Green optical networks: power savings vs. network performance

Paolo Monti

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

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

**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**
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
ICT energy consumption

- 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

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?
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
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
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 connections 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


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 ($\xi > 0$)
Performance results: ILP formulation (COST 239)

Network power consumption

Number of links in sleep mode

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 increase significantly with MP-S, while number active links decrease

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
Backup sharing vs. energy efficiency

(a) Minimizing capacity
- Primary=4, backup=3
- Number of fibers in active mode=4

(b) Minimizing power
- Primary=5, backup=4
- Number of fibers in active mode=3

Longer primaries, backup sharing not effective
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

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

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%.

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
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


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

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

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

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

<table>
<thead>
<tr>
<th>Links off</th>
<th>Nodes off</th>
<th>Blocked requests</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/8 ≈ 35%</td>
<td>1/7 ≈ 14%</td>
<td>1/4 ≈ 25%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Links off</th>
<th>Nodes off</th>
<th>Blocked requests</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/8 ≈ 12%</td>
<td>0/7 ≈ 0%</td>
<td>0/4 ≈ 0%</td>
</tr>
</tbody>
</table>

1 fiber/dir
2 lambdas/fiber
Weighted power-aware RWA (COST 239)

\[ C_l = \begin{cases} 
\alpha \cdot P_{\text{link},l}, & l \text{ in use} \\
P_{\text{link},l}, & l \text{ not in use}
\end{cases} \]

\[ \alpha \in [0,1], \forall l \in \mathcal{P} \]

\( \alpha \) 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.

Link utilization distribution (COST 239)

Dynamic weight assignment mechanism

Yes

$L_{xy} < T$

$C_{xy} = E_{xy}$

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

No

$C_{xy} = M \times L_{xy}$

Use load aware weight assignment when the link load is big

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

Energy-aware DPP provisioning

<table>
<thead>
<tr>
<th>Request</th>
<th>Energy -Unaware</th>
<th>Energy -Aware</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Primary</td>
<td>Secondary</td>
</tr>
<tr>
<td>R1(1-5)</td>
<td>P1(1-3-5)</td>
<td>S1(1-2-4-6-5)</td>
</tr>
<tr>
<td>R2(1-4)</td>
<td>P2(1-2-4)</td>
<td>S2(1-3-4)</td>
</tr>
<tr>
<td>R3(4-5)</td>
<td>P3(4-6-5)</td>
<td>S3(4-3-5)</td>
</tr>
</tbody>
</table>
Energy-Aware DPP provisioning (COST 239)

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

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.
  - ...
References

ONLab

• 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


• C. Cavdar, “Energy Efficient Connection Provisioning in Optical WDM Networks,” in Proc. OFC, 2011


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


Green optical networks: power savings vs. network performance

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

Submission deadline
January 2013