Gradually Reconfiguring Virtual Network Topologies Based on Estimated Traffic Matrices

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Oki Lab – Progress Report
Presentation Outline

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Introduction (1/2)

• Optical layer traffic engineering (TE):
  – efficient way to handle unpredictable traffic in backbone networks.
  – assumes network is made up of IP routers and Optical cross-connects (OXC)s.
  – Outbound port of an edge IP router is connected to an OXC port.
  – Lightpaths are created by configuring OXC+s along the route between 2 IP routers.
  – between 2 routers traffic is carried over the Virtual Topology Network (VNT) using IP layer routing.
  – Traffic Matrix (TM) is required as an input.

• VNT reconfiguration needs TM to setup a new VNT wherein constraints are satisfied.
Introduction (2/2)

• Two basic methods to obtain TM:
  – Direct measurements: very difficult to realize.

• Estimated TM as input of a TE method:
  – greatly large impacts the performance of TE methods
  – may cause significant large utilizations of optical layers paths.

• Reconfiguring the VNT redundantly may reduce estimation errors.

• VNT redundant reconfiguration require unacceptable amount of resources, if TM estimation error too large.
Goal

• Develop a *Gradual Reconfiguration Method* to reduce estimation errors:
  – VNT reconfiguration process is made up of multiple stages
  – TM estimation method uses information from prior stages to calibrate and reduce estimation errors

• Reducing estimation errors helps to build efficient VNT without monitoring TM directly.
Related Work

A. VNT reconfiguration methods
   – Full reconfiguration
   – Partial reconfiguration

B. Traffic Matrix Estimation methods
   – Tomogravity
   – Gaussian distribution based method
Terminology

- **Traffic Matrix**: a matrix indicating the amount of traffic between all OD pairs of IP routers in a network.

- **Physical Topology**: physically built topology in the optical layer made up of OXCs and WDM optical fibres.

- **Optical Layer Path (OLP)**: a lightpath configured between 2 OXCs.

- **VNT**: a topology built with OLPs.

- **Packet Layer Path (PLP)**: an end-to-end packet-layer traffic traversing the VNT.

- **Route of a PLP**: a set of OLPs passed by the PLP.

- **Utilization of an OLP**: amount of traffic traversing the OLP divided by the capacity of the OLP.
Gradual Reconfiguration (1/2)

Gradual Reconfiguration (GR) process:

- VNT reconfiguration is divided in several stages.
- Each stage it’s assumed that both the packet and optical layer routes are calculated by a path computation element (PCE).
- OXCs and routers in the network are configured according to the calculated routes.
- Fig. 1 illustrates the idea.

![Fig. 1 – Overview of the gradual reconfiguration of VNT](image-url)
The operations in each GR stage:

The basic idea is to avoid adding or deleting too many OLP before TM estimation errors are sufficiently low.

Question is: How to reduce TM estimation errors during the Gradual Reconfiguration?
TM Estimation Method Suitable for GR

(1/3)

A. Basic Idea
• It’s assumed that the network is stable
  – Variation of traffic between 2 consecutive stages is small
  – Any change in the measured utilization of an OLP is caused by difference in the PLPs
• Estimation method called *Additional Equation Method*
  – uses utilization of the OLPs monitored from stage 0 to stage n of the reconfiguration.

\[
\begin{bmatrix}
  X_0 \\
  \vdots \\
  X_i \\
  \vdots \\
  X_{n-1} \\
  X_n
\end{bmatrix} =
\begin{bmatrix}
  A_0 \\
  \vdots \\
  A_i \\
  \vdots \\
  A_{n-1} \\
  A_n
\end{bmatrix} T_n +
\begin{bmatrix}
  \epsilon_{0,n} \\
  \vdots \\
  \epsilon_{i,n} \\
  \vdots \\
  \epsilon_{n-1,n} \\
  0
\end{bmatrix} \tag{1}
\]

\[
\hat{T}_n = \bar{A}_n^+ \bar{X}_n \tag{2}
\]
TM Estimation Method Suitable for GR

(2/3)

Step 1: Let $\hat{T}_n^{(0)} \leftarrow \hat{T}_n$.

Step 2: Calculate $\hat{T}_n^{(i)}$ from $\hat{T}_n^{(i-1)}$ by using

$$\hat{T}_n^{(i)} = \hat{T}_n^{(i-1)} + A_n^+ (X_n - A_n \hat{T}_n^{(i-1)})$$

where $\hat{T}_n^{(i)}$ is a matrix in which we replace all negative values of $\hat{T}_n^{(i)}$ with zero.

Step 3: If all elements in $\hat{T}_n^{(i)}$ are nonnegative values, go to Step 4, or else back to Step 2.

Step 4: Let $\hat{T}_n^{(i)}$ be the final result of traffic matrix $\hat{T}_n$. 
B. Dealing With Non-negligible Changes in Traffic

• In real network, traffic may vary from the beginning of the reconfiguration.
• Significant traffic variation causes TM estimations errors
• Violates the assumption previously mentioned.
• We remove the information about non-negligible change so as to maintain the assumption previously mentioned, using 3 steps:
  – **Step 1:** Identify the PLPs with non-negligible changes.
  – **Step 2:** Remove the information about the traffic of the identified paths with non-negligible changes monitored at previous stages.
  – **Step 3:** Estimate the TM by using the information in which the non-negligible changes information has been removed.
A. Partial Reconfiguration Method

• Our GR method uses an extended version of partial reconfiguration method.
• This method adds N new OLPs to mitigate congestion and, if possible, deletes a N currently underutilized OLPs for reclamation.
• At each stage N may affects the number of additional equations and the estimation errors.
• The method uses two thresholds for utilization of each OLP:
  – $T_H$: define a congested OLP.
  – $T_L$: define underutilized OLP.
    • It’s assumed: $T_L = \frac{1}{2}T_H$
    • $N$: maximum number of OLPs added/deleted ($N = \infty$)
A. Partial Reconfiguration Method (cont.)

• **Step 1**: check the utilization of all OLPs. If at least one OLP congested (utilization $\geq T_H$) is found, go to OLP addition phase (step 2). If there’s an OLP whose utilization is under $T_L$, go to OLP deletion phase (step 3).

• **Step 2**: execute the OLPs addition, then go to step 4.

• **Step 3**: execute the OLPs deletion, then go to step 4.

• **Step 4**: calculate the routes of PLPs over new VNT and obtain the expected utilization of all OLPs of the new VNT.
  
  – When utilization of a PLP in the previous stage are lower than ($T_H - \eta$), route’s kept in the current stage. (Note: $\eta = 0.1* T_H$)
  
  – Otherwise, the route is calculated using constraint-based CSPF to limit the maximum utilizations to less than ($T_H - \eta$).

• **Step 5**: decrement the number of OLPs to be added/deleted in this stage, i.e., $N = N - 1$. If $N = 0$, go to End. Otherwise, go back to step 1.

• **Step 6**: End.
**Evaluation (3/6)**

**B. Simulation Conditions**

EON is made up of:

a) 19 nodes and 37 links

b) Circles represent OXCs, lines are optical fibres (each set with 16 wavelengths)

c) For the Additional Equation Method, a parameter $\Gamma = 0.2 \cdot T_h$, which indicates sensitivity for detection in traffic

- Traffic whose increase is larger than $\Gamma$ is identified as non-negligible changes
- Previously monitored about the traffic isn’t used for TM estimation

Estimation methods were implemented in MATLAB, using a ordinary PC with 3.2 GHz Intel Pentium D Processor and 2 GB of RAM

Fig. 3 – European Optical Network (EON)
C. The Case Without Change of Traffic (1/2)

1. Improvement of Accuracy of the Estimation:
Comparison of accuracy between of estimation method between Additional Equation Method and Tomogravity Method. It’s used 10 different TMs and $N = 1, 3, 5$

Fig. 4 Root Mean Squared Relative Error
Evaluation (5/6)

C. The Case Without Change of Traffic (2/2)

2. Effectiveness of Gradual Reconfiguration

Fig. 5 Number added/deleted OLPs vs. maximum utilization.

Fig. 6 Maximum utilization with various N
Evaluation (6/6)

D. Case With Traffic Changes

1) Adaptability to the Fluctuations in Traffic

Fig. 7 – RMSREs of additional equation method

Fig. 8 – Maximum utilization
Conclusion

• New method that reduces estimation errors during VNT by cooperating with the VNT reconfiguration.
• Reconfiguration is done gradually divided in multiple stages.
• Doing so, TM estimation calibrates and reduces estimation errors in each stage by using prior monitored information.
• Method improve accuracy of TM estimation and achieves adequate VNT.
The End