Green optical networks: power savings vs. network performance

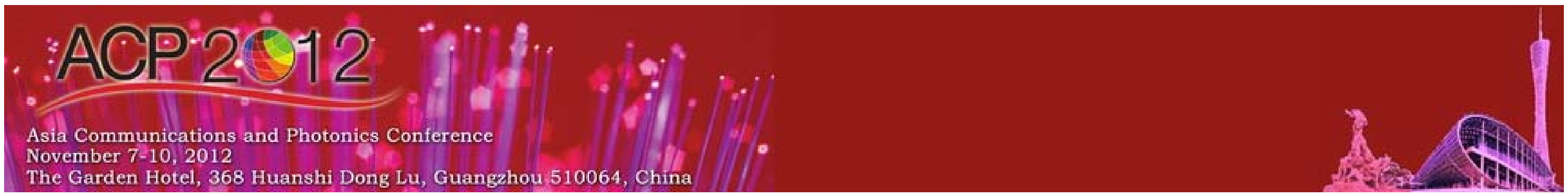
Paolo Monti

Optical Networks Laboratory (ONLab)
Communication System Department (COS)
Royal Institute of Technology (KTH)
Sweden

ROYAL INSTITUTE OF TECHNOLOGY

ONLab

Asia Communications and Photonics Conference (ACP)
Guangzhou, November 10, 2012



ROYAL INSTITUTE OF TECHNOLOGY

ONLab

Acknoledgments

- People
  - Prof. Piero Castoldi (SSSUP, Italy)
  - Prof. Anna Tzanakaki (AIT, Greece)
  - Prof. Lena Wosinska (ONLab)
  - Dr. Cicek Cavdar (ONLab)
  - Dr. Isabella Cerutti (SSSUP, Italy)
  - Dr. Amornrat Jirattigalachote (ONLab)
  - Dr. Luis Velasco (UPC, Spain)
  - Ajmal Muhammad (PhD student, ONLab)
  - Marc Ruiz (PhD student, UPC)
  - Shabnam Sadat Jalalinia (MS student, ONLab)
  - Pawel Wiatr (PhD student, ONLab)
- Projects
  - Cost Action IC-0804: energy efficiency in large scale distributed systems (http://www.cost804.org/)
  - Building the future Optical Network in Europe (BONE): EU FP7 Network of Excellence (http://www.ict-bone.eu/)
  - Energy-Efficient Wireless Networking (eWIN) and Optical Networking Systems (ONS) project: The Next Generation (TNG) Strategic Research Area (SRA) initiative at KTH (http://www.kth.se/en/forskning)

ROYAL INSTITUTE OF TECHNOLOGY

ONLab

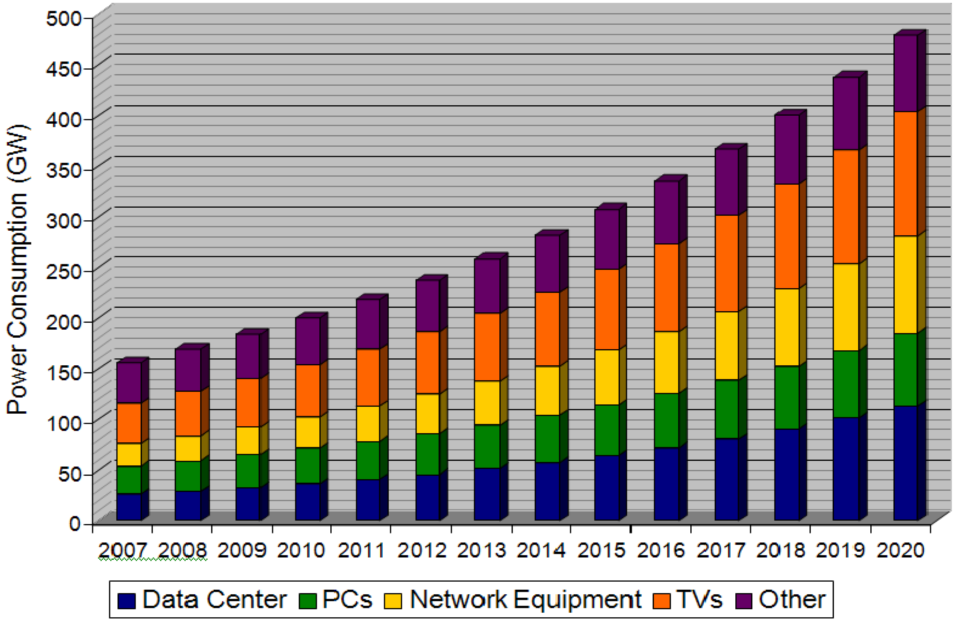
Outline

- Motivation
- Sleep mode concept
- Static provisioning and EE
  - EE vs. cost
  - EE vs. backup sharing
  - EE vs. QoT
- Dynamic provisioning and EE
  - EE vs. blocking probability
- Conclusions

ROYAL INSTITUTE OF TECHNOLOGY

ONLab

ICT energy consumption



ICT Power Consumption Forecast, W. Vereecken, Universiteit Gent

- ICT consumes about 6-8% of total energy consumption worldwide
  - tremendous growth of traffic demands
  - high penetration, 24/7 use, new services/devices, etc.
- WDM technology: power-efficient option compared to electronic-based IP network counterpart

An energy efficient optical layer

- Energy efficiency in the optical layer has attracted a lot of interest
- Wide range of topics are addressed in the literature
  - energy-efficient strategies for *network design* (linear programming formulations and heuristics)
  - *static* and *dynamic provisioning* heuristics proposed to minimize the power necessary to support traffic demands
- Common denominator: set unused or lightly used network resources in a low power consuming state, i.e., into *sleep*

Sleep mode concept

- Sleep mode in optical network devices
  - low-power inactive state from which devices can be suddenly waken-up
  - not yet available in most network devices, but advocated by current efforts from standardization bodies, e.g., Energy star(*)
- It is possible to define a number of operational modes
  - Off: null power consumption - disconnected
  - Sleep: negligible amount of power - promptly switchable to active mode
  - Active: power consumption - constant amount + portion dependent on traffic load

(*) Energy Star, "*Small Network Equipment*," http://www.energystar.gov/index.cfm?c=new specs.small network equip.

Devices in sleep mode: is it overall a good choice?

- *Benefits* in terms of energy efficiency of using network resource in sleep mode are unquestionable
- When setting resources in sleep mode are we *sacrificing* any other network performance metric?

ROYAL INSTITUTE OF TECHNOLOGY

ONLab

Outline

- Motivation
- Sleep mode concept
- Static provisioning and EE
  - EE vs. Cost
  - EE vs. Backup sharing
  - EE vs. QoT
- Dynamic provisioning and EE
  - EE vs. blocking probability
- Conclusions

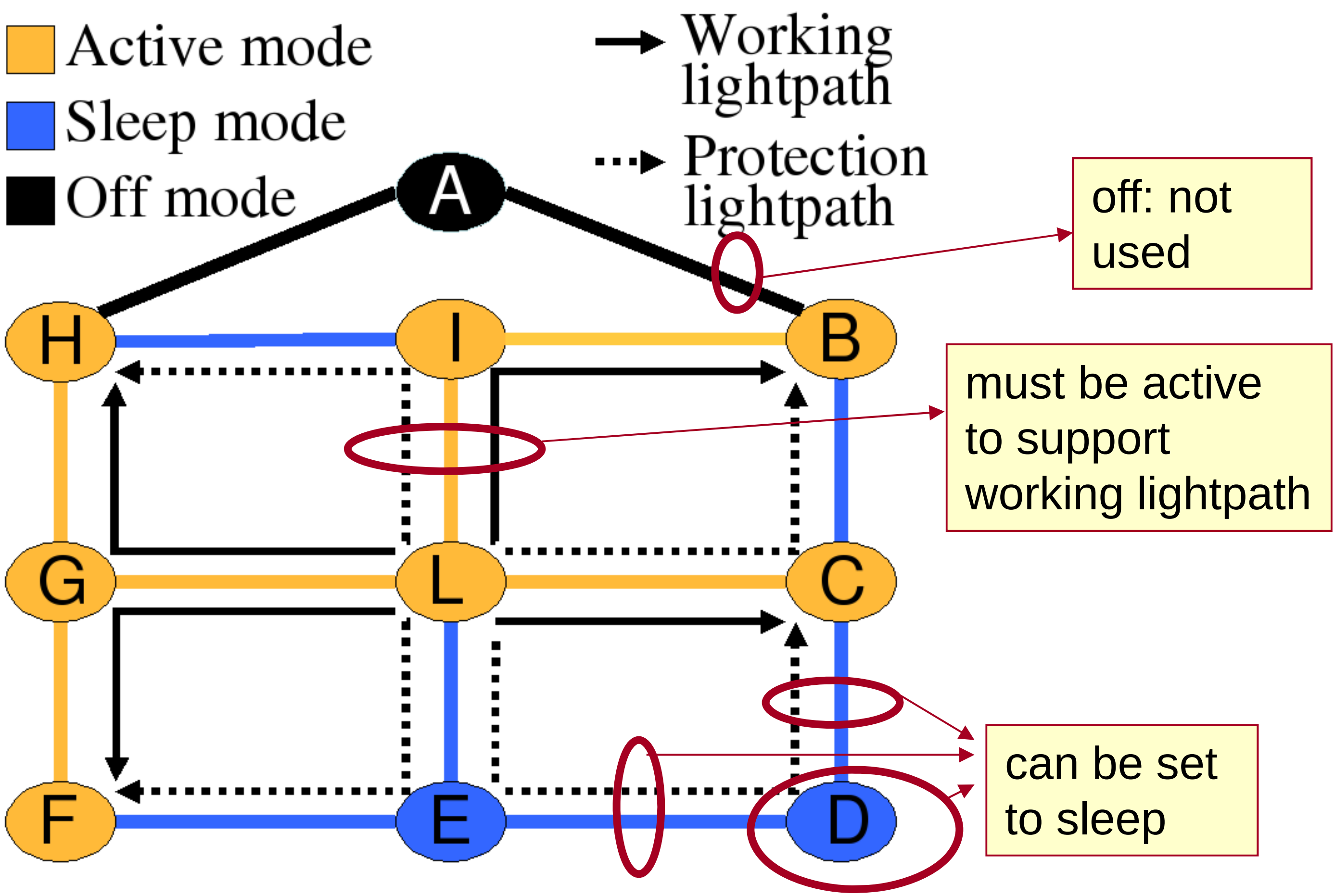
ROYAL INSTITUTE OF TECHNOLOGY

ONLab

Protection and energy efficiency

- Dedicated Path Protection: for each working, one dedicated (link/node) disjoint protection lightpath

- Intuition: use the sleep mode option for backup resources
  - e.g., amplifiers, optical switches
- Objective: reduce the total power consumption for the optical circuit switching layer



KTH VETENSKAP OCH KONST

ROYAL INSTITUTE OF TECHNOLOGY

ONLab

Sleep aware survivable static routing: possible solutions

- Problem can be formulated as integer linear programming (*ILP*)(*) where:
  - a set of pre-computed paths are used for routing
  - wavelength conversion is assumed to be available at each node

- Problem can also be solved using a design *heuristic* based on Surballe algorithm(**) where:
  - all connection are ordered by their increasing estimated power consumption
  - starting from first in the list, connections are provisioned in the network
  - weight of each link/node are varied according to their use

(*) A. Muhammad, P. Monti, I. Cerutti, L. Wosinska, P. Castoldi, A. Tzanakaki, "*Energy-Efficient WDM Network Planning with Dedicated Protection Resources in Sleep Mode*," in Proc. **IEEE Globecom**, 2010

(**) P. Monti, A. Muhammad, I. Cerutti, C. Cavdar, L. Wosinska, P. Castoldi, A. Tzanakaki, "*Energy-Efficient Lightpath Provisioning in a Static WDM Network with Dedicated Path Protection*," in Proc. **IEEE ICTON**, 2011

KTH VETENSKAP OCH KONST
ROYAL INSTITUTE OF TECHNOLOGY
ONLab

Sleep aware survivable static routing: evaluated strategies

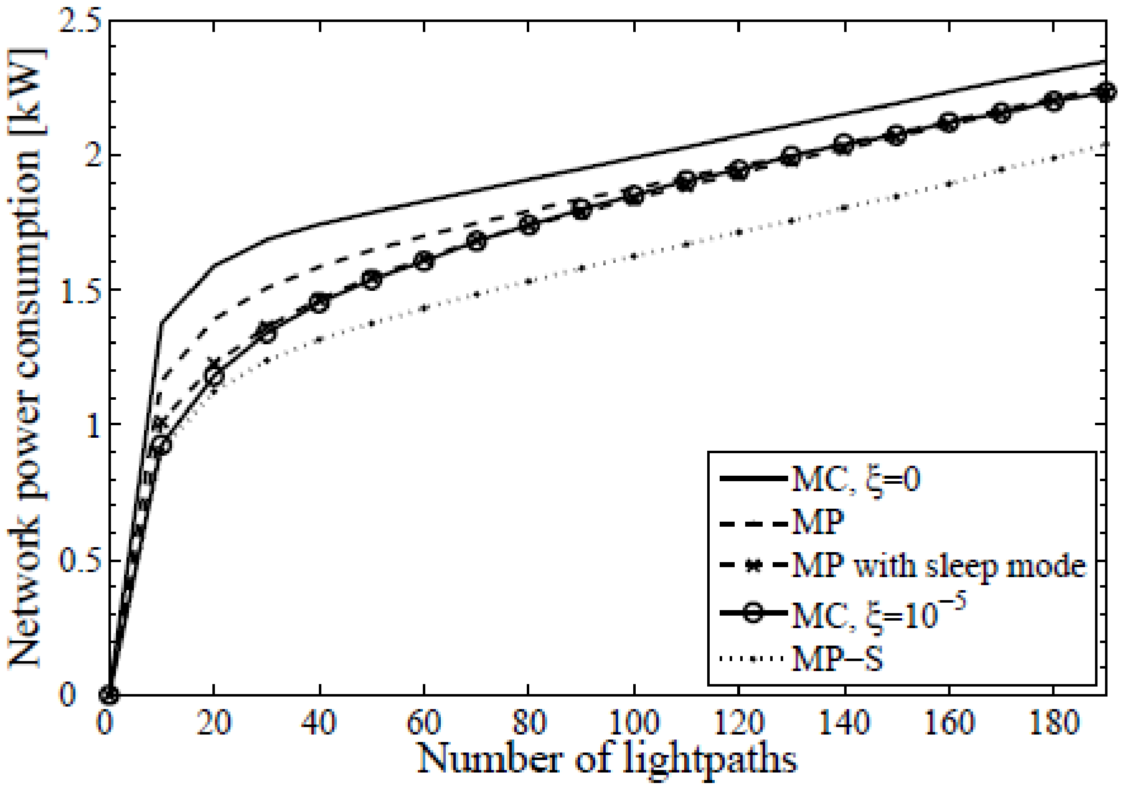
- MP-S: design at minimum power with devices in sleep mode
- MP-S can be compared to:
  - MP: design at minimum power with devices without sleep mode enabled
  - MP with sleep mode: MP design in which devices can be set to sleep mode
  - MC: design at minimum cost in terms of wavelengths requirement and minimum energy consumption
    - i.e., CAPEX minimization
    - second objective function can be power minimization ($\xi > 0$)

ROYAL INSTITUTE OF TECHNOLOGY

ONLab

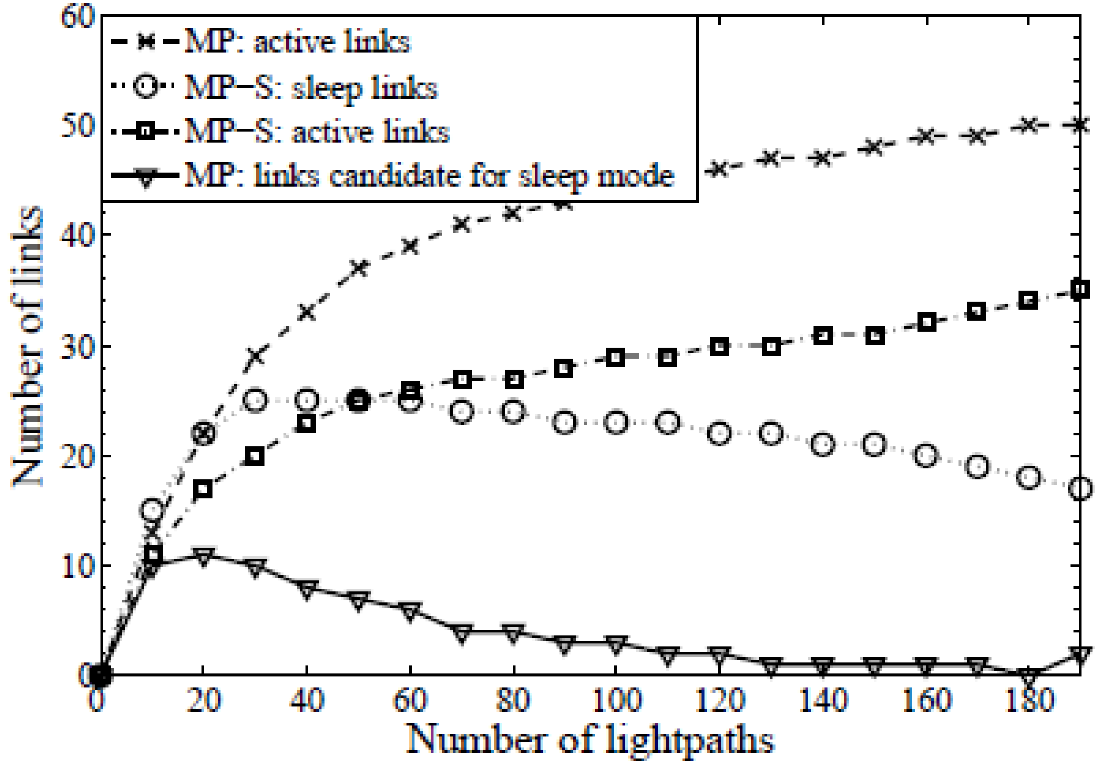
Performance results: ILP formulation (COST 239)

Network power consumption



MP-S saves 25% compared to MC, 15% to MP, and 10% compared to MP with sleep mode support

Number of links in sleep mode



Number of links in sleep mode increase significantly with MP-S, while number active links decrease

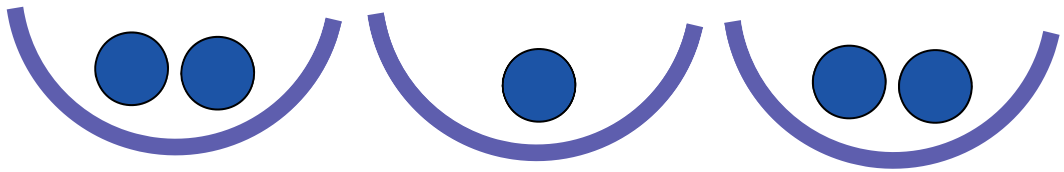
A. Muhammad, P. Monti, I. Cerutti, L. Wosinska, P. Castoldi, A. Tzanakaki, "*Energy-Efficient WDM Network Planning with Dedicated Protection Resources in Sleep Mode*," in Proc. **IEEE Globecom**, 2010

Survivability and energy efficiency

Energy-efficient routing

...tends to concentrate connections on few links to switch-off lightly loaded resources

Survivable routing

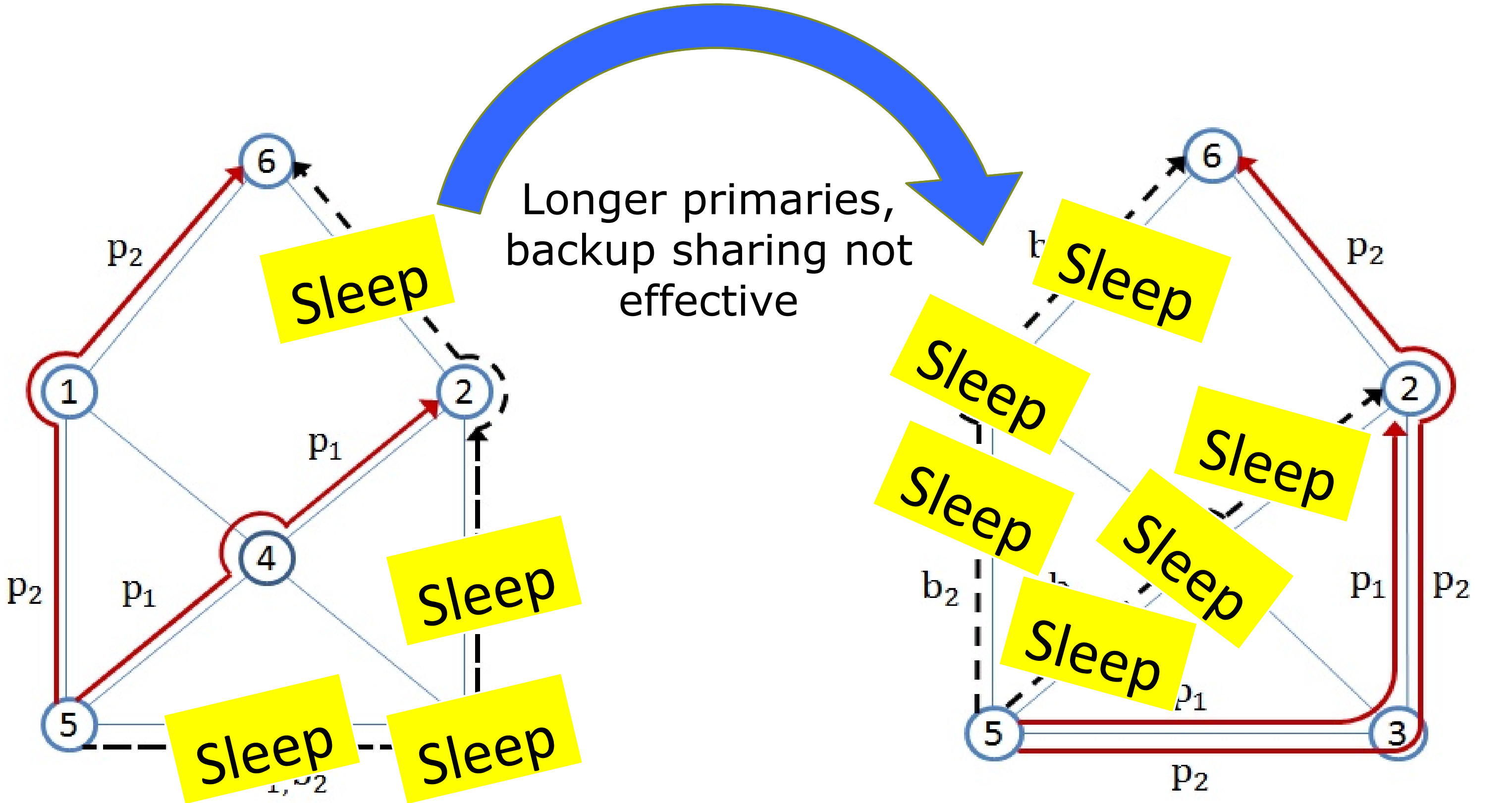


...tries to spread traffic over multiple links to use efficiently resources and to decrease the disruptive impact of a failure

ROYAL INSTITUTE OF TECHNOLOGY

ONLab

Backup sharing vs. energy-efficiency



(a) Minimizing capacity

(b) Minimizing power

- Primary=4, backup=3
- Number of fibers in *active* mode=4

- Primary=5, backup=4
- Number of fibers in *active* mode=3

ROYAL INSTITUTE OF TECHNOLOGY

ONLab

Possible solution?

- Problem formulated as integer linear programming (ILP) (*)
  - energy and capacity are jointly optimized
- Heuristic (**)
  - using separate auxiliary graphs for primary and backup path routing to encourage both shareability and energy-efficiency
  - a tuning parameter T defined to help finding a compromise between capacity and power consumption

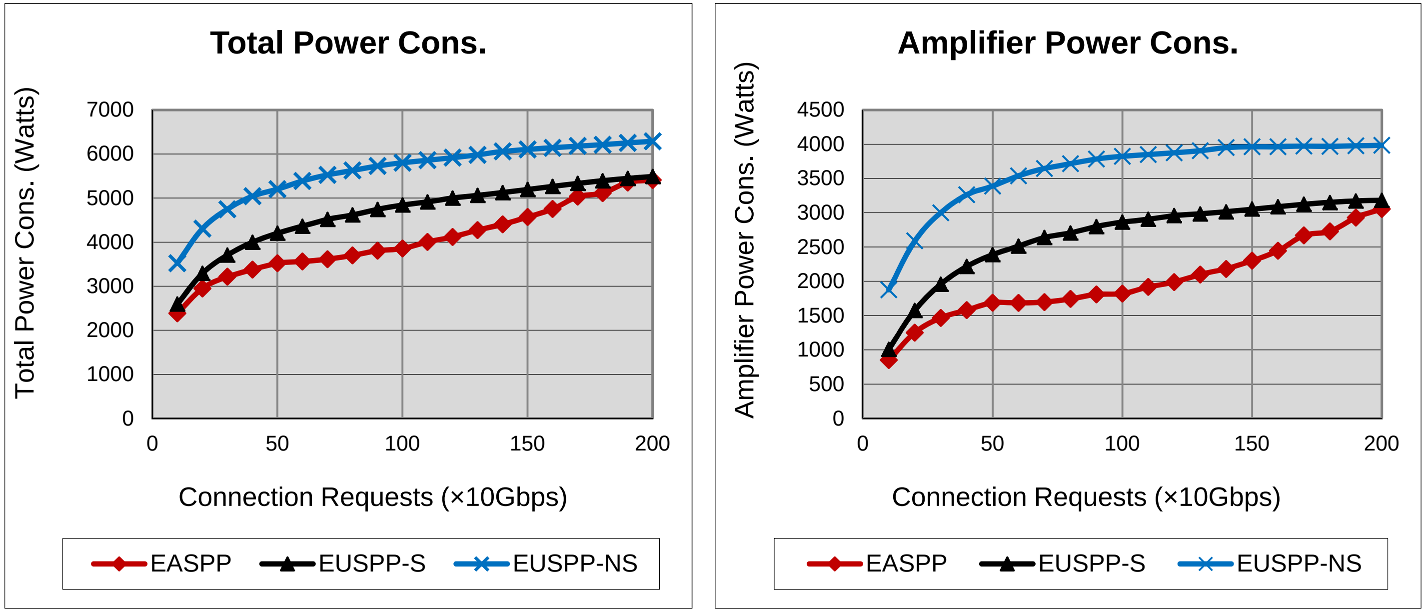
(*) C. Cavdar, F. Bazluca, L. Wosinska, "*Energy-Efficient Design of Survivable WDM Networks with Shared Backup*," in Proc. **IEEE Globecom**, 2010

(**) S. Jalalinia, C. Cavdar, L. Wosinska, "*Survivable Green Optical Backbone Networks with Shared Path Protection*," in Proc. **OFC** 2012

ROYAL INSTITUTE OF TECHNOLOGY

ONLab

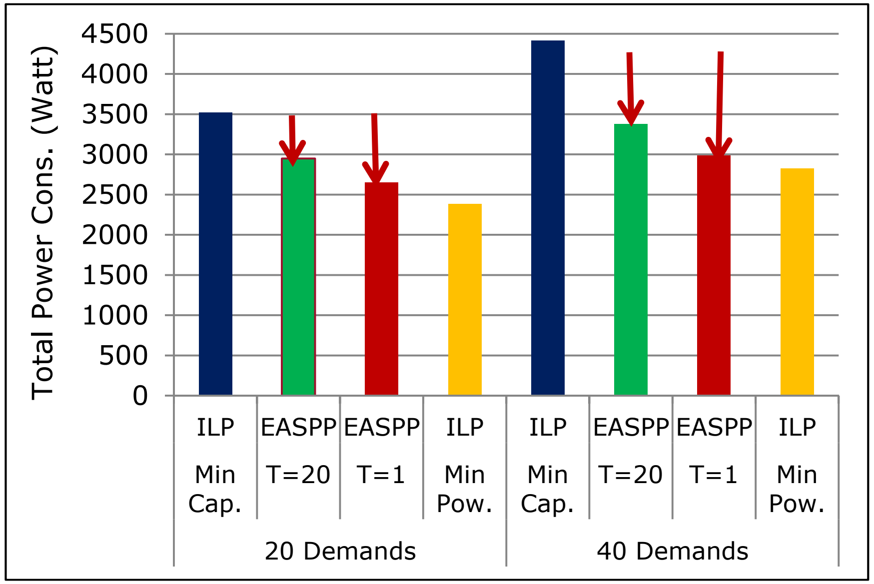
EASPP heuristic: power consumption results (COST 239)

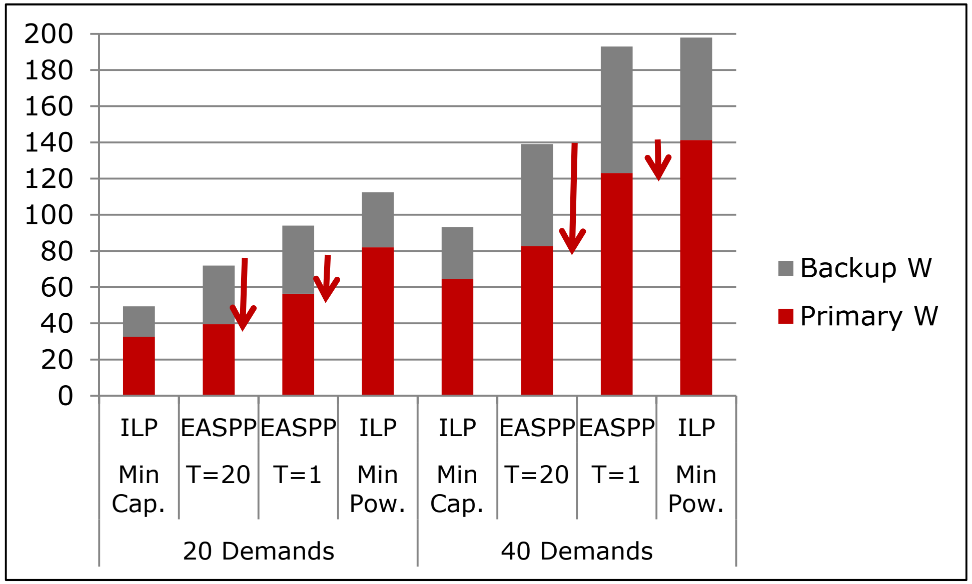


- In terms of total power consumption
  - EASPP outperforms EUSPP-S except for larger number of connection requests
  - EASPP saves up to 26% and 35% power compared to EUSPP-S and EUSPP-NS respectively

S. Jalalinia, C. Cavdar, L. Wosinska, "*Survivable Green Optical Backbone Networks with Shared Path Protection*," in Proc. **OFC** 2012

EASPP heuristic vs. ILP results (COST 239)





- EASPP (T=20) saves 53% of wavelength-links used by primary paths compared to minimum-power ILP and 24% of power compared to minimum-capacity ILP
- With the packing parameter T tuned to 1, the power saving increases to 32% while the capacity consumption gain becomes 31%

S. Jalalinia, C. Cavdar, L. Wosinska, "*Survivable Green Optical Backbone Networks with Shared Path Protection*," in Proc. **OFC** 2012

ROYAL INSTITUTE OF TECHNOLOGY
ONLab

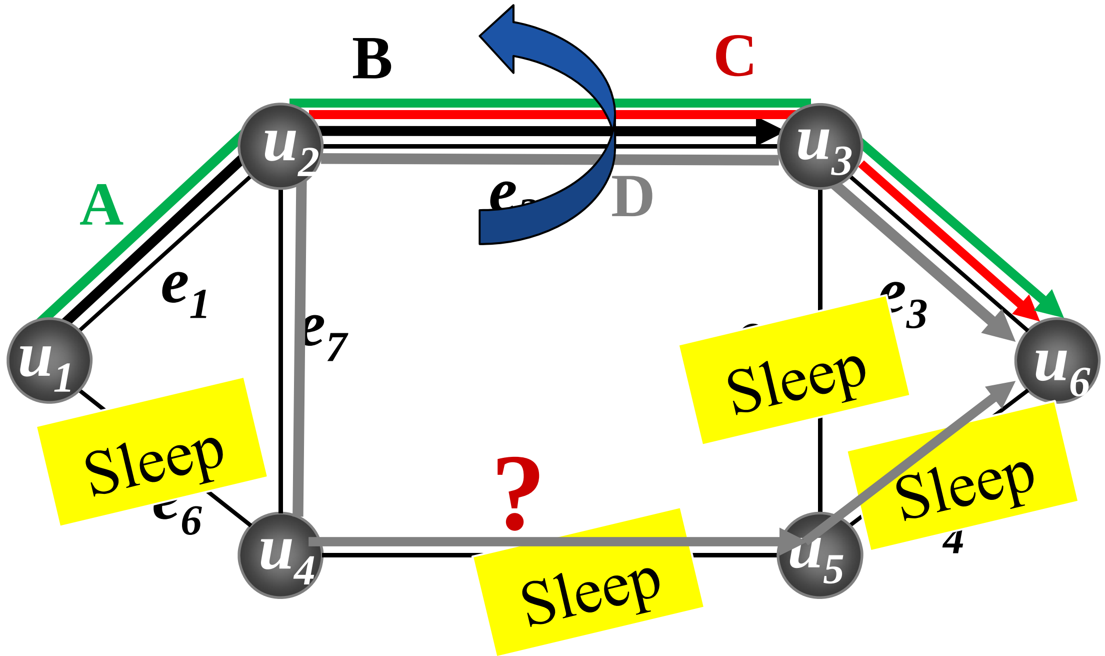
Energy efficiency and optical signal quality guarantee

Energy-Aware Routing

+

transmission impairments

Impairment and Energy Aware RWA Mechanism



- Longer paths: worse attenuation levels
- Denser fiber links: higher XPM and cross talk levels

KTH VETENSKAP OCH KONST

ROYAL INSTITUTE OF TECHNOLOGY

ONLab

Problem objective and solution

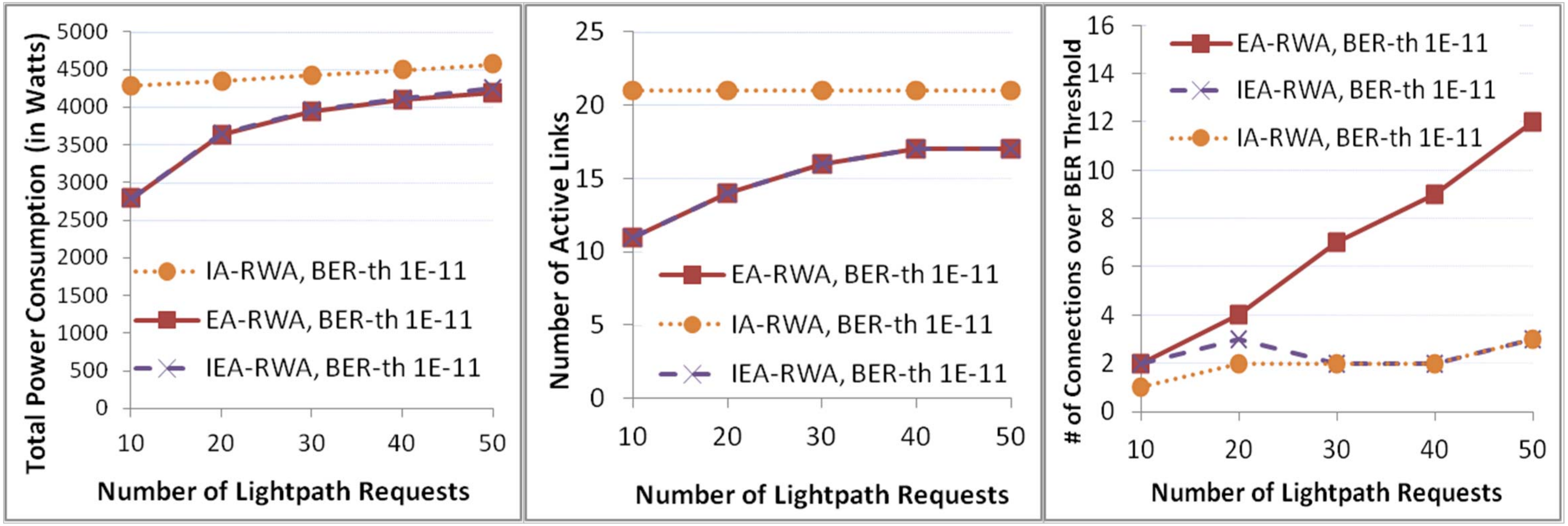
- Objective: find a design approach for energy efficient optical networks with signal-quality guarantee accounting for the *trade-off* between energy saving and impairment-aware network planning

- Solution: problem formulated as mixed integer linear programming (MILP) (*)
  - accounts for, in a linearized form, the impact of linear and non linear optical impairment as a constraint(**)
  - using a set of pre-computed paths for routing
  - wavelength conversion is assumed to be available at each node

(*) C. Cavdar, M. Ruiz, P. Monti, L. Velasco, L. Wosinska, *"Design of Green Optical Networks with Signal Quality Guarantee,"* in Proc. **IEEE ICC**, 2012

(**) M. Ruiz, L. Velasco, P. Monti, L. Wosinska, *"A Linearized Statistical XPM Model for Accurate Q-factor Computation,"* in **IEEE Communication Letters**, 2012

IEA-RWA performance evaluation (COST 239)



- IEA-RWA and EA-RWA achieve same total power consumption reduction (up to 35%) compare to IA-RWA
- IEA-RWA and EA-RWA comparable fiber usage performances, IA-RWA activates all the fibers
- IEA-RWA provides signal quality levels close to IA-RWA while minimizing total power consumption

C. Cavdar, M. Ruiz, P. Monti, L. Velasco, L. Wosinska, "*Design of Green Optical Networks with Signal Quality Guarantee*," in Proc. **IEEE ICC**, 2012

ROYAL INSTITUTE OF TECHNOLOGY

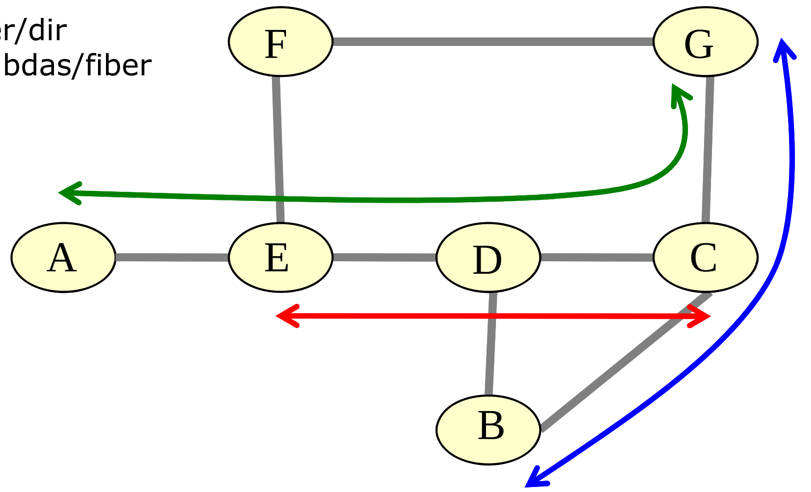
ONLab

Outline

- Motivation
- Sleep mode concept
- Static provisioning and EE
  - EE vs. Cost
  - EE vs. Backup sharing
  - EE vs. QoT
- Dynamic provisioning and EE
  - EE vs. blocking probability
- Conclusions

Energy efficiency vs. blocking probability

1 fiber/dir
2 lambdas/fiber



Power minimization

R1: E-C, route: E-D-C
R2: A-G, route: A-E-D-C-G
R3: B-G, route: B-C-G
R4: C-G, route: blocked

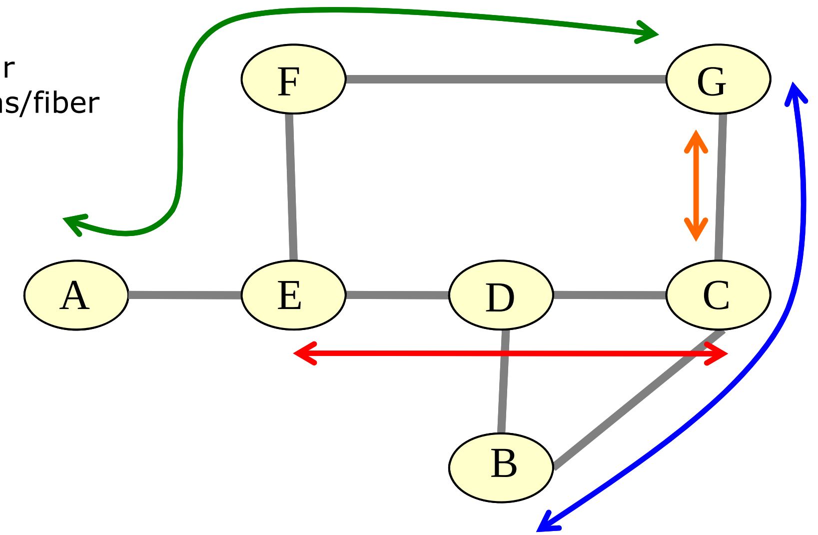
Links off	Nodes off	Blocked requests
3/8 ≅ 35%	1/7 ≅ 14%	1/4 ≅ 25%

Path hop minimization

R1: E-C, route: E-D-C
R2: A-G, route: A-E-F-G
R3: B-G, route: B-C-G
R4: C-G, route: C-G

Links off	Nodes off	Blocked requests
1/8 ≅ 12%	0/7 ≅ 0%	0/4 ≅ 0%

1 fiber/dir
2 lambdas/fiber

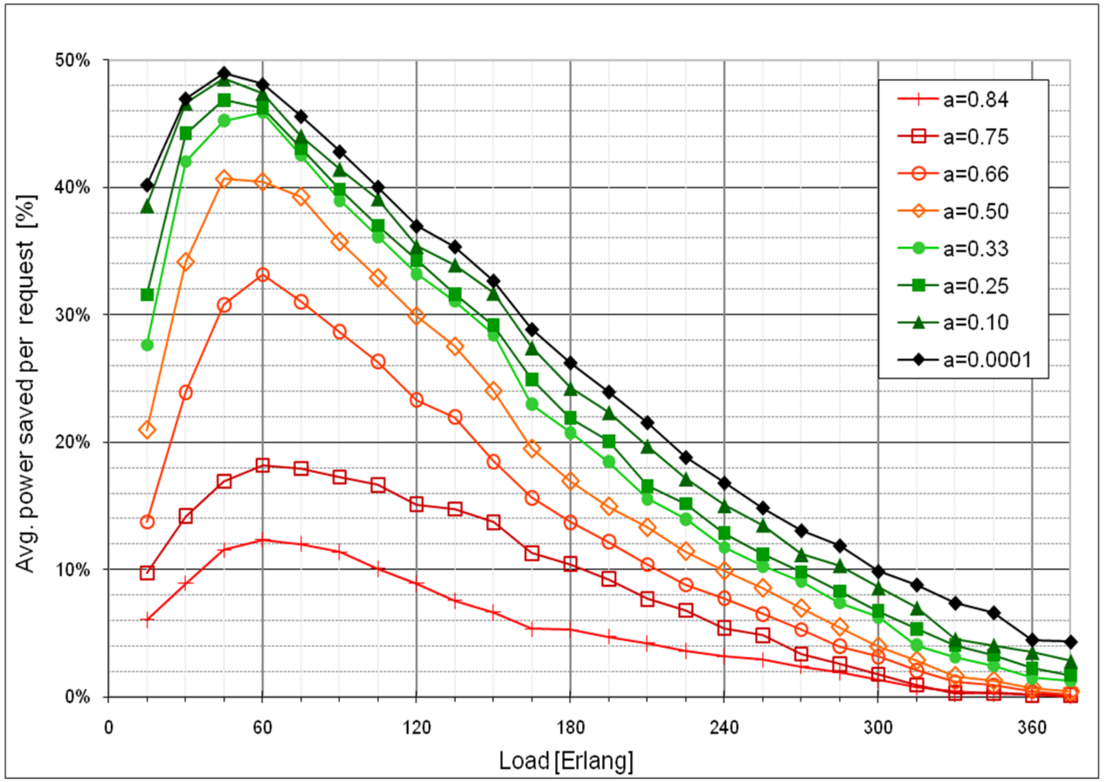


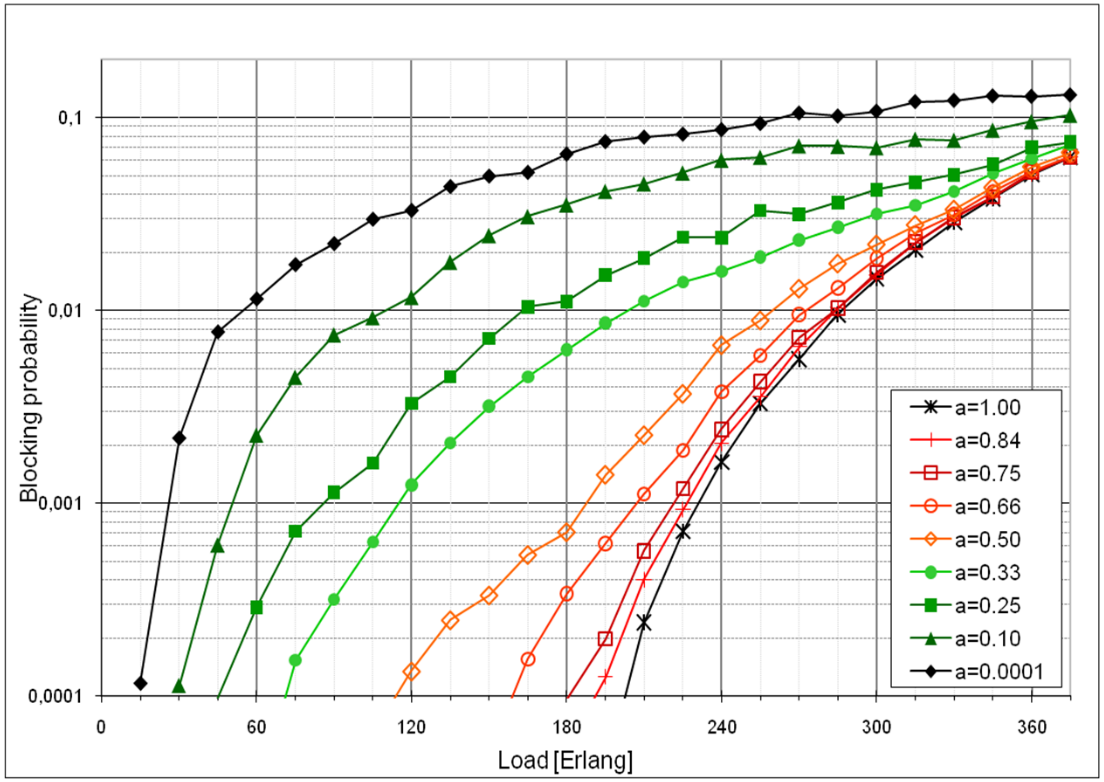
Weighted power-aware RWA (COST 239)

ROYAL INSTITUTE OF TECHNOLOGY

ONLab

$$C_l = \begin{cases} \alpha \cdot P_{link,l}, & l \text{ in use} \\ P_{link,l}, & l \text{ not in use} \end{cases} \qquad \alpha \in [0,1], \forall l \in p$$





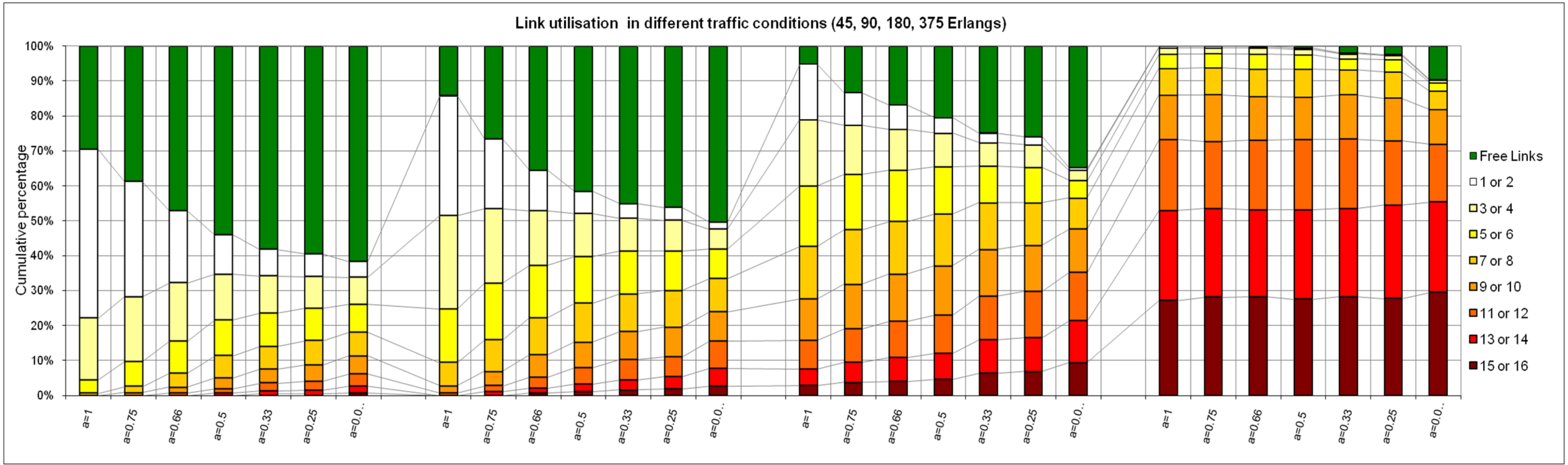
α between 0.66 and 1, no significant impact on the blocking probability, but the power saved per request is still significant, e.g., 30% and 15 % in low and medium traffic conditions

P. Wiatr, P. Monti, L. Wosinska, "*Power Savings Versus Network Performance in Dynamically Provisioned WDM Networks,*" in ***IEEE Communication Magazine***, 2012

ROYAL INSTITUTE OF TECHNOLOGY

ONLab

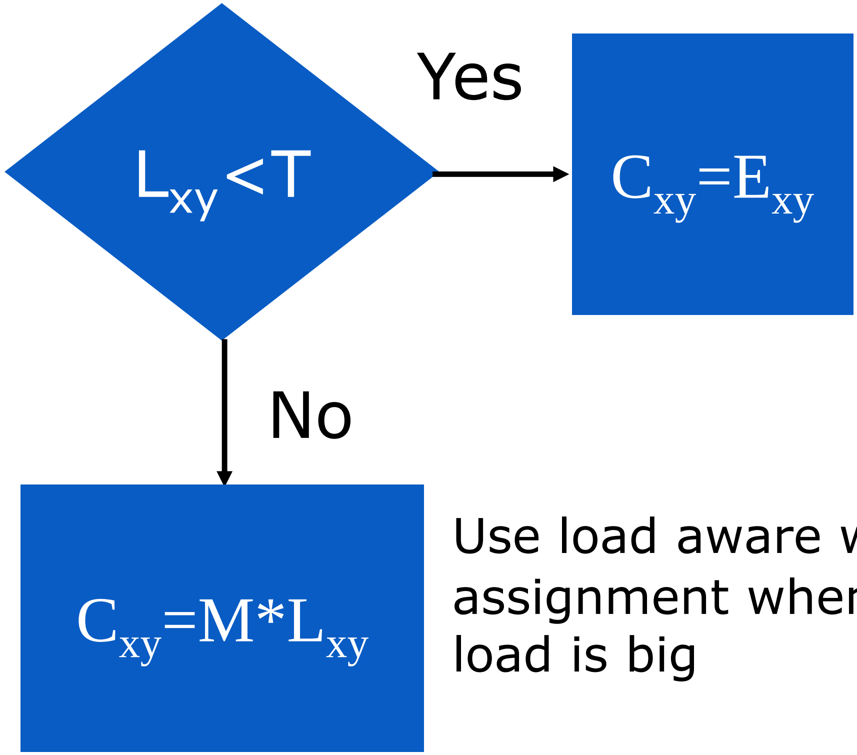
Link utilization distribution (COST 239)



P. Wiatr, P. Monti, L. Wosinska, "*Power Savings Versus Network Performance in Dynamically Provisioned WDM Networks,*" in ***IEEE Communication Magazine***, 2012

KTH VETENSKAP OCH KONST
ROYAL INSTITUTE OF TECHNOLOGY
ONLab

Dynamic weight assignment mechanism



Use energy-aware weight assignment when the link load is small

Use load aware weight assignment when the link load is big

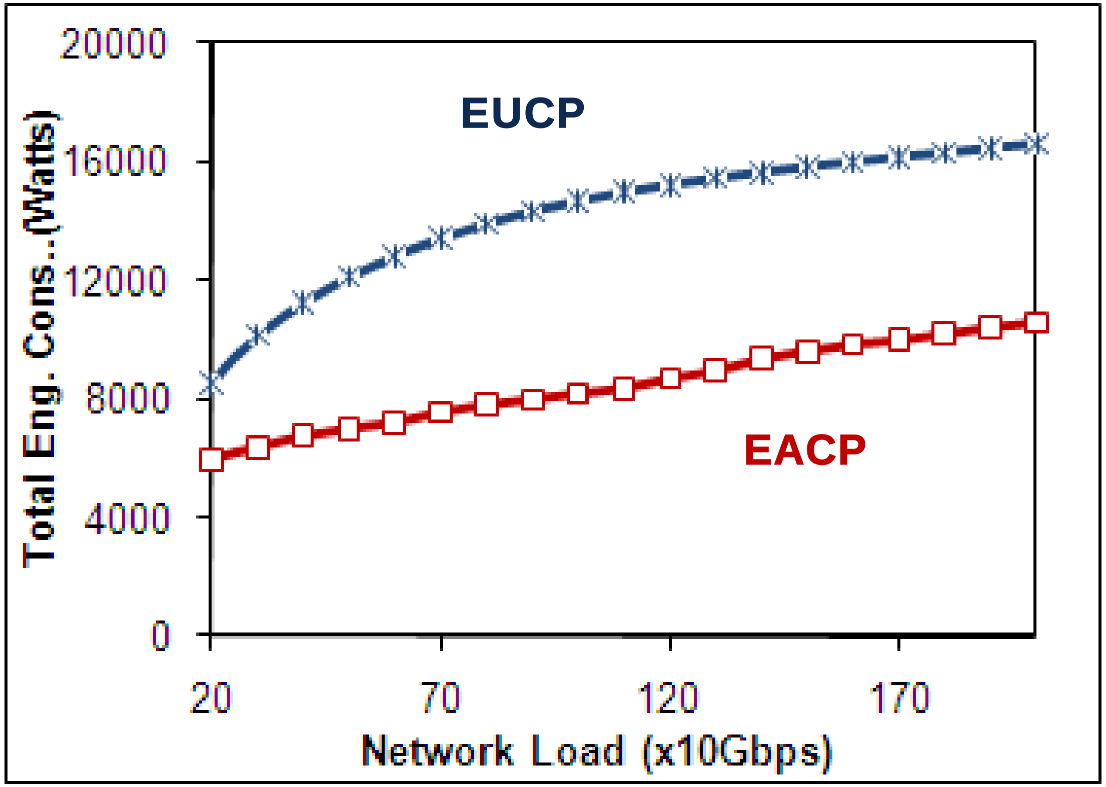
C. Cavdar, "*Energy Efficient Connection Provisioning in Optical WDM Networks*," ***OFC/NFOEC***, 2011

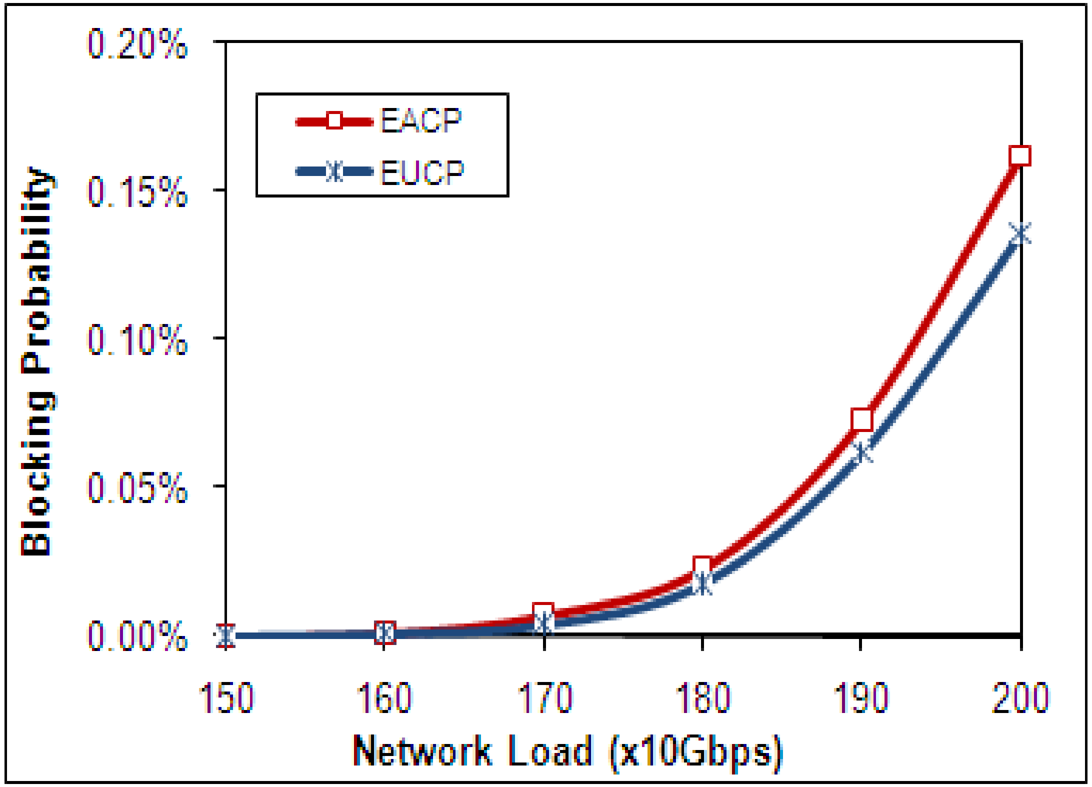
ROYAL INSTITUTE OF TECHNOLOGY

ONLab

Performance results (COST 239)

- EUCP: energy un-aware connection provisioning
- EACP: energy aware connection provisioning



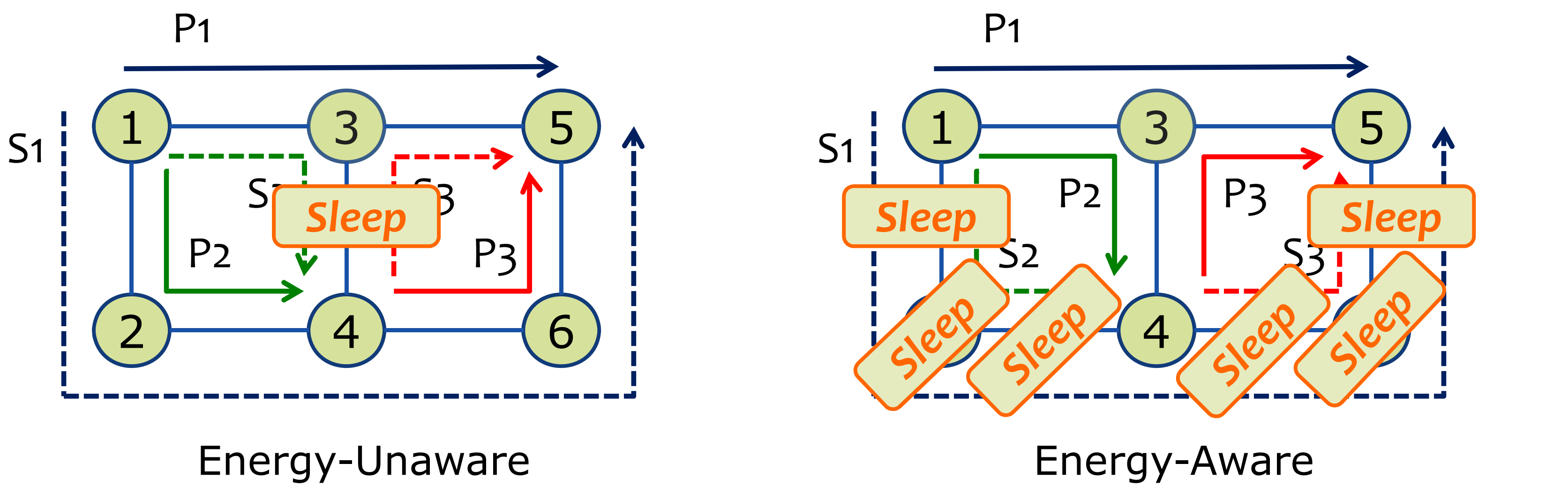


% gain in total energy consumption between 43% and % 36, without drastically impacting the blocking probability

C. Cavdar, "*Energy Efficient Connection Provisioning in Optical WDM Networks*," ***OFC/NFOEC***, 2011

ROYAL INSTITUTE OF TECHNOLOGY
ONLab

Energy-aware DPP provisioning



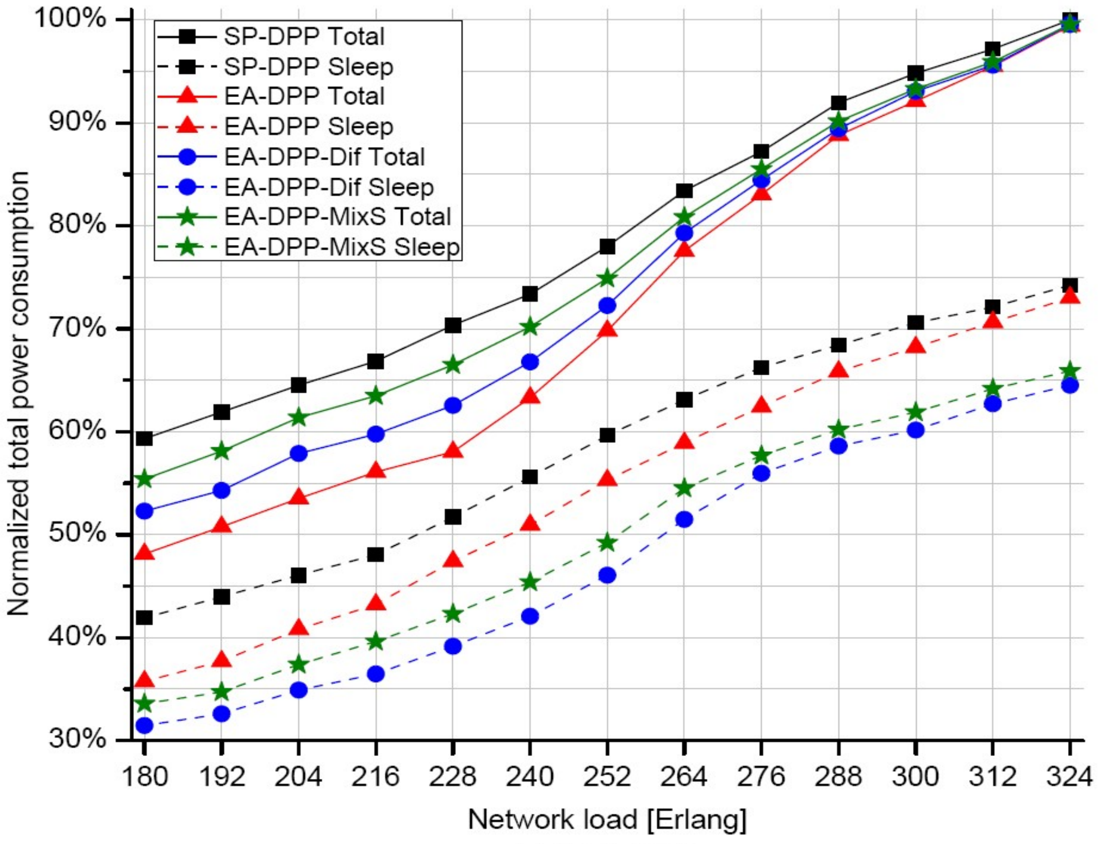
Request	Energy -Unaware		Energy -Aware	
	Primary	Secondary	Primary	Secondary
R1(1-5)	P1(1-3-5)	S1(1-2-4-6-5)	P1(1-3-5)	S1(1-2-4-6-5)
R2(1-4)	P2(1-2-4)	S2(1-3-4)	P2(1-3-4)	S2(1-2-4)
R3(4-5)	P3(4-6-5)	S3(4-3-5)	P3(4-3-5)	S3(4-6-5)

Energy-Aware DPP provisioning (COST 239)

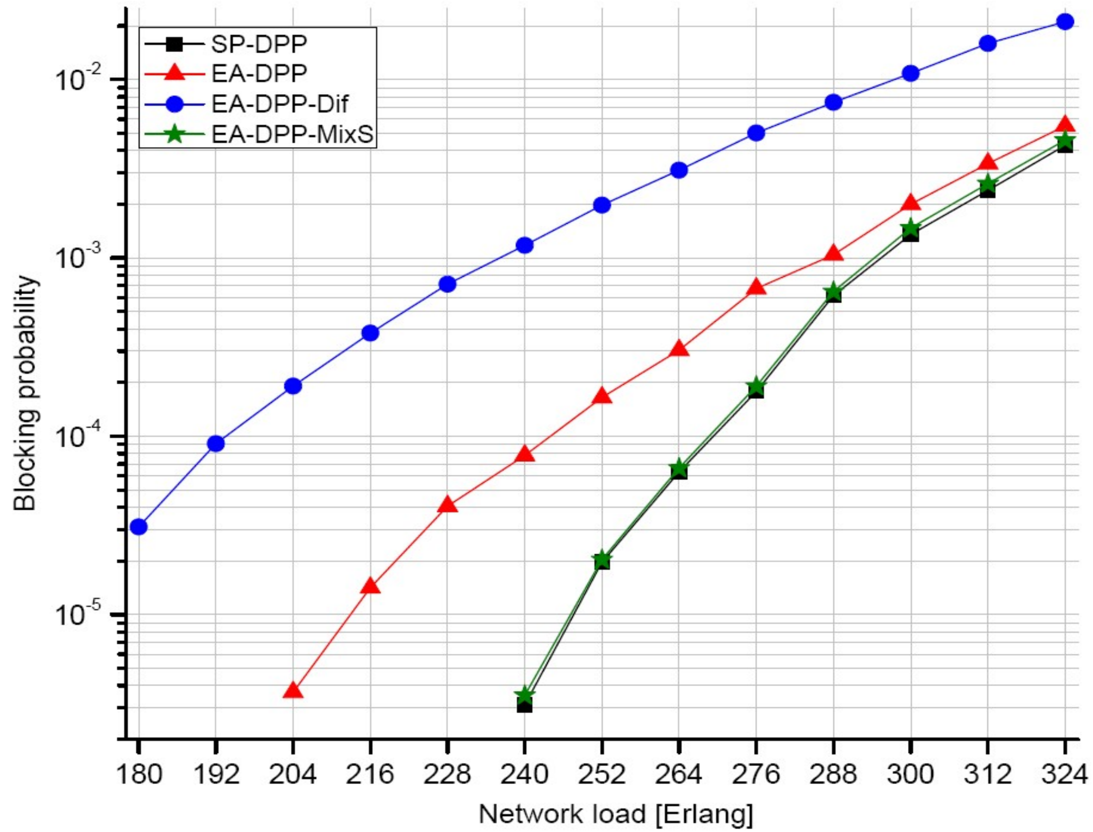
ROYAL INSTITUTE OF TECHNOLOGY

ONLab

- EA-DPP-Dif: primary and secondary resources kept separated as much as possible
- EA-DPP-MixS: only primary paths receive special attention



(a) COST 239



(a) COST 239

A. Jirattigalachote, C. Cavdar, P. Monti, L. Wosinska, A. Tzanakaki, "*Dynamic Provisioning Strategies for Energy Efficient WDM Networks with Dedicated Path Protection*," **OSN,** Vol. 8, No. 3, July 2011.

ROYAL INSTITUTE
OF TECHNOLOGY

ONLab

Conclusions

- Presented a number of solutions and results that highlight that energy consumption reduction is indeed important but not enough
- A number of trade offs are at play: QoT, resource usage, cost, etc.
- Future studies can not neglect this important new dimensions
- For example studies may include:
  - reach vs. spectral efficiency vs. energy efficiency
  - energy efficiency vs. quality of protection
  - physical/technological constraints of components
  - theoretical limits
  - …

ROYAL INSTITUTE
OF TECHNOLOGY

ONLab

References

- C. Cavdar, F. Bazluca, L. Wosinska, “Energy-Efficient Design of Survivable WDM Networks with Shared Backup,” in Proc. of IEEE Global Communication Conference (GLOBECOM), December 6-10, Miami, FL, USA, 2010
- A. Muhammad, P. Monti, I. Cerutti, L. Wosinska, P. Castoldi, A. Tzanakaki, “Energy-Efficient WDM Network Planning with Dedicated Protection Resources in Sleep Mode,” in Proc. of IEEE Global Communication Conference (GLOBECOM), December 6-10, Miami, FL, USA, 2010
- C. Cavdar, “Energy Efficient Connection Provisioning in Optical WDM Networks,” in Proc. OFC, 2011
- P. Monti, A. Muhammad, I. Cerutti, C. Cavdar, L. Wosinska, P. Castoldi, A. Tzanakaki, "Energy-Efficient Lightpath Provisioning in a Static WDM Network with Dedicated Path Protection," in Proc. of IEEE International Conference on Transparent Optical Networks (ICTON), June 27-30, Stockholm, Sweden, 2011
- A. Jirattigalachote, N. Skorin-Kapov, M. Furdek, J. Chen, P. Monti, L. Wosinska, "Sparse Power Equalization Placement for Limiting Jamming Attack Propagation in Transparent Optical Networks", Optical Switching and Networking (OSN) Journal, Vol. 8, No. 4, pp. 249-258, December 2011
- S. Jalalinia, C. Cavdar, L. Wosinska, "Survivable Green Optical Backbone Networks with Shared Path Protection,” in Proc. OFC 2012
- P. Wiatr, P. Monti, L. Wosinska, "Power savings versus network performance in dynamically provisioned WDM networks," IEEE Communication Magazine - Optical Communication Series, Vol. 50, No. 5, pp. 48-55, May 2012
- C. Cavdar, M. Ruiz, P. Monti, L. Velasco, L. Wosinska, "Design of Green Optical Networks With Signal Quality Guarantee," in Proc. of IEEE International Conference on Communications (ICC), June 10-15, Ottawa, Canada, 2012
- M. Ruiz, L. Velasco, P. Monti, L. Wosinska, "A Linearized Statistical XPM Model for Accurate Q-factor Computation," IEEE Communications Letters, Vol. 16, No. 8, 1324-1327, August 2012

Green optical networks: power savings vs. network performance

ROYAL INSTITUTE OF TECHNOLOGY

ONLab

Paolo Monti

Contact info

pmonti@kth.se

http://web.it.kth.se/~pmonti

ONLab website: http://www.ict.kth.se/MAP/FMI/Negonet/

Green broadband access: energy efficient wireless and wired network solutions Workshop

9-13 JUNE • BUDAPEST , HUNGARY

Submission deadline January 2013