Designing Reliable WDM Networks — A Global Approach

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Introduction

In this paper we propose:

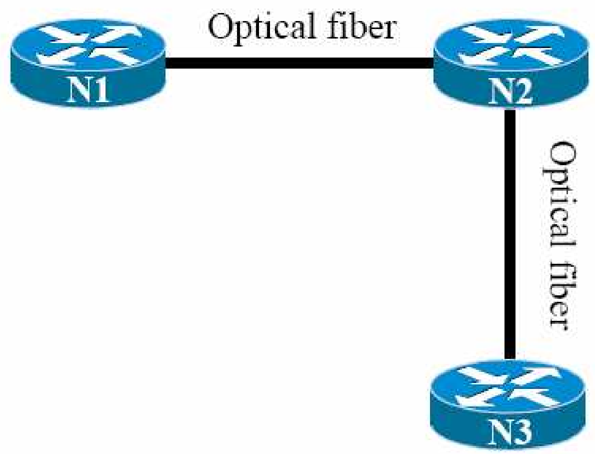
- A mathematical model for the global design problem of WDM networks including the traffic grooming. This problem consists in
  - finding the number of fibers between each pair of nodes (i.e., the physical topology);
  - finding the number of transponders to install at each node;
  - choosing the set of lightpaths (i.e., the virtual topology);
  - routing these lightpaths over the physical topology;
  - grooming and routing the traffic over the lightpaths.
- A heuristic algorithm to find “good” feasible solutions.
- Finally, numerical results are presented and analyzed.

Introduction (cont'd)

- Traffic grooming is a well known traffic engineering technique which packs low-speed traffic streams into high-capacity optical channels.
- The traffic streams are composed of connections and each connection is a traffic flow of a certain rate (e.g., OC-3 and OC-12) between two nodes.
- The traffic grooming permits grouping several connections, possibly of different origin-destination node pairs into the same lightpath.

Introduction (cont'd)

Traffic grooming example.

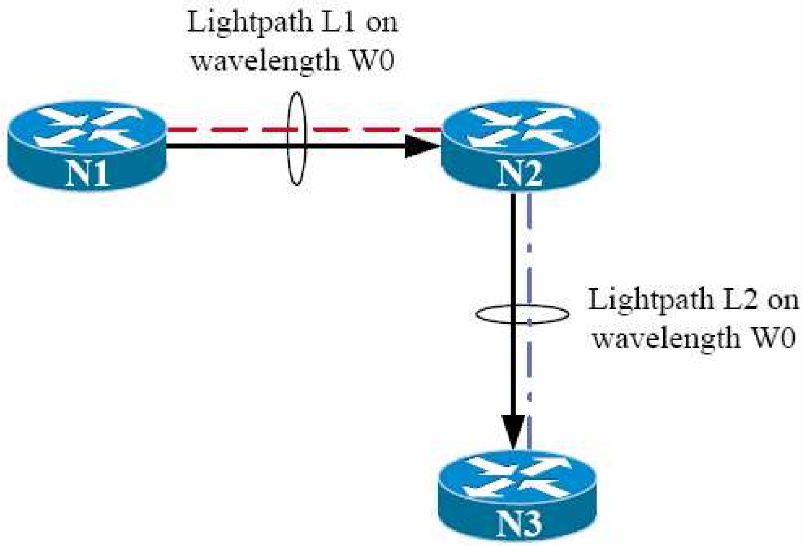


(a)

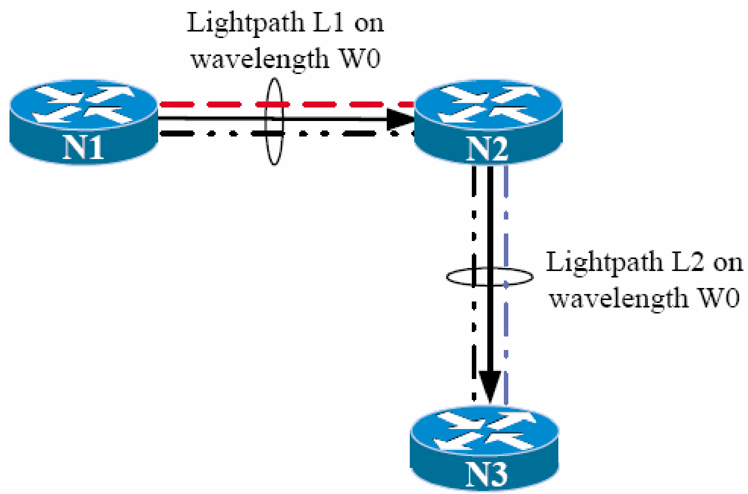
Table 1: Number of reception and transmission transponders for each node

Node	Number of reception transponders	Number of transmission transponders
N1	1	1
N2	3	3
N3	2	2

Introduction (cont’d)



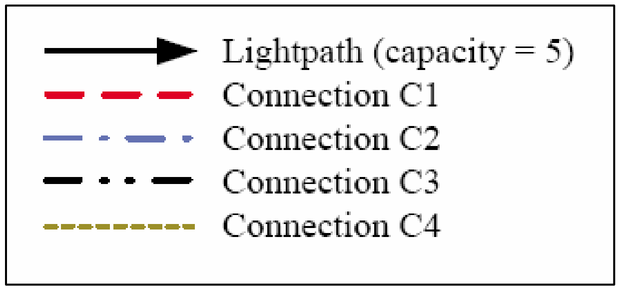
(b)



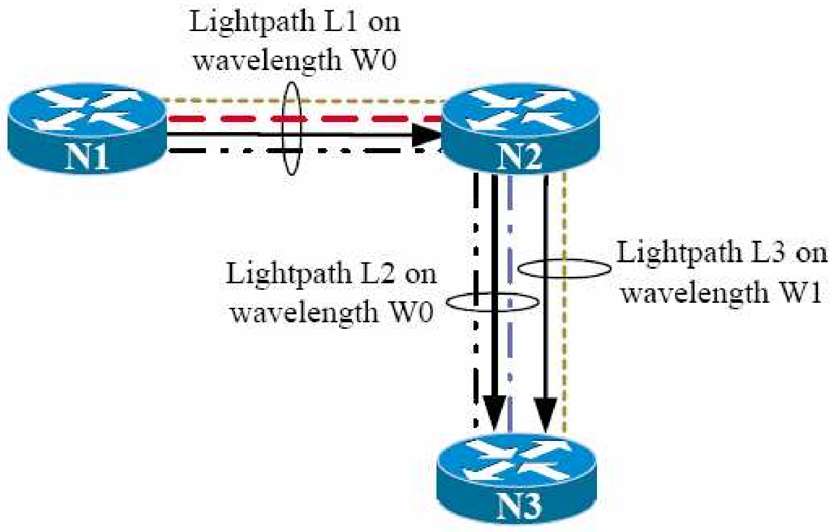
(c)

Table 2: Characteristics of the connections

Connection	Origin node	Destination node	Demand
C1	N1	N2	1
C2	N2	N3	2
C3	N1	N3	2
C4	N1	N3	2



Introduction (cont'd)



(d)

Assumptions

The following information is considered known:

1. The location of the optical nodes.
2. The origin-destination connection demand (i.e., the number of OC-3, OC-12, etc.) between each pair of nodes.
3. The maximum number of optical fibers that can be installed between each pair of nodes.
4. The maximum number of wavelengths that can be used into a fiber.
5. The cost of the links between each pair of nodes as a function of the number of fibers including the installation cost (for the patch panels, the patch cords, the labor, etc.).
6. The cost the transponders including the installation cost.

Assumptions (cont'd)

We make the following assumptions about the network organization:

1. A link (one or more fibers) can be installed between each pair of nodes.
2. The number of fibers installed between two nodes cannot exceed the maximum allowed.
3. The number of wavelengths used into a fiber cannot exceed the maximum allowed.
4. Each node have full grooming facilities.
5. There is no wavelength conversion in the network.
6. A connection can use more than one lightpath (multi-hop).

The network design problem

The global WDM network design problem consists in finding

- the number of optical fibers between each pair of nodes (i.e., the physical topology);
- the number of transponders to install at each node;
- the set of lightpaths (i.e., the virtual topology);

as well as

- routing the lightpaths over the physical topology;
- grooming the traffic and finally,
- routing the traffic over the virtual topology.

The objective is to minimize the cost of the network.

The model

P: Minimize

Cost of the network (i.e., the cost of the links and the cost of the transponders)

Subject to :

Physical topology constraints

Virtual topology constraints

Virtual topology over physical topology constraints

Traffic constraints

Intergrality constraints

Exact solution with CPLEX

- A Sun Java workstation under Linux with an AMD Opteron 150 CPU and 2GB of RAM was used for the tests.
- CPLEX 9.0 is used to solve the model.

Table 3: Coordinates of the optical nodes

Node	x (km)	y (km)	
1	0	600	(Vancouver)
2	740	840	(Calgary)
3	2080	620	(Winnipeg)
4	3500	0	(Toronto)
5	3800	180	(Montreal)

Exact solution with CPLEX (cont'd)

Table 4: Cost of the network components

Component	Cost
One-fiber link	3 750$/km
Two-fiber link	6 250$/km
Multi-rate transponder	20 000$

Table 5: Technological parameters

Parameter	Value
$\|F_{ij}\|$	2
$\|\Omega\|$	2
TR_i	8
RR_i	8

Exact solution with CPLEX (cont'd)

- The capacity of each wavelength is OC-12.
- The demand is uniform and four scenarios are considered.

Table 6: Demand scenarios

Scenario	Demand
1	1 OC-3
2	2 OC-3
3	1 OC-3 and 1 OC-12
4	2 OC-12

Exact solution with CPLEX (cont’d)

Table 7: Results without traffic grooming

Scenario	Equivalent number of OC-3	Number of links	Number of lightpaths	Cost (k$)	Lightpath utilization
1	20	7	20	54 655	25%
2	40	10	40	107 975	25%
3	100	10	40	107 975	62.5%
4	160	10	40	107 975	100%

Table 8: Results with traffic grooming

Scenario	Equivalent number of OC-3	Number of links	Number of lightpaths	Cost (k$)	Lightpath utilization
1	20	6	8	23 981	100%
2	40	6	16	37 823	87.5%
3	100	8	28	73 960	97.3%
4	160	10	40	107 975	100%

Exact solution with CPLEX (cont'd)

Table 9: CPU times of scenario 3 for different network sizes

Network size	CPU time	
4	0,58 sec	
5	7,49 sec	
6	$>$ 30 hours	(Quebec)

A tabu search algorithm

- For the tabu search (TS) algorithm, blocking is allowed.
- The objective function used included a penalty factor for the blocked connections.

Cost of the network + Cost of the blocked connections

- Starting solution: Complete network.
- Moves: Single fiber add/drop.
- Tabu moves: The chosen link is tabu for a number of iterations randomly selected on the interval [1,5].
- Stop criteria: The number of iterations (1000).

A tabu search algorithm (cont'd)

- When the physical topology is fixed, two heuristics (H1 and H2) can be used to find the virtual topology and routing the connections.
- The main steps of the heuristics H1 and H2 are
  - construct a virtual topology;
  - route the requests in single hop over the virtual topology and,
  - route the remaining requests in multi-hop.
- The heuristic H2 builds a lightpath on each wavelength into each fiber.

Numerical results

- The capacity of each wavelength is OC-48.
- Four demand scenarios are considered.
- The demand between each pair of nodes is given below for each scenario. The notation 4/2/0.1 means that between two nodes there is a connection demand of up to four OC-3, up to two OC-12 and a probability of 0.1 to have a demand for an OC-48.

Scenario	Traffic profile
1	2/2/0.1
2	4/2/0.1
3	4/4/0.1
4	4/4/0.2

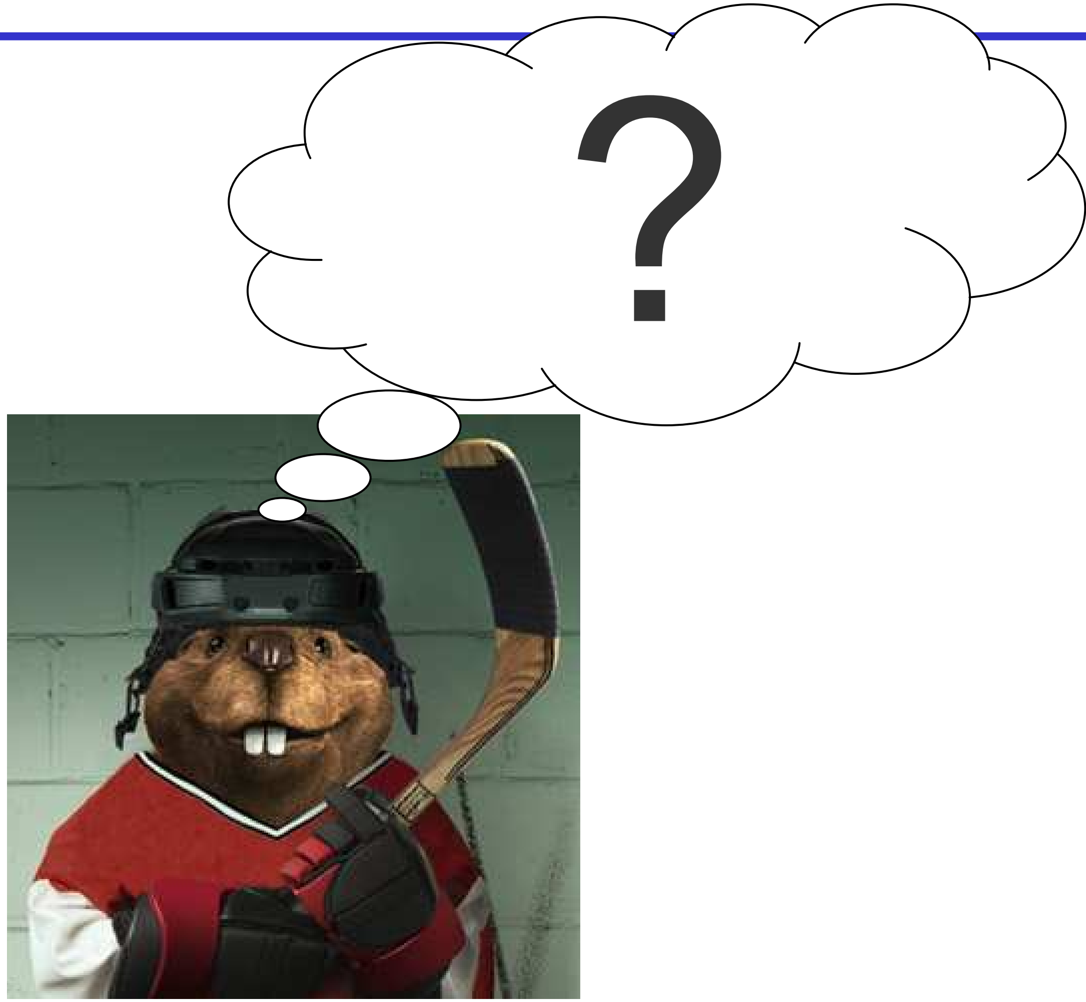
Numerical results (cont'd)

Nework size	Scenario	LS-H1 Cost (k$)	LS-H2 Cost (k$)	TS-H1 Cost (k$)	TS-H2 Cost (k$)
5	1	45 953	35 774	40 416	35 774
	2	41 872	39 308	40 930	38 415
	3	58 364	56 366	52 775	54 410
	4	67 111	60 602	65 898	60 602
10	1	128 552	103 826	113 283	100 192
	2	145 078	116 797	131 203	110 711
	3	180 156	158 748	173 388	155 197
	4	264 173	220 372	220 080	216 071
15	1	255 467	219 947	246 939	219 947
	2	264 173	257 486	259 021	253 574
	3	475 842	482 684	473 346	473 873
	4	526 706	484 897	501 778	480 892
20	1	560 113	427 942	545 403	427 942
	2	612 810	480 892	605 380	469 844
	3	898 598	816 491	819 730	816 346
	4	1 086 986	940 200	1 015 652	924 501

Conclusions

- In this paper, we have proposed:
  - A mathematical model for the design problem of WDM networks including the traffic grooming.
  - A heuristic algorithm based on the tabu search principle.
- It was found that it is difficult to find the optimal solution even for small-size instances of the problem (i.e., with six nodes).
- For the test problems considered, the tabu search algorithm can find solutions for real-size instance of the problem.
- The solutions found can be up to 20% better than those found with local search.
- Further works:
  - Improve the heuristic algorithms.

Questions



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