Net2Plan: The open-source network planner

José Luis Izquierdo Zaragoza
josel.izquierdo@upct.es
http://ait.upct.es/~jlizquierdo

Politecnico di Milano

Milano, Italy, November 22-27, 2013

This research was partially supported by a predoctoral FPU fellowship from the Spanish Ministry of Education, Culture and Sport (reference no. FPU12/04571) and a mobility grant from Universidad Politécnica de Cartagena (PMPDI-UPCT-2013)

Outline

Outline

Lab work

- “Network design” integrated course covers a number of network design problems
- In this seminar we are reviewing Net2Plan, an open-source network planning tool
- It’s time to put everything together!
  - ILP models for RFWA } Communication Network Design
  - Heuristic for RFWA } (Prof. Tornatore)
  - Column generation ← Graph Optimization (Prof. Carello)

ILP models for RFWA
Lab work

- Several ILP models for RFWA have been presented:
  - Unprotected case: FF/RF/SF VWP/WP
  - Dedicated path protection: “Max half” VWP, FF/RF VWP/WP
  - Shared path protection: RF VWP/WP, FF VWP
  - Dedicated/Shared link protection: FF VWP
- We are going to focus on some of them:
  - Unprotected case: FF/RF VWP, RF WP
- For all examples, the objective is to minimize the number of installed fibers

Unprotected case, flow formulation, VWP

ILP models for RFWA

Solenoidality	$\sum_{k \in A_l} x_{k,l,c} - \sum_{k \in A_l} x_{l,k,c} = \begin{cases} v_c & \text{if } l = d_c \\ -v_c & \text{if } l = s_c \\ 0 & \text{otherwise} \end{cases} \quad \forall\, l,c$
Capacity	$\sum_c x_{l,k,c} \leq W \cdot F_{l,k} \quad \forall (l,k)$
Integrity	$x_{l,k,c}$ integer $\quad \forall c,(l,k)$ $F_{l,k}$ integer $\quad \forall (l,k)$

Unprotected case, route formulation, VWP

ILP models for RFWA

- $r_{c,n}$: number of connections routed on the *n-th* admissible path between source destination nodes of the node-couple *c*
- $R_{(l,k)}$: set of all admissible paths passing through link *(l,k)*

Solenoidality	$\sum_{n} r_{c,n} = v_c \quad \forall c$
Capacity	$\sum_{r_{c,n} \in R_{l,k}} r_{c,n} \leq W \cdot F_{l,k} \quad \forall (l,k)$
Integrity	$r_{c,n}$ integer $\quad \forall (c,n)$ $F_{l,k}$ integer $\quad \forall (l,k)$

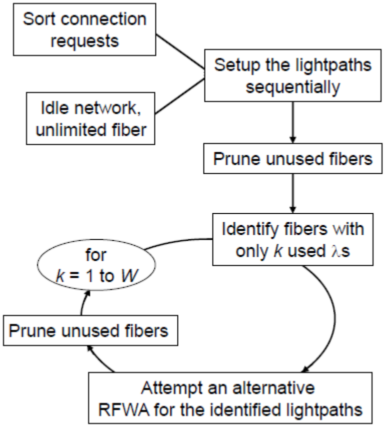
Unprotected case, route formulation, WP

ILP models for RFWA

- $r_{c,n,\lambda}$ = number of connection routed on the *n-th* admissible connection between node couple *c* (source-destination) on wavelength λ

Solenoidality	$\sum_n r_{c,n,\lambda} = v_{c,\lambda}$	$\forall c, \lambda$
	$\sum_\lambda v_{c,\lambda} = v_c$	$\forall c$
Capacity	$\sum_{r_{c,n} \in R_{l,k}} r_{c,n,\lambda} \leq F_{l,k}$	$\forall (l,k), \lambda$
Integrity	$r_{c,n,\lambda}$ integer	$\forall (c,n), \lambda$
	$F_{l,k}$ integer	$\forall (l,k)$
	$v_{c,\lambda}$ integer	$\forall c, \lambda$

Heuristic for RFWA
Lab work



- Connection request sorting rules
  - Longest first
  - Most requested couples first
  - **Balanced**
  - Random
- Processing of an individual lightpath
  - Routing, Fiber and Wavelength Assignment (RFWA) criteria
  - Dijkstra's algorithm performed on the multifiber layered graph

Column generation for FA I

Lab work

- Given a problem with exponentially many variables (set P)
- Initially a problem is solved with a subset of the variables $P_0 \subset S$ (Restricted Master Problem, RMP)
- In the dual problem of the RMP only a subset of constraints is considered
- Let x^* be the optimal solution of RMP and u^* the corresponding complementary dual solution: if u^* is feasible for the whole problem in which all the dual constraints are considered $\rightarrow$ both solutions are optimal
- Otherwise:
  - x^* is not optimal
  - At least one dual constraint, associated to a primal variable not belonging to P_0 is violated
  - Such constraint must be found out and added to the dual problem (pricing procedure)

Column generation for FA II

Lab work

- The set of columns of RMP is updated and RMP is solved again

$$\min \rho$$

$$\sum_{p \in P_d} x_p = h_d \qquad \forall d \in D \qquad \lambda_d$$

$$\sum_{d \in D} \sum_{p \in P_d} x_p = \rho \cdot u_e \qquad \forall e \in E \qquad \pi_e \leq 0$$

$$x_p \in \{0, 1\}$$

$$\rho \in \mathbb{Z}^+$$

- Dual constraint: For each demand $d \in D$ and each path $p \in P_d$, the dual constraint is:

$$\lambda_d + \sum_{e \in p} \pi_e \leq 0$$

Column generation for FA III
Lab work

- Pricing:
  - Find a path such that the corresponding dual constraint is violated

$$\sum_{e \in p} -\pi_e \leq \lambda_d$$

  - That is, we are looking for the shortest path from the ingress node to the egress node of demand d on a graph on which the cost of link $e \in E$ is

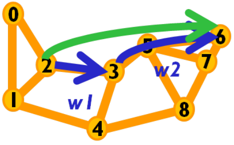
$$-\pi_e$$

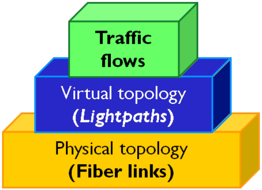
  - If the shortest path length is greater than λ_d, for all the demands, the solution of the RMP is optimal for the original problem
  - Otherwise, there exists at least one demand such that the corresponding dual constraint is violated: add a new variable to the RMP

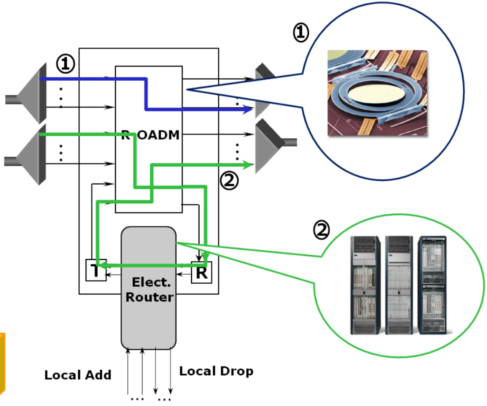
Outline

Transparent Optical Networks in a nutshell
Real-world case study: IP-over-WDM

- Lightpath: All-optical path between two nodes







Problem statement
Real-world case study: IP-over-WDM

- Our aim: Complete IP-over-WDM case study using Net2Plan

  P. Pavon-Marino, J.L. Izquierdo-Zaragoza, "Net2Plan: An open-source network planning tool for bridging the gap between academia and industry," submitted to *IEEE Network Magazine*
- Three main parts:
  - Offline multilayer network planning
  - Resilience analysis
  - Energy-efficiency analysis

Offline multilayer network planning I

Real-world case study: IP-over-WDM

- Given a fiber plant, the number of wavelengths per fiber, the binary rate per wavelength and an IP traffic matrix, to solve the VTD problem
- Requirements:
  - OSPF/ECMP routing at the IP layer
  - 1+1 dedicated lightpath protection, (sub-)path restoration
  - Lightpath utilization below 50%
  - E2E delay below 50 ms
  - Optical reach: 2800 km
  - Full wavelength conversion
- Objective function: Minimize CAPEX (transponders + regenerators/wavelength converters)

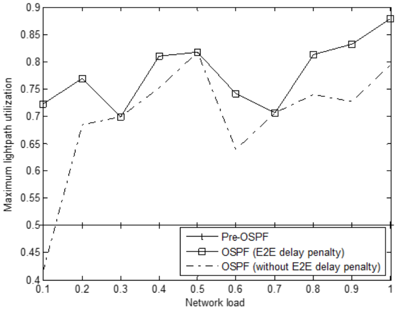
Offline multilayer network planning II
Real-world case study: IP-over-WDM

- Two-step heuristic:
  - Step 1: Build a full-mesh virtual topology (so, no grooming) using an ILP DPP route formulation
  - Step 2: Try to reduce the number of lightpaths by adding grooming to the picture with OSPF
    - Sort lightpaths in descending order of cost (in number of regenerators/wavelength converters)
    - Reroute traffic by optimizing OSPF weights while link utilization is not violated. If possible, remove it

Offline multilayer network planning III

Real-world case study: IP-over-WDM

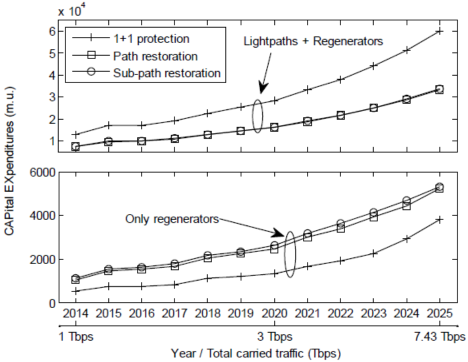
- Problem: OSPF reduces the power of grooming



Offline multilayer network planning IV

Real-world case study: IP-over-WDM

- CAPEX predictions under 20% CAGR:



Resilience analysis

Real-world case study: IP-over-WDM

- Upon completion, the design is evaluated in terms of resilience under failures and energy-efficiency
- Resilience analysis is divided into two parts: availability analysis and disaster vulnerability
- Availability results:

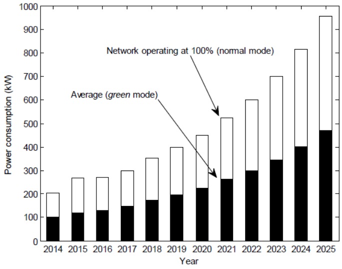
Year	1+1 protection		Path restoration		Sub-path restoration	
	Report	Simulation	Report	Simulation	Report	Simulation
2014	99.724%	99.721%	99.999%	99.999%	99.999%	99.999%
2020	99.721%	99.714%	99.999%	99.999%	99.999%	99.999%
2025	99.724%	99.716%	99.999%	99.999%	99.999%	99.999%

- Disaster vulnerability results:

Year	1+1 protection	Path restoration	Sub-path restoration
2014	80.60%	85.71%	85.71%
2020	81.12%	85.71%	85.71%
2025	82.09%	85.71%	85.71%

Energy-efficiency analysis
Real-world case study: IP-over-WDM

- Finally, we know that Internet traffic varies along the day, so let's take advantage to save energy (and money)
- Main idea: Try to switch off as many lightpaths as possible so that the total energy consumption is minimized
- Results:



Universidad Politécnica de Cartagena

git Ingeniería Telemática

Thank you for your attention!!! Questions?

José Luis Izquierdo Zaragoza
http://ait.upct.es/~jlizquierdo
josel.izquierdo@upct.es

Net2Plan: The open-source network planner

José Luis Izquierdo Zaragoza
josel.izquierdo@upct.es
http://ait.upct.es/~jlizquierdo

Politecnico di Milano

Milano, Italy, November 22-27, 2013

This research was partially supported by a predoctoral FPU fellowship from the Spanish Ministry of Education, Culture and Sport (reference no. FPU12/04571) and a mobility grant from Universidad Politécnica de Cartagena (PMPDI-UPCT-2013)