On the integration of IP routing and wavelength routing in IP over WDM networks

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IP over WDM networks

- IP packets are forwarded on lightpaths
  - This doesn't require any electronic packet processing at the intermediate nodes
- Construct a logical topology in the WDM layer and IP packets are forwarded on that topology
- How to construct a logical topology?
  - Statically, depending on measured traffic statistics
  - Dynamically, depending on a network status

Route on which IP packets are actually forwarded

Logical topology

Need not to process IP packets

Route on which IP packets are forwarded
Disaccord of routing of IP and WDM

- IP networks and WDM networks have their own routing mechanisms
  - Lightpaths configured in the WDM network may not be fully utilized by the IP network
  - Wavelength resources are not used efficiently
- We need the integrated routing method to utilize wavelength resources more efficiently
Research objective

- Propose the integrated routing method in IP over WDM networks
  - Provide efficient wavelength resource utilization
    - IP packets surely use lightpaths configured in the WDM layer
  - Provide flexible adaptation against traffic changes
    - Construct logical topologies dynamically depending on the network status
Related works

- They assumed IP/MPLS as IP networks
  - They dealt with LSP (Label Switching Path) setting requests that require specific bandwidth as IP traffic
  - Their objective is to improve blocking probability

- IP/MPLS over WDM is redundant
  - It requires to introduce MPLS-capable linecards into routers
  - Resource optimization becomes difficult as the number of layers increase

- It is important to evaluate performance by throughput or delay in IP (directly) over WDM networks

Network model and virtual-link

- Assumed network
  - Node: IP router and OXC
  - Link: Optical fiber
  - Configure one lightpath between each adjacency node
    - To ensure end-to-end reachability

- Virtual-link
  - “Virtual” links
  - Configure in the logical topology when calculating routes
  - Integrate routing by using virtual-links
Integrated routing with virtual-link

Algorithm
1. Set virtual-links
2. Assign cost values to the virtual-links
3. Search a minimum cost route from logical topology including virtual-links
4. Activate virtual-links if the resulting route contains the virtual-links

Calculate necessary lightpaths at the same time when selecting IP

Selected lightpaths are surely utilized for forwarding IP packets because those are selected by using IP routing method
Cost function of virtual-links

- **Main objective**
  - To reduce the load of nodes

- **Use the load of the destination node of the virtual-link**
  - Prevent IP traffic from flowing into over-loaded nodes
  - Balance the load of nodes

- **Cost function**
  \[ C_{ij} = \alpha \cdot (v_j)^2 + \beta \]
  - **$C_{ij}$**: Cost value of the virtual-link from node $i$ to $j$
  - **$v_j$**: Load of node $j$
  - $[0, 1]$
Simulation model (1/2)

- Topology
  - NSFNET (14 nodes, 21 links)
  - European Optical Network (19 nodes, 38 links)

- Parameters
  - Number of wavelength: 8
  - Processing capacity of routers: 10 Gbps
  - Bandwidth per a wavelength channel: 10 Gbps

- Traffic
  - Flows arrive according to Poisson process with rate $d_{ij}$
    - $d_{ij}$: traffic demand from node $i$ to node $j$
  - Flow length is exponential distributed with mean value 75 Mbytes
Simulation model (2/2)

- Traffic demand matrix \( D = \{d_{ij}\} \)
  - Randomly generated traffic demand matrix
  - Actual traffic demand matrix in Ref. [11]

- Static topology design methods
  - SHLDA [9]
  - MLDA [11]

- Flow-level simulation method based on fluid flow model

Average end-to-end delay (random matrix)

(a) Without traffic change

Introduce traffic change by regenerating traffic demand matrices randomly every 200 seconds, and change the matrices 15 times in one simulation.

Our method shows a little better performance than SHLDA/MLDA.

The result of EON topology also shows the same tendency.

The degradation of our method is much less than that of SHLDA/MLDA.

(b) With traffic change

EON
APOC 2005

NSFNET
EON
Average end-to-end delay (matrix in [11])

- Traffic demand matrix in Ref. [11] has large variation
- The degradation of our proposal is also much less than that of SHLDA/MLDA when traffic changes
- There is no difference between the result of our method and SHLDA/MLDA when traffic doesn’t change

Load of nodes

- NSFNET topology
- With traffic change
- Total traffic amount of network
  - Proposal: 45 Gbps
  - SHLDA: 33 Gbps
  - MLDA: 30 Gbps

Evaluate at the saturation points
Proposal method balances the load around 0.6
SHLDA/MLDA don’t balance the load
  - The node 12 is saturated while other nodes are under-utilized
Conclusions and future works

- **Conclusion**
  - We proposed the integrated routing method in IP over WDM networks
  - Our method showed almost same end-to-end delay performance as statically designed topology without traffic changes
  - Our method was robust against traffic changes

- **Future work**
  - We will solve this problem
    - Little difference between our proposal and SHLDA/MLDA was observed when traffic matrices varied greatly was used