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

Yuichi Ohsita
Osaka Univ.

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

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

\[
\begin{align*}
\text{TM Estimation} & \quad \text{Estimated TM} & \quad \text{Traffic Engineering} \\
X(n - M + 1) & + A(n)(\text{link loads monitored at each time}) & = X(n) \\
& + A(n) \quad \text{Routing matrix at time n}
\end{align*}
\]

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
  \[
  E_i(n) = \sum_{k=0}^{\frac{2\pi n}{2\pi}} \sum_{l=1}^{\frac{2\pi n}{2\pi}} \left( \frac{2\pi n}{2\pi} \right) \sum_{h=1}^{\frac{2\pi n}{2\pi}} \left( \frac{2\pi n}{2\pi} \right)
  \]
- We estimate by setting \(a_{k,l}\) so as to fit all the link loads (including previously monitored link loads)

\[
\text{minimize } \sum_{k=0}^{\frac{2\pi n}{2\pi}} \sum_{l=1}^{\frac{2\pi n}{2\pi}} \sum_{h=1}^{\frac{2\pi n}{2\pi}} \left| X(n) A(\Omega)F_k(n) + X(n) \right|^2
\]

\[
\text{where } F_k(n) = \sum_{h=1}^{\frac{2\pi n}{2\pi}} \left( \frac{2\pi n}{2\pi} \right) \sum_{l=1}^{\frac{2\pi n}{2\pi}} \left( \frac{2\pi n}{2\pi} \right)
\]


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

\[
\text{minimize } T(n) - \hat{T}(n) \]

\[
\text{s.t. } A(n)T(n) = X(n) \]

Detection of the Change of Variations
- Detect the change when \(|c_i(n) - \hat{c}_i(n)|\) 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, \(|c_i(n) - \hat{c}_i(n)|\) is large
  - The detection is done by Smirnov-Grubbs tests

Handling the Change of Variations
- When traffic variations change
  - Traffic changes significantly
  - 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 variations
- Steps to handle the change of variation
  1. Detect the change
  2. Delete information before the change
  3. Re-estimate the long-term variations
Deletion of Information before the Change
- Delete only information corresponding to the changing traffic
  - From routing matrices
    - Set elements corresponding to the detected traffic to 0
  - From monitored link loads
    - Remove the estimated amount of the detected traffic from each link loads
    \[ N'(i) - X(i) = A'(i) - A(i) \]
    - 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
  - Tomography method
  - Additional Equation method
  - Our method (without re-estimation)
  - Our method (with re-estimation)
- Metrics
  - \[ \text{RMSE} = \frac{1}{\text{number of elements}} \sum (\text{estimated value} - \text{actual value})^2 \]
- 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
  - Tomography 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
  - Maximum link utilization after TE performed by using the estimated traffic matrices (target value=0.7)
- Results
  - 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.