Estimating current traffic matrices accurately by using long-term variations information

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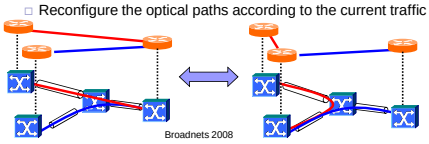
Traffic Engineering (TE)

- Dynamically reconfiguring the network topologies or routes so as to effectively accommodate current traffic
  - Example：Optical layer Traffic Engineering (TE)
    - Environment：IP-over-WDM networks
      - Construct optical paths over physical network
      - A set of optical paths forms a virtual network topology for IP network
    - Method：
      - Reconfigure the optical paths according to the current traffic



Input of Traffic Engineering Methods

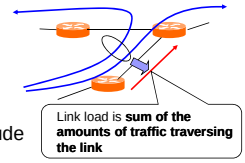
- Current traffic demands between all nodes（traffic matrices）
  - Hard to monitor directly
    - Construct fully meshed label switched paths (LSPs)
      - Require N-squared LSPs
    - Count packets of each flow
      - Require non-negligible amount of CPU resources at the edge nodes
  - Estimate traffic matrices from link loads
    - Link loads are monitored more easily even in large network

Traffic Matrix Estimation

- Traditional estimation methods：
  - Estimate from the equations based on the link loads

$$X = AT$$

    - X: Link loads
    - A: Routing matrix
    - T: Traffic matrix
  - Estimated traffic matrices include estimated errors
    - **The number of equations is much smaller than the number of entries in traffic matrix**



  - **The estimation errors degrade the performance of traffic engineering**

Using the Additional Information

- Method to increase the accuracy of estimation by using additional measurements
  - The additional information is obtained by using the measurements both before and after traffic engineering [12]

  - Add the link loads monitored after the traffic engineering to the equations

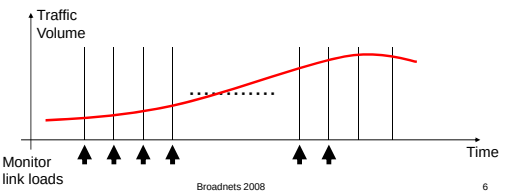
$$\begin{bmatrix} X(n-M+1) \\ \vdots \\ X(n) \end{bmatrix} = \begin{bmatrix} A(n-M+1) \\ \vdots \\ A(n) \end{bmatrix} T$$

$X(n)$: Link loads monitored at time n
$A(n)$: Routing matrix at time n

[12] Y Ohsita et al, "Gradually Reconfiguring Virtual Network Topologies based on Estimated Traffic Matrices," *in Proc. INFOCOM 2007*, May 2007

Necessity of Consideration of Traffic Variations

- If it takes a long time to obtain sufficient number of measurements…
  - Current traffic may differ from the initially monitored traffic
    - We need to consider the traffic variations

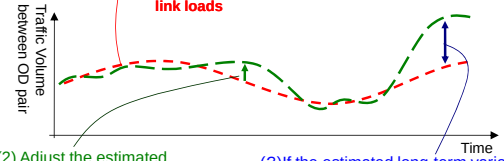


Goal of this work

- Estimate traffic matrices accurately by collaborating with traffic engineering
  - Obtain the additional information by using the route changes caused by traffic engineering
  - Use the additional information considering the traffic variations

Overview of proposed method

(1) Estimate long-term variations
- Model the variations as **periodical functions**
- Estimate the parameters in the model by using the **both previously and currently monitored link loads**



(2) Adjust the estimated variations so as to **fit the current link loads**

(3)If the estimated long-term variation does not match the current variations
- Detect the mismatch
- Re-estimate the long-term variations

Estimation of Long-term Variations

- We model the long-term variations as periodical functions [14]
  - By using the Fourier series expansion, the periodic functions are represented as

$$f_{i,j}(n) = \sum_{h=0}^{N_f} \alpha_{h,i,j} \cos\left(\frac{2\pi nh}{N^{cycle}}\right) + \sum_{h=0}^{N_f} \alpha_{h+N_f,i,j} \sin\left(\frac{2\pi nh}{N^{cycle}}\right)$$

Traffic between nodes i and j at time n — Cycle

  - We estimate by setting $\alpha_{h,i,j}$ so as to fit all the link loads (including previously monitored link loads)

$$minimize \sum_{k=n-M+1}^{n} |X(k) - A(k)\hat{T}^{est}(k)|^2 \quad \text{where} \quad \hat{T}^{est}(k) = \begin{bmatrix} f_{0,0}(k) \\ \vdots \\ f_{i,j}(k) \\ \vdots \\ f_{N,N}(k) \end{bmatrix}.$$

[14] A. Soule, A. Nucci, R. Cruz, E. Leonardi, and N. Taft, "Estimating dynamic traffic matrices by using viable routing changes," IEEE/ACM Transactions on Networking, vol. 13, pp. 485–498, June 2007.

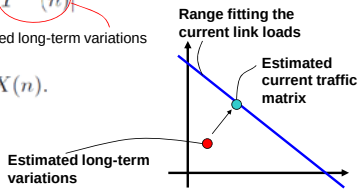
Adjustment of the Estimated Long-term Variations

- Obtain the current traffic matrices which fits the current link loads and is close to the estimated long-term variations

$$minimize |\hat{T}(n) - \hat{T}^{est}(n)|^2$$

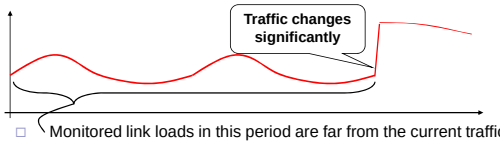
Estimated long-term variations

s.t. $A(n)\hat{T}(n) = X(n).$



Handling the Change of Variations

- When traffic variations change



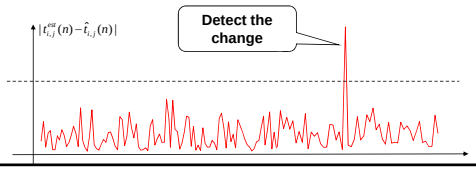
  - Monitored link loads in this period are far from the current traffic variations

⇨ If we use the link loads monitored before the change, **we cannot estimate long-term variations so as to fit the current traffic**

- Steps to handle the change of variation
  1. Detect the change
  2. Delete information before the change
  3. Re-estimate the long-term variations

Detection of the Change of Variations

- Detect the change when $|t_{i,j}^{est}(n) - \hat{t}_{i,j}(n)|$ is significantly larger than before.
  - The traffic matrices after adjustment fit the current traffic
    - If the estimated long-term variations is far from the current traffic, $|t_{i,j}^{est}(n) - \hat{t}_{i,j}(n)|$ is large
  - The detection is done by Smirnov-Grubbs tests



Deletion of Information before the Change

- Delete only information corresponding to the changing traffic
  - From routing matrices

$A(i)$ → **Set elements corresponding to the detected traffic to 0** → $A'(i)$

  - From monitored link loads
    - Remove the estimated amount of the detected traffic from each link loads

$$X'(i) = X(i) - (A(i) - A'(i))\hat{T}'^{\mathrm{est}}(i).$$

Estimated amount of the detected traffic

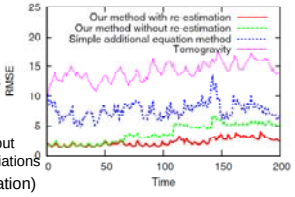
- Re-estimate long-term variations by using $A'(i)$ and $X'(i)$

Evaluation

- Environment
  - Topology
    - EON backbone topology
  - Traffic demand:
    - Generate by adding variations to *sin* functions whose amplitudes and phases were randomly generated.
  - Traffic engineering method:
    - Optical layer TE
      - Add optical layer paths so as to make the maximum link utilization less than 0.7
    - We perform the TE method once an hour

Accuracy of the estimation

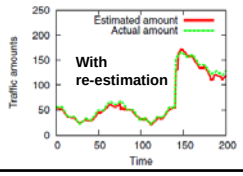
- Methods
  - Tomogravity method
    - Method using only the currently monitored link loads
  - Additional Equation method
    - Method using link loads monitored at previous times but not considering the traffic variations
  - Our method (without re-estimation)
  - Our method (with re-estimation)

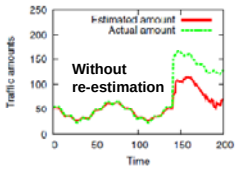


- Metrics
  - (RMSE) $= \frac{1}{\text{numberof elements}}\sqrt{\sum(\text{estimatedvalue} - \text{actualvalue})^2}$
- Results
  - Our method can estimate traffic matrices the most accurately
    - Our method can use many additional information considering the traffic variations

Estimated Amount of Traffic Changing Significantly

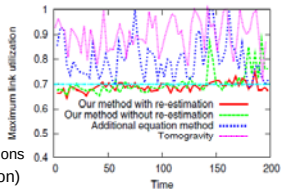
- Method
  - Our method (with re-estimation)
  - Our method (without re-estimation)
- Results
  - By re-estimating the long-term variations, we can estimate the traffic amount even when traffic changes significantly





Maximum link utilization achieved by TE using estimated traffic matrices

- Methods
  - Tomogravity method
    - Method using only the currently monitored link loads
  - Additional Equation method
    - Method using also link loads monitored at previous times but not considering the traffic variations
  - Our method (without re-estimation)
  - Our method (with re-estimation)



- Metrics
  - Maximum link utilization after TE performed by using the estimated traffic matrices (**target value=0.7**)
- Result
  - Our method (with re-estimation) can decrease the maximum link utilization sufficiently

Conclusion

- We propose an estimation method which uses additional measurements considering the traffic variations
  - **Estimate long-term variations** by using the link loads monitored **at previous times**
  - **Adjust** the estimated long-term variations so as to **fit the current link loads**
  - Re-estimate the long-term variations, when the traffic variations changes significantly
- Evaluation results show that our method can estimate traffic matrices accurately.