Design, Routing and Wavelength assignment in Optical Networks

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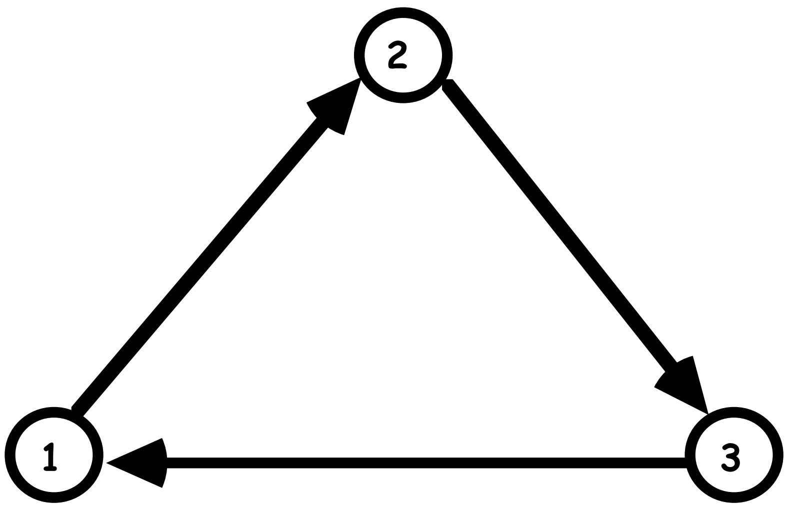
Routing and wavelength assignment in optical networks

Given: a network (nodes and links) and capacities
a traffic demand (# of dedicated O/D channels)
WDM technology



Capacity = 2
1-3: 1 channel
2-1: 1 channel
3-2: 1 channel

Route all the traffic assigning wavelengths (colors) to dedicated channels

Routing and wavelength assignment in optical networks

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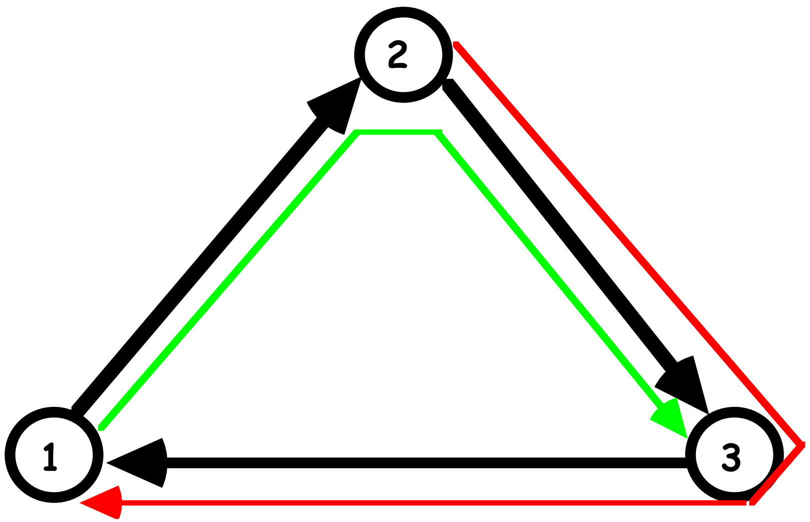

Capacity = 2
1-3: 1 channel
2-1: 1 channel
3-2: 1 channel ??

In this network we cannot route all the traffic unless we introduce an OPTICAL CROSS CONNECT (OXC)

Approaches in the literature:

- OXC in each node (⇒ multicommodity flow)
- NO OXC

- OXC's are very expansive

  ⇒ selective placement of OXC

  (one of the most challenging problem in the field)

Are they really necessary or is it more worthy allocating more capacity in the links?

ILP formulation of the routing and selective OXC placement

some valid inequalities

Capacity allocation vs. OXC placement

- ILP model

  routing + WL assignment + network design
- valid inequalities
- experiments on real networks (metro and geographical)

Assumption: all the traffic of each commodity is routed along the same path

NOTATION

Oriented graph $G=(N,A)$

$p \in P^k$: feasible path for commodity $k \in K$ (O/D pair (s^k, t^k))

$P(u,v)$: set of paths containing arc (u,v)

d^k : demand of commodity k

H : set of available WL

$$x_p = \begin{cases} 1 & \text{traffic of commodity } k \text{ is routed through } p \in P^k \\ 0 & \text{otherwise} \end{cases}$$

$$y_{uv}^{kh} = \begin{cases} 1 & \text{WL } h \text{ assigned to a unit of commodity } k \text{ on arc (u,v)} \\ 0 & \text{otherwise} \end{cases}$$

$$z_v^k = \begin{cases} 1 & \text{a WL occurs at node } v \text{ commodity } k \\ 0 & \text{otherwise} \end{cases}$$

Minimizing the number of switches

$$\min \sum_{v \in N} \max_k z_v^k$$

$$\sum_{p \in P^k} x_p = 1 \qquad \forall\, k \in K$$

$$\sum_{k \in K} y_{uv}^{kh} \leq 1 \qquad \forall\, h \in H,\ \forall\, (u,v) \in A$$

$$\sum_{h \in H} y_{uv}^{kh} = \sum_{p \in P^k \cap P(u,v)} d^k x_p \qquad \forall\, k \in K,\ \forall\, (u,v) \in A$$

$$z_v^k \geq y_{wv}^{kh} - y_{vu}^{kh} - \Big(1 - \sum_{p \in P^k \cap P(w,v) \cap P(v,u)} x_p\Big) \qquad \forall k \in K, \forall h \in H,\ \forall (w,v),(v,u) \in A$$

$$z_v^k \geq y_{vu}^{kh} - y_{wv}^{kh} - \Big(1 - \sum_{p \in P^k \cap P(w,v) \cap P(v,u)} x_p\Big)$$

The constraints setting z variables derive from:

$z_v^k = | y_{wv}^{kh} - y_{vu}^{kh} |$ if commodity k is routed through arcs (w,v) and (v,u)

there is a switch if and only if a lightpath leaves a node with a color different from the entering one

Including the capacity allocation into the model

c_e : capacity of the link if WDM device e is installed

g_e : cost of device e

f_v : cost of OXC in node v

assume: $c_e > c_{e-1}$, and $g_e > g_{e-1}$ ($c_0 = g_0 = 0$)

we allocate the capacity incrementally

$$Y_{uv}^{e} = \begin{cases} 1 & \text{capacity } (c_e > c_{e-1}) \text{ is added to arc } (u,v) \\ 0 & \text{otherwise} \end{cases}$$

$$\min \sum_{v \in N} f_v \max_k z_v^k + \sum_{e \in L} (g_e - g_{e-1}) \sum_{(u,v) \in A} Y_{uv}^e$$

$$\sum_{k \in K} \sum_{h \in H} y_{uv}^{kh} \leq \sum_{e \in L} (c_e - c_{e-1}) Y_{uv}^e \qquad \forall (u,v) \in A$$

$$Y_{uv}^e \leq Y_{uv}^{e-1} \qquad e = 2, \ldots, |L|, \ \forall (u,v) \in A$$

{the other constraints defined before}

Valid inequalities (1)

"Cover" inequalities on the arc capacities

Let $K(u,v)$ be the set of commodities which may use arc (u,v) and let e such that $c_{e-1} < \sum_{k \in K(u,v)} d^k \leq c_e$

The following inequalities are valid:

$$\sum_{k \in K(u,v)} \sum_{p \in P^k \cap P(u,v)} x_p - |K(u,v)| + 1 \leq Y_{uv}^e$$

They can be applied to any subset $K'(u,v) \subseteq K(u,v)$ including singletons

Valid inequalities (2)

Derived from the selective OXC placement problem

Let $G^*=(V,E)$ be the conflict graph of paths and C a clique in G^* such that $\sum_{p \in C} d^{k(p)} > |H|$

where $k(p)$ is the commodity of path p

The following inequalities are valid:

$$\sum_{p \in C} x_p - |C| + 1 \leq \frac{\sum_{p \in C} \sum_{v \in V(C)} z_v^{k(p)}}{(|C|-2)}$$

where $V(C)$ is the set of nodes belonging to pairs of paths in C

COMPUTATIONAL EXPERIMENTS

Metropolitan network:

11 nodes, 42/43 arcs, 136/142 paths, 22/23 commodities

Scenario 1: normal costs (example provided by Cox associated)
Scenario 2: high OXC costs
Scenario 3: low OXC costs

In scenarios 2 and 3 the graph an the demand have been modified wrt to scenario 1 in order to have the alternative between introducing an OXC or a new fiber

Geographical Network (NFS Net):

14 nodes, 54 arcs, 35 commodities
we generated a subset of 110 paths
two scenarios depending on OXC costs

	metro network			NFS net	
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
LP relaxation	207850	513788	513788	945313	945313
GAP	73%	52%	50%	42%	41%
Best integer after 10 h of CPLEX	787500	1410200	1278801	4400000	1722001
after simple cuts (singletons)	733000	945083	945083	1400750	1400750
GAP	4.12%	11.46%	7.12%	13.91%	11.74%
after "cover" cuts and "placement" cuts	752827	1057582	1004533	1571417	1531391
GAP	1.53%	0.93%	1.27%	3.42%	3.50%
rounding heuristic	764500	1072500	1017501	1627000	1627000
GAP	0%	0.47%	0%	0%	2.52%
optimal solution	764500	1067500	1017501	1627000	1587001
number of OXC	0	0	1	0	1

FUTURE RESEARCH

- Column generation and Branch&Cut
- More sophisticated heuristics

- Study the case where the flow is allowed to split among different paths