechanism by making local decisions
- **Flow-based**
 - The solution acts on the routing algorithm
 - Links are switched off as a consequence of routing decisions
- A. Coiro, F. Iervini and M. Listanti, “*Distributed and Adaptive Interface Switch Off for Internet Energy Saving*”, **ICCCN 2011**, Maui, August 2011.

DAISIES: Main Advantages

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- line card switch-off/activation process transparent to the routing protocol
 - No routing instabilities during the link switch-off process
- Neither packet loss nor out of order delivering
- Both traffic decreasing and increasing automatically managed
- No change is required to current routing and signalling protocols.

DAISIES: Basic Operation

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- Each traffic flow is rerouted when its capacity changes
- The rerouting aims to keep unused as many line cards as possible
- A particular **cost function** is used to compute link weights

DAISIES: Performance Evaluation

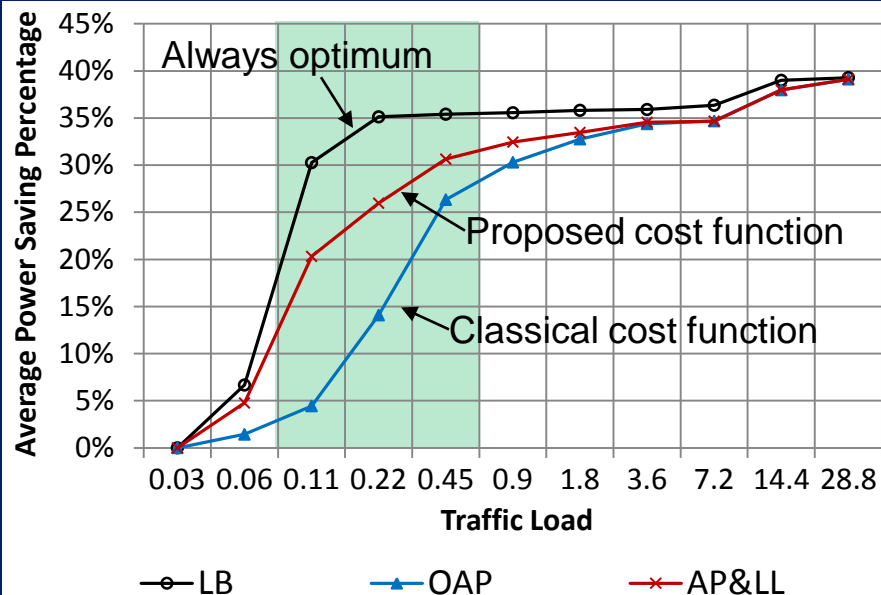
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- Average power saving (considering the traffic variation during a day) with respect to a static **Base Network (BN)**
- **Optimal Base Network** designed considering the **peak traffic** and solving the mathematical **optimization** problem
- Energy efficiency considering a lower bound
 - Represents the average power consumption that would be obtained if at any instant the network worked in optimal conditions
- Results expressed Vs. the ratio
$$TL = \text{Avg_TrafficFlow} / \text{LineCard_Capacity}$$
 - Determines how the Base Network is meshed

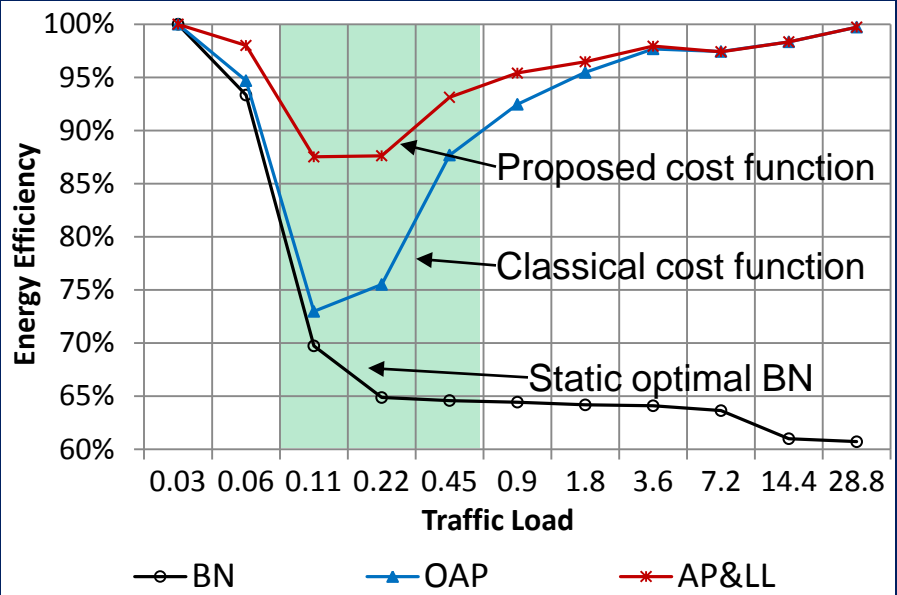
DAISIES: Results

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Power saving with respect to the static BN



Energy efficiency



- The proposed cost function performs better than the “classical” approach
- At most a further 12% of saving is needed to reach the Lower Bound
- About 20%-30% of saving with respect to an **optimal BN**

Energy consumption minimization at the WDM optical layer

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**SOLUTIONS TO IMPROVE THE ENERGY EFFICIENCY OF
THE WDM OPTICAL NETWORK**

Energy Saving in Optical Networks

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- **OBJECTIVE:** minimize the number of optical amplifiers kept active by using a subset of all deployed fibres
- **TWO DIFFERENT STRATEGIES**
 - Power-Aware Routing and Wavelength Assignment (PA-RWA)
 - ✦ Lightpaths are established taking into account the power consumption of the network
 - Dynamic fibre switch-off
 - ✦ Some fibres are switched off, and lightpaths on them rerouted on the rest of the network, when the traffic load decreases

Dynamic PA-RWA

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SOLUTION BASED ON THE DEFINITION OF A POWER-AWARE RWA ALGORITHM

PA-RWA Algorithm

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- **ROUTING**: Load Based Cost (LBC) algorithm
 - Uses a cost function to compute link weights
 - **WAVELENGTH ASSIGNMENT**: two different algorithms
 - Least Additional Power-First Fit (LAP-FF)
 - ✦ Based on the FF algorithm
 - Least Cost Wavelength
 - ✦ Novel approach: works as a routing algorithm assigning a cost to each wavelength
-
- A. Coiro, M. Listanti, A. Valenti and F. Matera, “*Power-Aware Routing and Wavelength Assignment in Multi-Fiber Optical Networks*” **IEEE JOCN**
 - A. Coiro, M. Listanti, A. Valenti, “*Dynamic Power-Aware Routing and Wavelength Assignment for Green WDM Optical Networks*” **ICC 2011**, Kyoto, Jun 2011.

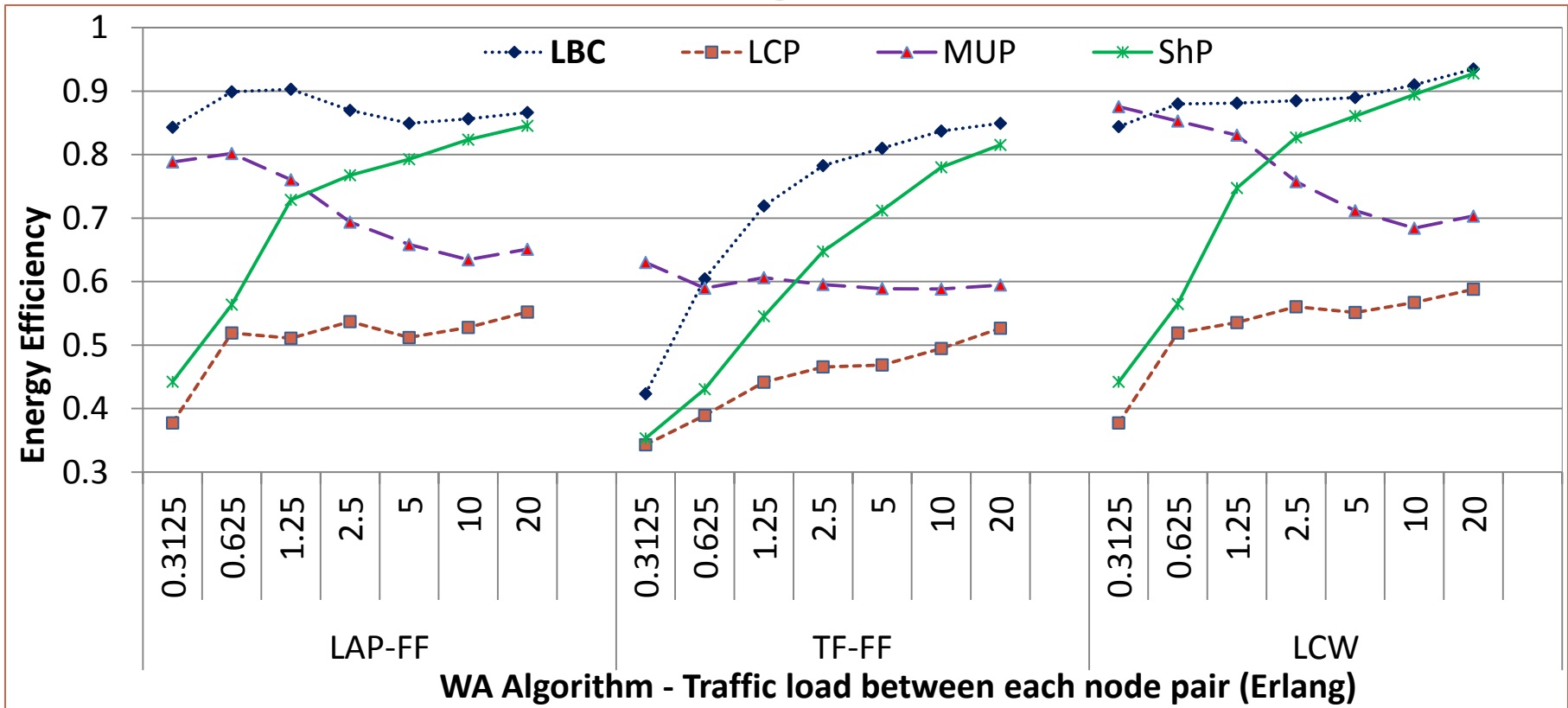
PA-RWA: Performance Evaluation

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- Two metrics: Energy efficiency and blocking probability
- Comparison
 - Routing algorithms:
 - ✦ Most Used Path (MUP): a power-aware algorithm proposed in [PoLiTo]
 - ✦ Power Aware-Shortest Path (ShP): power aware version of shortest path
 - ✦ Least Congested Path (LCP): the most used algorithm in optical networks due to its good performance in terms of blocking probability
 - Wavelength assignment algorithms:
 - ✦ First Fit (FF): the most used algorithm in optical networks due to its good performance in terms of blocking probability
 - ✦ Two Phases – FF (TP-FF): modified version of FF proposed in [PoLiTo]
 - Optimal solution used to evaluate the energy efficiency

PA-RWA: Energy Efficiency

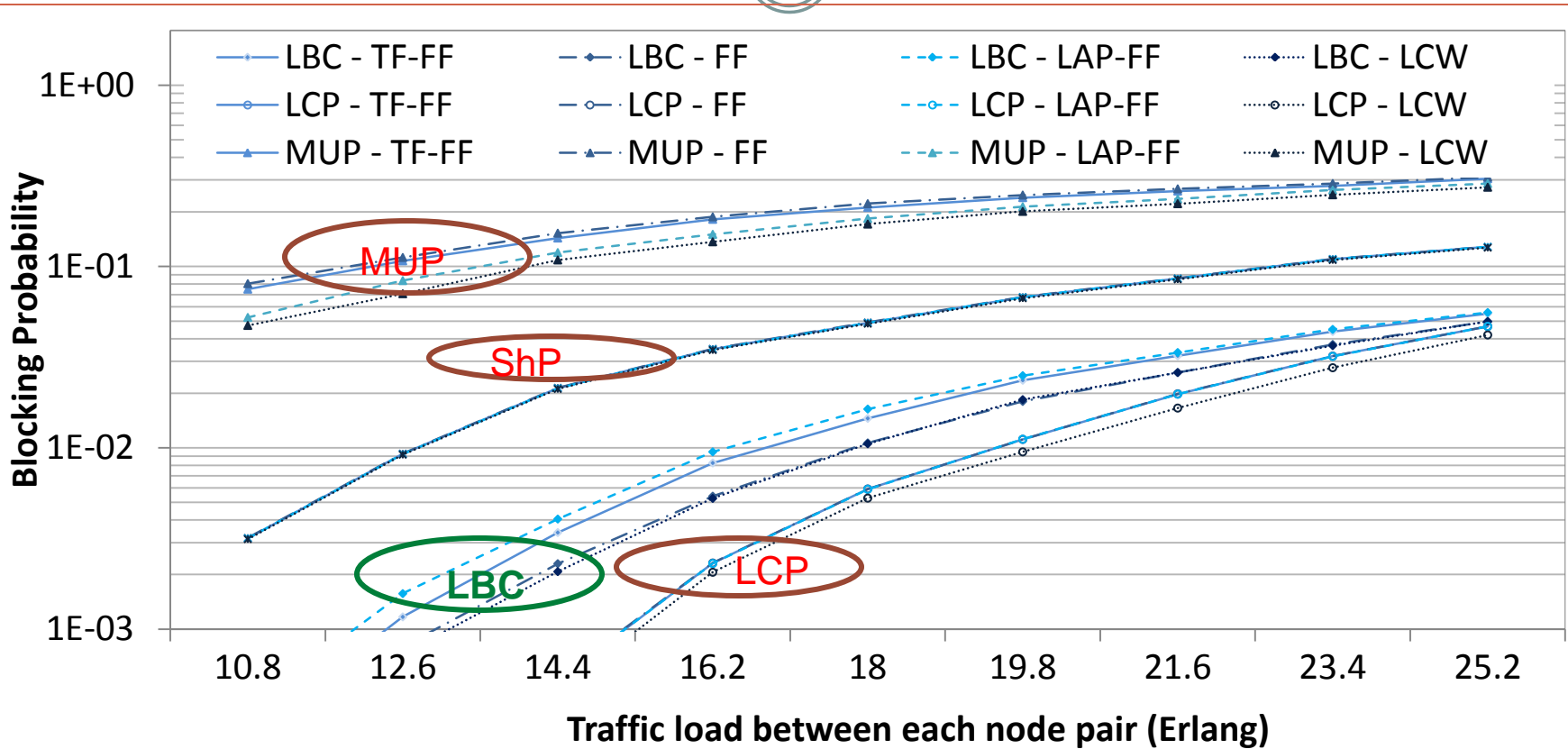
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- Both LBC and LCW outperform all other algorithms

PA-RWA: Blocking Probability

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- MUP and ShP performs badly
- LBC performs close to LCP when the traffic load grows
- LCW outperforms FF

Fiber Switch-Off

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**SOLUTION BASED ON A DYNAMIC SWITCH-OFF OF
OPTICAL FIBERS DURING LOW TRAFFIC LOAD PERIODS**

Selective Switch-off of Optical Fibres

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- A classical power unaware RWA algorithm is used to set up lightpaths
- An iterative algorithm is run trying to switch-off fibres
 - Fibres are ordered according to a given criterion
 - ✦ Both traffic and topological considerations are taken into account
 - If lightpaths on the selected fiber can be routed elsewhere in the network the fiber can be switched off
 - The *GMPLS graceful shutdown* mechanism is used to reroute lightpaths
 - ✦ No traffic interruption
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Conclusion

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Conclusion

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- Power consumption model and problem formalization in IP over WDM backbone networks
- IP network layer
 - Virtual topology design considering a fixed traffic matrix: the “Start-SH&ReR” algorithm
 - ✦ Outperforms other algorithms proposed in the literature
 - Dynamic interface switch off following the traffic variability: the DAISIES mechanism
 - ✦ Allows to achieve at least 87% of energy efficiency
- WDM network layer
 - PA-RWA problem: LBC+LCW outperform other algorithms proposed so far
 - Fiber switch-off mechanisms using GMPLS

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- **Conference Proceedings**

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Grazie

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