

# Gradual Reconfiguration of Virtual Network Topologies based on Estimated Traffic Matrices

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2/18/2008 INFOCOM 2007 1

## Outline

- Background
  - Multilayer traffic engineering
  - Impact of estimation errors of traffic matrix
- Gradual reconfiguration method based on the estimated traffic matrix
  - Reconfiguration method to limit the number of added/deleted optical paths
  - Estimation method using the additional information of change in routes caused by the VNT reconfiguration
- Evaluation
- Conclusion

2/18/2008 INFOCOM 2007 2

## IP / optical multi-layer network

- Packet layer
  - Packet-layer traffic is routed over the VNT
- Optical layer
  - A set of optical paths forms a VNT.
  - By adding or deleting optical paths, we can easily change the logical topology

2/18/2008 INFOCOM 2007 3

## Traffic engineering (TE) in multilayer network

- Packet layer TE
  - Optimize the routes of packet paths
- Optical layer TE
  - Reconfigure the VNT
- Multi-layer TE
  - Optimize both packet-layer and optical layer
  - Achieve more efficient accommodation of traffic
  - Need traffic matrices as an input

packet layer TE	multilayer TE
Without TE	optical layer TE

2/18/2008 INFOCOM 2007 4

## Traffic matrix estimation

- Estimate from the link utilizations
 
$$X = AT$$

X: link utilization  
A: Routing matrix  
T: Traffic matrix

  - The number of equations is much smaller than the number of entries in traffic matrix
    - Number of equations: number of links
    - Number of entries: (number of nodes)<sup>2</sup>
- Estimated traffic matrices include estimation errors
- The estimation errors degrade the performance of traffic engineering
  - We need a VNT reconfiguration method which is robust to estimation errors

2/18/2008 INFOCOM 2007 5

## Goal of this work

- VNT reconfiguration taking traffic matrix estimation into consideration
  - Limit the impact of estimation errors
    - Gradual reconfiguration
      - Divide the VNT transition sequence into multiple stages
      - Limit the number of addition or deletion of optical paths at a stage
  - Reduce the estimation errors by collaborating with traffic matrix estimation
    - Traffic matrix estimation method using information monitored at multiple stages

2/18/2008 INFOCOM 2007 6

## Overview of gradual reconfiguration

- If we change the current VNT to the optimal VNT at once
  - Estimation errors degrade the performance of TE for a long time

Timeline diagram: A horizontal axis represents time. A single 'Reconfiguration Period' is shown as a blue arrow. Following this, a long period of 'Monitoring link utilizations' is shown, with 'Estimation VNT reconfiguration' points marked by red arrows. This indicates that after a one-time reconfiguration, the system remains in a state of monitoring and estimation for a long duration.

- Gradual reconfiguration
  - We divide the whole VNT transition sequence into multiple stages

Timeline diagram: A horizontal axis represents time. Multiple 'Reconfiguration Period' blocks are shown as blue arrows, separated by 'Monitoring link utilizations' periods. 'Estimation VNT reconfiguration' points are marked by red arrows at the beginning of each stage. This shows a more frequent and gradual reconfiguration process.

2/18/2008 INFOCOM 2007 7

## Relation between VNT reconfiguration and traffic matrix estimation

Flowchart: A blue box labeled 'TM estimation' has an arrow pointing to a blue box labeled 'VNT reconfiguration'. A feedback loop arrow goes from 'VNT reconfiguration' back to 'TM estimation'. Callout boxes provide details: 'Add the information monitored at previous stages' points to the feedback loop, and 'Limit the number of added/deleted optical paths' points to the 'VNT reconfiguration' box.

- As stages go on
  - Traffic matrix estimation:
    - Use more information
  - VNT reconfiguration:
    - Use more accurate traffic matrix

2/18/2008 INFOCOM 2007 8

## Algorithm for gradual reconfiguration

- VNT reconfiguration with the limitation of number of optical paths added/deleted at a stage.
  - Nr: maximum number of added/deleted optical paths
  - Aim of reconfiguration
    - Make the maximum link utilization less than Th
    - Minimize the constructed optical paths
  - Method:
    - Perform following Steps Nr times
      - Calculate the link utilizations by using the estimated traffic matrix
      - If the maximum link utilization is more than Th
        - Add an optical path to reroute the congested path
      - If the maximum link utilization is smaller than Th
        - The optical path is torn down for resource reclamation

2/18/2008 INFOCOM 2007 9

## Additional equation method

- Add the link utilizations monitored at each stage to the simultaneous equations

$$\begin{bmatrix} X_0 \\ \vdots \\ X_n \end{bmatrix} = \begin{bmatrix} A_0 \\ \vdots \\ A_n \end{bmatrix} T$$

$X_n$ : Link utilization at stage n  
 $A_n$ : Routing matrix at stage n

- The number of equations increases as stages go on
- Estimation errors are reduced as stages go on

2/18/2008 INFOCOM 2007 10

## Evaluation

- Simulation Conditions
  - Topology
    - Backbone topology of Abilene
    - Maximum number of wavelength: 64
  - Traffic demand:
    - Generate sudden change to traffic demand monitored at Abilene
    - We assume the traffic matrix is constant after the beginning of reconfiguration
- Metrics
  - Estimation errors of traffic matrix
  - Number of added optical paths

Network topology diagram: A graph showing nodes (circles) and edges (lines) representing the backbone topology of Abilene.

2/18/2008 INFOCOM 2007 11

## Result (Estimation errors)

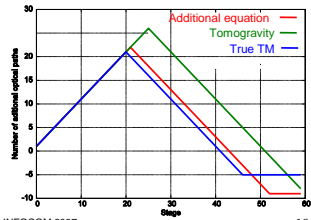
- Compare additional equation method with Tomography method
  - Additional equation method reduce the estimation errors dramatically
  - About setting Nr, there is a trade-off between convergence time and estimation errors
    - To estimate more accurately, small Nr is better
    - Small Nr needs a lot of stages to converge

Two line graphs: The left graph is titled 'Additional equation' and the right is 'Tomography'. Both graphs plot 'Average of estimated error' on the y-axis (0 to 200,000) against 'Stage' on the x-axis (0 to 60). Three lines are shown in each graph: red for Nr=1, green for Nr=3, and blue for Nr=5. In the 'Additional equation' graph, the error drops rapidly and stabilizes by stage 10. In the 'Tomography' graph, the error drops much more slowly and takes about 40 stages to stabilize.

2/18/2008 INFOCOM 2007 12

## Results (Number of optical paths)

- Additional equation methods adds smaller number of optical paths than tomogravity
  - By reducing the estimation errors, we can avoid adding insufficient optical paths



2/18/2008

INFOCOM 2007

13

## Conclusion and Future works

### ■ Conclusion

- Gradual VNT reconfiguration method taking the estimation errors into consideration
  - Divide the VNT transition sequence into multiple stages
    - VNT reconfiguration method limiting a number of added/deleted optical paths
    - Additional equation method

### ■ Future works

- Extend our method so as to estimate in the case of sudden change of traffic

2/18/2008

INFOCOM 2007

14