OPTICAL NETWORKS

Virtual Topology Reconfiguration

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Reconfiguration Studies

- A major advantage of an optical network:
  - it is able to reconfigure its virtual topology to adapt to changing traffic patterns.

- Many previous reconfiguration studies:
Reconfiguration Phase

- Reconfiguration may take place on:
  - hourly
  - daily
  - monthly

- The reconfiguration phase transforms the connections on virtual topology to a new virtual topology.

- During the reconfiguration existing lightpaths may be torn down, and new lightpaths may be established.
  - This may cause packet delay or loss.

- The impact of the reconfiguration phase should be considered.

- It is desirable to have a fast reconfiguration with smallest changes possible, without sacrificing the performance.
Sub-problems

- There are two sub-problems in reconfiguration:
  - Design the new virtual topology for the new traffic pattern.
  - Transfigure the current virtual topology to the new virtual topology while minimally disrupting the ongoing traffic.

- The transformation may be:
  - sudden, by tearing down all existing lightpaths and setting up simultaneously all lightpaths in the new virtual topology.
  - step-by-step, by slowly changing the current virtual topology to reach the new one.
Step-by-step Changes: Branch Exchange Sequence

- Just two links at a time are changed.
- Overall transition is long.
- Successive link pairs are exchanged during intermediate steps towards the goal configuration.
- Two successive diagrams differ by two lightpaths: The exchange of destinations of two lightpaths.
MILP Approach

- In the ideal situation, given a small change in the traffic matrix, the new virtual topology would be largely similar to the previous virtual topology.
- This helps to minimize the changes in the number of WRS configurations needed to adapt from the existing virtual topology to the new virtual topology.
- More formally, it would be preferable if a large number of the variables:
  - $V_{ij}$
  - $P_{ij}^m_n$
retain the same values in the two solutions, without compromising the quality of the solution.
MILP Approach

- Let us consider the snapshot of two traffic matrices, \( \Lambda^1_{sd} \) and \( \Lambda^2_{sd} \)
  - each taken at two not-too-distant time instants
- We assume that there is a certain amount of correlation between these two traffic matrices.
- Given a certain traffic matrix, there may be many different virtual topologies, each of which has the same optimal value with regard to the objective function.
- Usually, an LP solver will terminate after it has found the first such optimal solution.
- The reconfiguration algorithm finds the virtual topology corresponding to \( \Lambda^2_{sd} \) which matches “closest” with the virtual topology corresponding to \( \Lambda^1_{sd} \)
Reconfiguration with MILP Approach

Perform the following sequence of actions:

- Generate linear formulations $F(1)$ and $F(2)$, corresponding to traffic matrices $\Lambda_{sd}^1$ and $\Lambda_{sd}^2$ based on the formulation for VT design.
- Derive solutions $S(1)$ and $S(2)$, corresponding to $F(1)$ and $F(2)$, respectively.
- Denote the variables’ values in $S(1)$ as $V_{ij}(1), P_{mn}^{ij}(1), \lambda_{sdij}(1)$, and those in $S(2)$ as $V_{ij}(2), P_{mn}^{ij}(2), \lambda_{sdij}(2)$
- The values of the objective function for $S(1)$ and $S(2)$ are $OPT1$ and $OPT2$. 
Reconfiguration with MILP Approach

- Modify $F(2)$ to $F'(2)$ by adding the new constraint:

$$\frac{1}{\sum_{s,d} \Lambda_{sd}} \sum_{i,j} \sum_{s,d} \lambda_{ij}^{sd} = OPT_2$$

- This ensures that all the virtual topologies generated by $F'(2)$ be optimal with regard to the objective function.

- The new objective function for $F'(2)$ is:

$$\text{Minimize} : \sum_{ij} |V_{ij}(2) - V_{ij}(1)|$$
Simulations

- We generate two sequences of 25 traffic matrices each.
- In the first sequence, exactly 20% of the entries in successive traffic matrices in the sequence are forced to differ.
- In the second sequence, 80% of the entries differ.
- The traffic sequence is created by generating an initial traffic matrix, and then swapping a fraction (either 20% or 80%, depending on the chosen sequence) of non-diagonal entries in the traffic matrix.
Simulations

- The algorithm was applied to this traffic sequence, in order to generate virtual topologies in a network with:
  - eight transceivers per node,
  - eight wavelengths per fiber.
- The figure plots the fraction of lightpath additions and deletions as observed over the sequence of 25 traffic matrices, for
  - 20% and
  - 80% changes in the traffic matrix.
- The fraction of common lightpaths between two successive traffic matrices remains fairly uniform throughout the entire sequence.
- As expected, the number of deleted lightpaths and added lightpaths increases when the difference between consecutive traffic matrices gets larger.
Simulation Results

![Graph showing simulation results](image-url)

- Added Lightpaths (20% change)
- Added Lightpaths (80% change)
- Deleted Lightpaths (20% change)
- Deleted Lightpaths (80% change)

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Summary

- Reconfiguration algorithms exhibit a trade-off between:
  - the optimality of the new network configuration and
  - the degree of network disruption incurred during the configuration migration
- Reconfiguration policies are important elements of a complete performance management solution.
- Further developments are needed in various topics, such as better mechanisms for transition, properly selecting the reconfiguration parameters for various algorithms, reconfiguration of survivable networks, complete solutions that take into account different aspects of the problem at the same time.