Energy-aware Traffic Allocation to Optical Lightpaths in Multilayer Core Networks

Prof. P. Demestichas, Dr. K. Tsagkaris, V. Foteinos, M. Logothetis
in cooperation with
Alcatel-Lucent Bell Labs France

Email: {pdemest, ktsagk, vfotein, mlogothe}@unipi.gr
http://tns.ds.unipi.gr/
Outline

- Motivation
- Energy-aware Traffic Allocation to Optical Lightpaths
- Autonomic Management Framework for Core Networks
- Future plans
Motivation [1|2]

- By the year 2014, the amount of Internet traffic will reach the 63.9 exabytes in a monthly basis
- Video traffic will dominate (more than 91 percent of the global consumed IP traffic)
- 1 billion online video users already
- Internet connection download speed and bandwidth needs to be improved
- Addition of resources to the current wired network and service infrastructures
- The levels of the consumed energy are affected
- Capacity and energy consumption of routers grow at an exponential rate
- Higher OPEX

Traffic Engineering Schemes

- Obvious need for advanced Traffic Engineering (TE) schemes that will exploit the already available ones for optimizing traffic routes
- TE schemes should be able to adapt in an autonomous manner to the traffic fluctuations
- Autonomicity and self-adaptation are key factors for taking fast, online and reliable TE decisions

Operators

- Stringent requirements to the operators' side
- The management of this intelligence cannot rely on the traditional command and control paradigm, which is slow and error prone
- Operator should have the flexibility to provide preferences and/or guidance to the behavior of the TE mechanism, in a human friendly and technology agnostic manner
Energy-aware Traffic Allocation to Optical Lightpaths [1|8]

- **Problem Statement**: find the most energy-efficient optical lightpath to accommodate the new traffic demand, while respecting the capacity of fibers and wavelengths.

- **Proposed Solution**
  - **Energy efficiency** is achieved through the allocation of traffic to dedicated lightpaths, which are restricted at the optical layer only.
  - **Minimum** overall Optical-to-Electrical-to-Optical (OEO) conversions.
  - **Minimum** number of activated transponders.

Energy Efficiency

- End to end lightpaths, restricted at the optical channel layer (OCh)
Mathematic Formulation

(Given data, Decision variables, objective function and constraints)

- Optimization problem
- Output corresponds to the optimal routing configuration
- IBM ILOG CPLEX Optimizer (CP algorithm)

<table>
<thead>
<tr>
<th>GIVEN DATA</th>
<th>Variables</th>
<th>Description</th>
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</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>Set of source to destination pairs.</td>
<td>$PLHN(p,l)$</td>
<td>Binary variable: 1 if fiber $l \in L$ has next fiber in path $p \in P$, 0 otherwise.</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>Set of paths.</td>
<td>$PLN(p,l)$</td>
<td>Fiber that follows fiber $l \in L$ in path $p \in P$.</td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>Set of optical fibers.</td>
<td>$CAPW(w)$</td>
<td>Capacity of wavelength $w \in W$.</td>
<td></td>
</tr>
<tr>
<td>W</td>
<td>Set of wavelengths.</td>
<td>$CC$</td>
<td>Cost of conversion.</td>
<td></td>
</tr>
<tr>
<td>$BS(s)$</td>
<td>Bandwidth demand for SD pair $s \in S$.</td>
<td>$CP(p)$</td>
<td>Cost of path $p \in P$ (length in number of hops).</td>
<td></td>
</tr>
<tr>
<td>$SP(s,p)$</td>
<td>Set of paths $p \in P$ for SD pair $s \in S$.</td>
<td>$CL(l)$</td>
<td>Cost of fiber $l \in L$.</td>
<td></td>
</tr>
<tr>
<td>$PL(p,l)$</td>
<td>Set of fibers $l \in L$ for path $p \in P$.</td>
<td>$CLW(l,w)$</td>
<td>Cost of wavelength $w \in W$ of fiber $l \in L$.</td>
<td></td>
</tr>
<tr>
<td>$LW(l,w)$</td>
<td>Set of wavelengths $w \in W$ for fiber $l \in L$.</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>DECISION VARIABLES</th>
<th>Variables</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Y_{SP}(s,p)$</td>
<td>Binary variable: 1 if path $p \in P$ is utilized from SD pair $s \in S$, 0 otherwise.</td>
<td></td>
</tr>
<tr>
<td>$Y_{P}(p)$</td>
<td>Binary variable: 1 if path $p \in P$ is activated, 0 otherwise.</td>
<td></td>
</tr>
<tr>
<td>$Y_{L}(l)$</td>
<td>Binary variable: 1 if fiber $l \in L$ is activated, 0 otherwise.</td>
<td></td>
</tr>
<tr>
<td>$Y_{LW}(l,w)$</td>
<td>Binary variable: 1 if wavelength $w \in W$ is activated in fiber $l \in L$, 0 otherwise.</td>
<td></td>
</tr>
<tr>
<td>$r_{SP}(s,p)$</td>
<td>Volume of traffic demand of SD pair $s \in S$, sent through path $p \in P$.</td>
<td></td>
</tr>
<tr>
<td>$d_{LW}(l,w)$</td>
<td>Aggregated traffic demand sent through wavelength $w \in W$ of fiber $l \in L$.</td>
<td></td>
</tr>
<tr>
<td>$d_{PLW}(p,l,w)$</td>
<td>Traffic demand sent through wavelength $w \in W$ of fiber $l \in L$ for path $p \in P$.</td>
<td></td>
</tr>
<tr>
<td>$Y_{CLW}(l,w)$</td>
<td>Integer variable: number of conversions at the next router for wavelength $w \in W$ in fiber $l \in L$.</td>
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</tbody>
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Objective function

- minimizes costs of paths, costs of links, costs of wavelengths and costs of conversions

\[
\begin{align*}
\min & \sum_p Y_P(p) \cdot C_P(p) + \sum_l Y_L(l) \cdot C_L(l) + \sum_l \sum_w Y_{LW}(l,w) \cdot C_{LW}(l,w) + \sum_l \sum_w Y_{C_{LW}}(l,w) \cdot C_c \\
\text{subject to:} & \\
Y_{C_{LW}}(l,w) & = \sum_l \sum_w Y_{LW}(l,w) \\
f(I,w) & = \sum \left( \left( \frac{d_{rw}(p,l,w)}{d_{rw}(p,l,w)} \right) \right) Y_p(p) = 1 \\
B_S(s) & = \sum_p r_{SP}(s,p) \cdot Y_{SP}(s,p) \\
Y_P(p) & = \left( \sum_s Y_{SP}(s,p) \right) > 0 \\
\sum_s r_{SP}(s,p) \cdot Y_{SP}(s,p) & = \sum_l \sum_w d_{LW}(l,w) \\
\sum_l \sum_w Y_{LW}(l,w) \cdot C_{AR}(w) & \geq \sum_l \sum_w d_{LW}(l,w) \cdot Y_{LW}(l,w) \\
d_{LW}(l,w) \cdot Y_{LW}(l,w) & = \sum_p d_{PLW}(p,l,w) \cdot Y_P(p) \\
Y_L(l) & = \left( \sum_w Y_{LW}(l,w) \right) > 0 \\
d_{PLW}(p,l,w) & \leq r_{SP}(s,p) \cdot Y_{SP}(s,p) \\
\forall s \in S, p \in P, l \in L, w \in W, s, p \in SP(s,p), p, l \in PL(p,l), l, w \in LW(l,w)
\end{align*}
\]
Energy-aware Traffic Allocation to Optical Lightpaths [5|8]

State Of The Art (energy efficiency)
- Selectively turning off (sleep mode) idle network elements
- Green architecture directly during the network design stage
- Energy efficient IP packet forwarding
- Green routing (traditional routing protocols updated)
- Two techniques:
  - Traffic grooming
  - Optical bypass

Energy-aware Traffic Allocation to optical Lightpaths (ETAL) algorithm:
- Allocation of traffic demands to the optimal lightpath(s), in terms of consumed energy
- Exploitation of the optical bypass technique
Evaluation: comparisons with energy-efficient routing schemes and other common routing protocols.

- OPTIMAL: Optimal routing configuration derived as the output of the mathematic formulation
- ETAL: Routing configuration derived from ETAL algorithm
- OSPF: OSPF routing configuration
- MIN-FIBERS: Minimum number of activated fibers in the network
- MIN-WAVELENGTHS: Minimum number of activated wavelengths in the network
Minimum consumed power, independently of traffic fluctuations, due to minimum OEO conversions.

Running Times for the accommodation of the overall traffic demands

- **ILOG**: Hundreds (even thousands) of seconds depending on the size of the problem
- **ETAL**: 1 or 2 seconds
Exploitation of available wavelengths for minimizing and stabilizing the consumed power.

**Conclusions**
- Due to time constraints, solving the mathematic formulation is inefficient and cannot be applied for online decisions.
- **ETAL** establishes lightpaths with minimum number of OEO conversions and minimum number of activated transponders.
- **ETAL** exploits the available resources.
- **ETAL** achieves near to optimal decisions in minimum time.
- **ETAL** is an acceptable energy-efficient solution for online traffic engineering.
Autonomic Management Framework for Core Networks

- Autonomic network management is based on the design and deployment of multiple, autonomic MAPE-K loops in the network.
- A framework for the plug n’ play deployment and unified management of these loops is required: **Unified Management Framework (UMF)**
  - **UMF Core services:** govern (policies) these loops, coordinate their autonomic behavior and provision them with always up-to-date knowledge; all these in a unified manner, independently of their method, scope and domain.
  - **NEMs:** to encapsulate the loops’ logic and provide them with the interface needed to render them manageable by the UMF core services.

- The presented algorithms are MAPE-K loops acting in the core network.
- Core TE NEMs are developed to render them manageable in the UMF context.
- UMF drives their behavior by expressing and propagating goals such as “Energy Efficiency”
  - Respected by TE decisions/Translated into actions in the network.

Future plans

- More Traffic Engineering algorithms (centralized, distributed) and their evaluation (simulation + emulation)

- Traffic Engineering in Software Defined Networks (SDNs)

- Traffic Engineering in Data Center networks
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