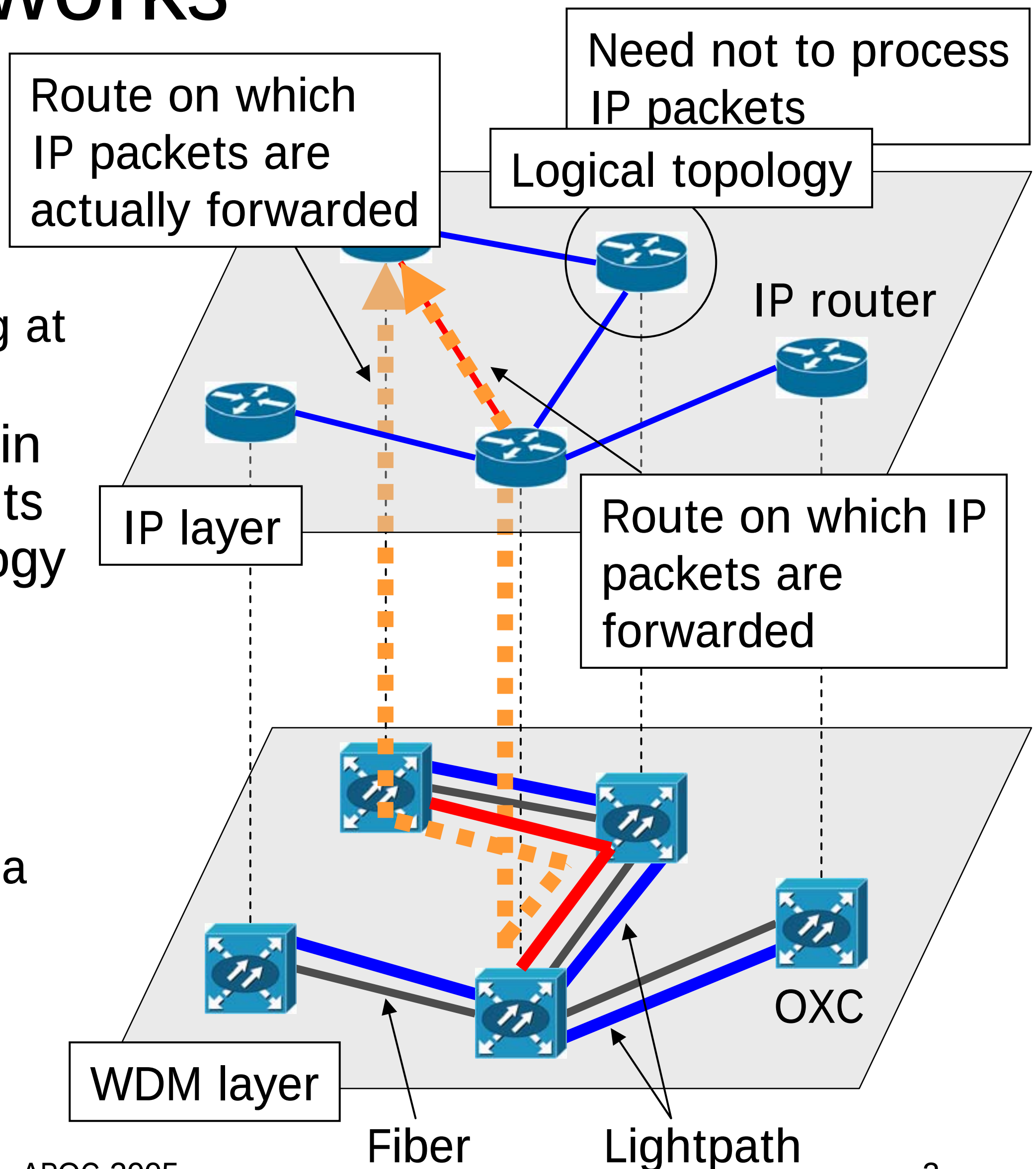
On the integration of IP routing and wavelength routing in IP over WDM networks

Yuki Koizumi, **Shin'ichi Arakawa and Masayuki Murata**
Osaka University, Japan
ykoizumi@ist.osaka-u.ac.jp

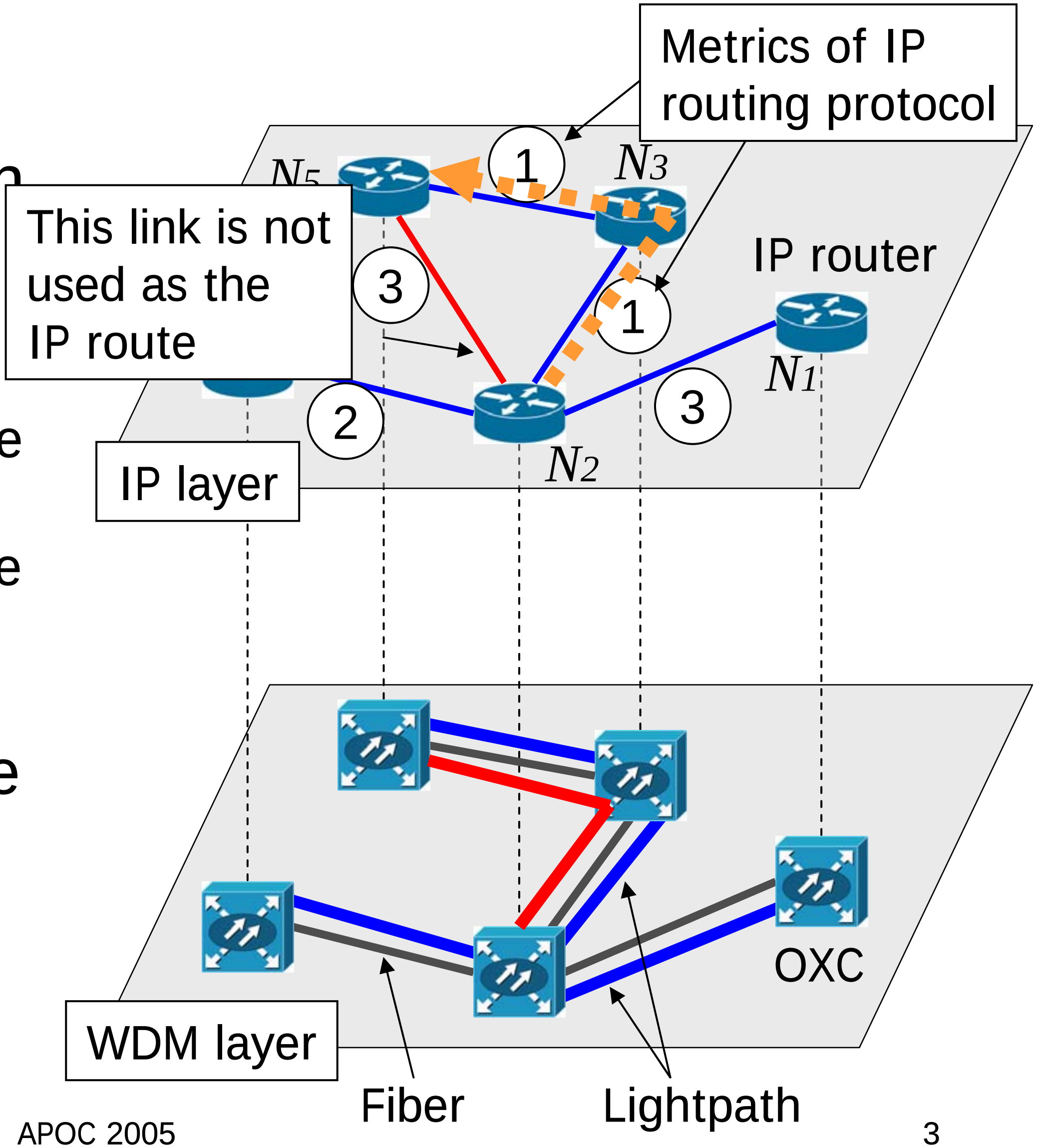
IP over WDM networks

- 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



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

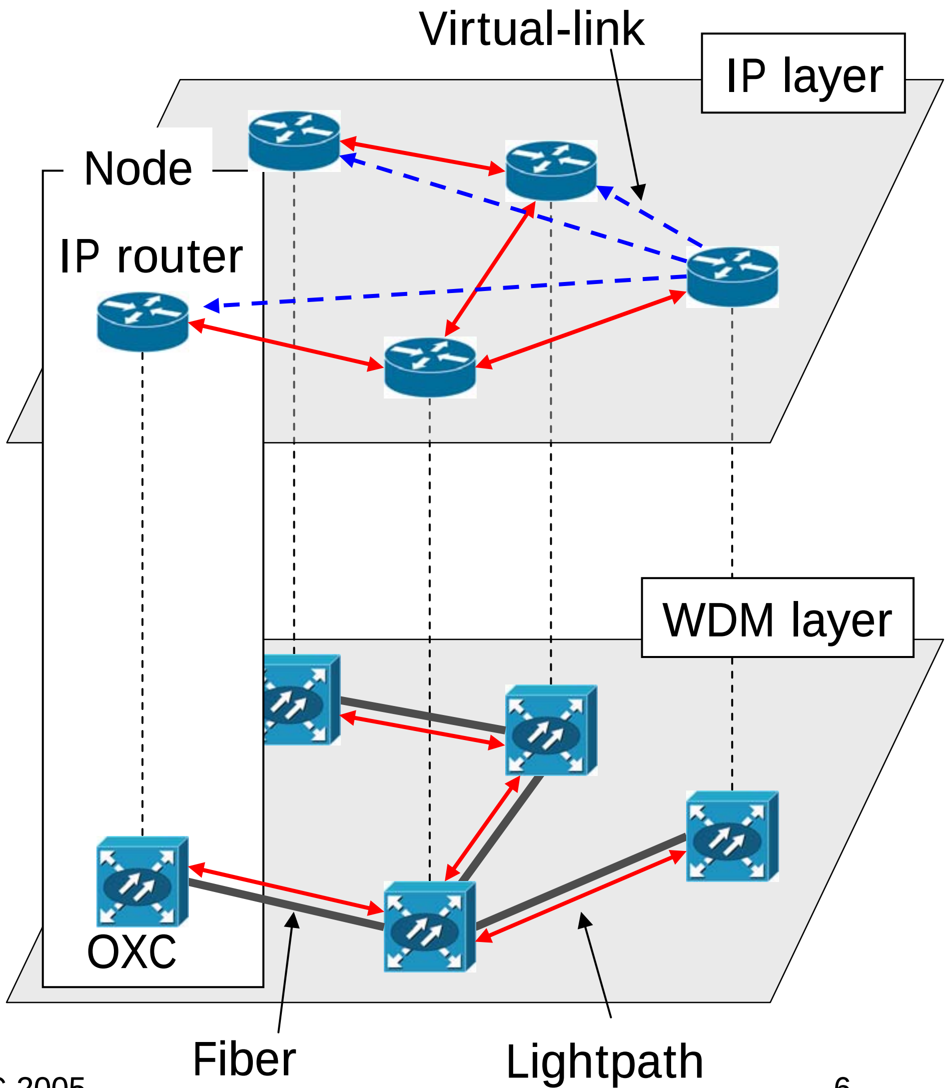
Related works

- 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

1. J. Li, G. Mohan, E. C. Tien, and K. C. Chua, "Dynamic routing with inaccurate link state information in integrated IP over WDM networks," *Computer Networks* **46**, pp. 829–851, Dec. 2004.
5. M. Kodialam and T. V. Lakshman, "Integrated dynamic IP and wavelength routing in IP over WDM networks," in *Proceeding of IEEE INFOCOM*, pp. 358–366, Apr. 2001.

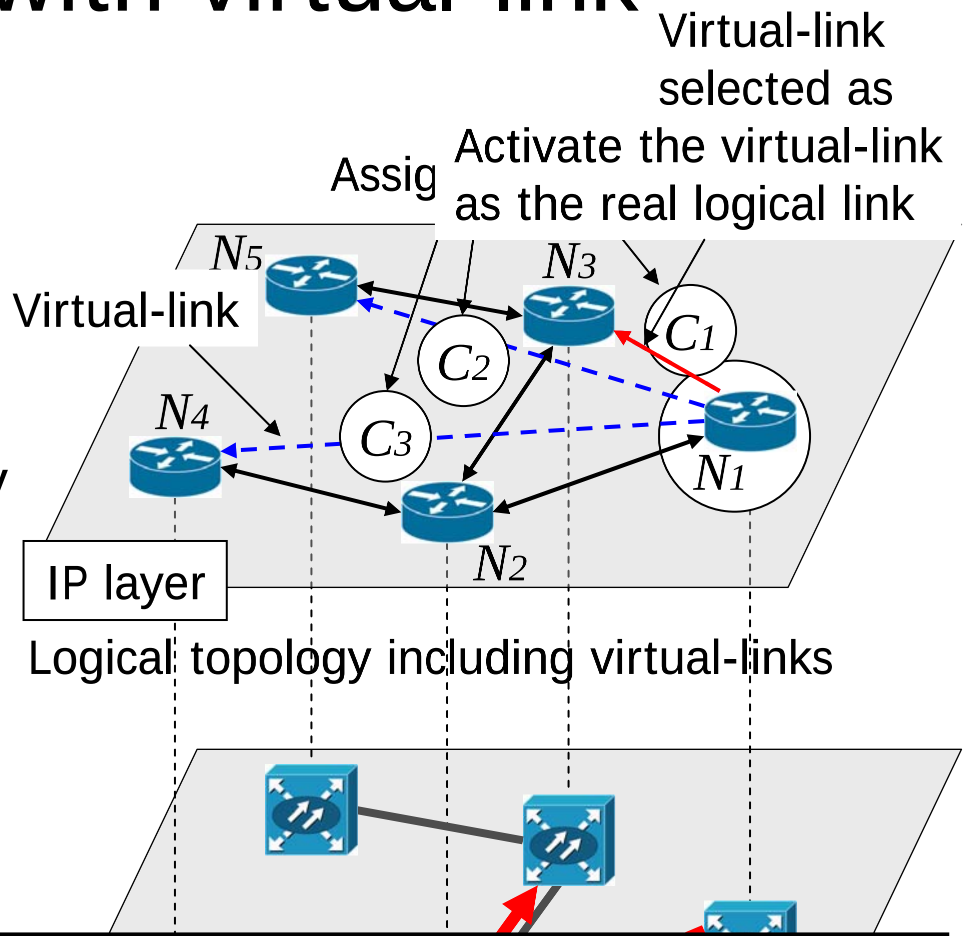
Network model and virtual-link

- 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

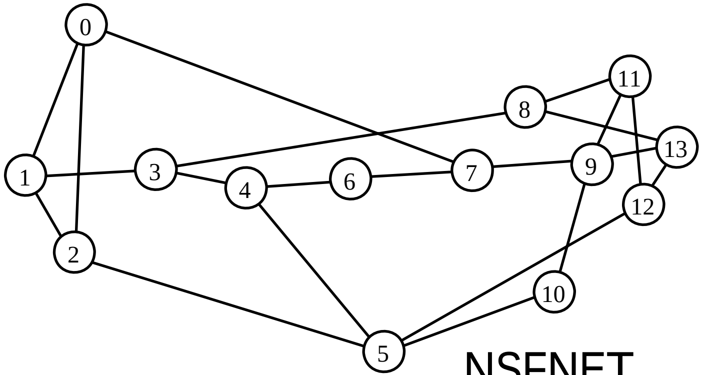
Cost function of virtual-links

- 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

$$C_{ij} = \alpha \cdot (v_j)^2 + \beta$$

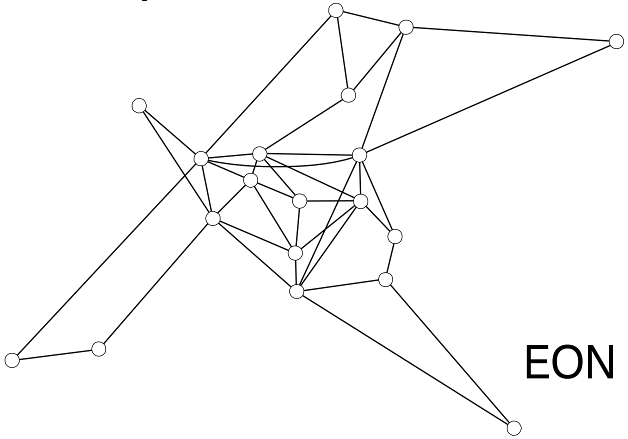
  - C_{ij}: Cost value of the virtual-link from node i to j
  - v_j: Load of node j
    - [0, 1]

Simulation model (1/2)



NSFNET

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


EON

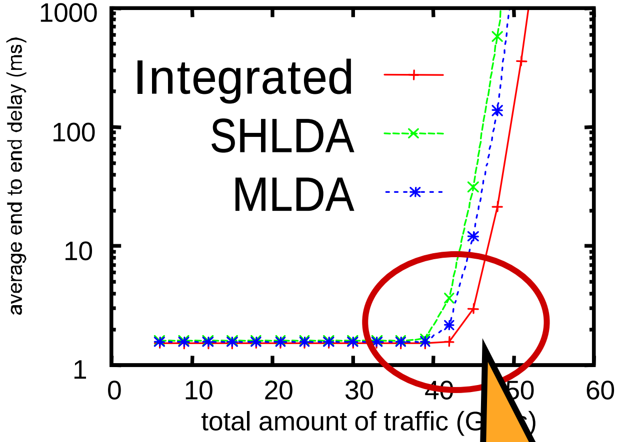
- Parameters
  - Number of wavelength: 8
  - Processing capacity of routers: 10 Gbps
  - Bandwidth per a wavelength channel: 10 Gbps
- Traffic
  - Flows arrive according to Poisson process with rate d_{ij}
    - d_{ij}: traffic demand from node i to node j
  - Flow length is exponential distributed with mean value 75 Mbytes

Simulation model (2/2)

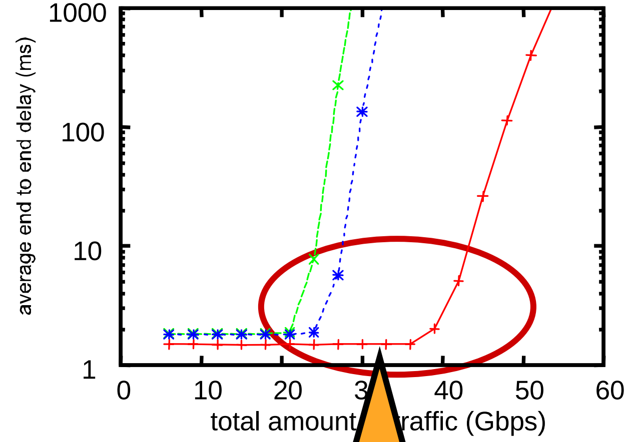
- Traffic demand matrix $D=\{d_{ij}\}$
  - Randomly generated traffic demand matrix
  - Actual traffic demand matrix in Ref. [11]
- Static topology design methods
  - SHLDA [9]
  - MLDA [11]
- Flow-level simulation method based on fluid flow model

9. J. Katou, S. Arakawa, and M. Murata, “A design method for logical topologies with stable packet routing in IP over WDM networks,” *IEICE Transactions on Communications* **E86-B**, pp. 2350–2357, Aug. 2003.
11. R. Ramaswami and K. N. Sivarajan, “Design of logical topologies for wavelength–routed optical networks,” *IEEE Journal on Selected Areas in Communications* **14**, pp. 840–851, June 1996.

Average end-to-end delay (random matrix)



(a) Without traffic nge



(b) With tr c change

NSFNET

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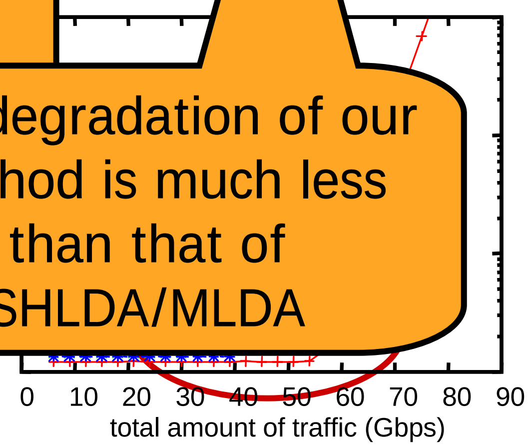
Our method
little better
performance than
SHLDA/MLDA

The result of EON
topology also shows
the same ten

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



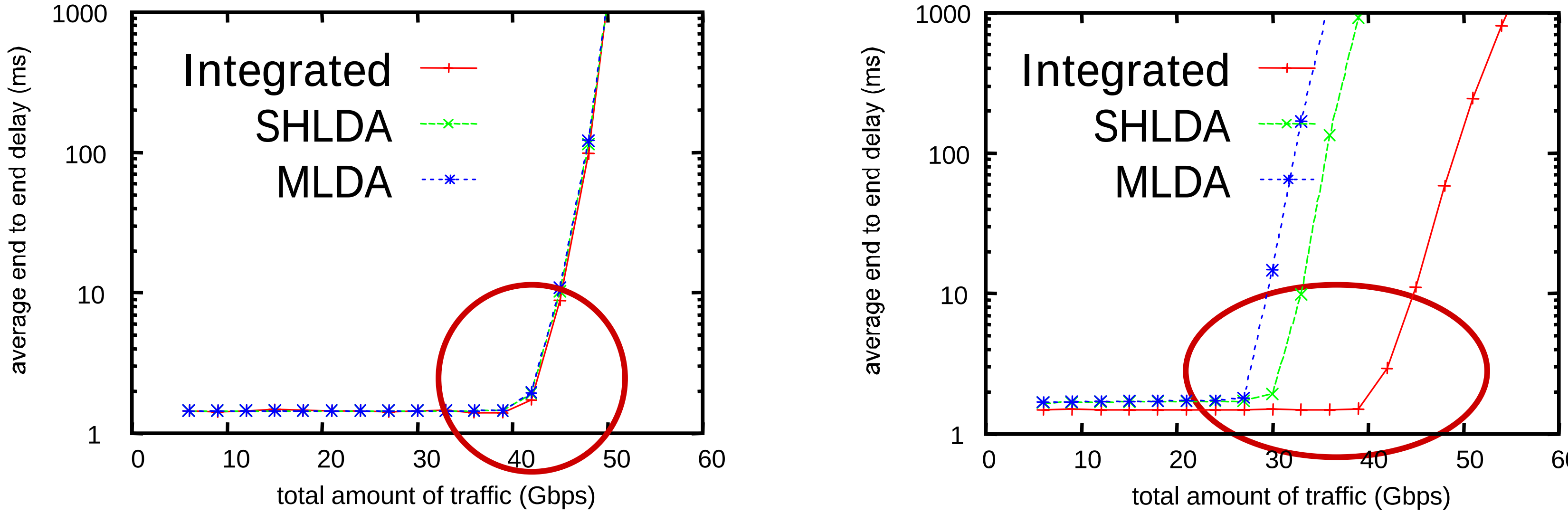
total amount of traffic (Gbps)

(a) Without traffic change

(b) With traffic change

EON

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

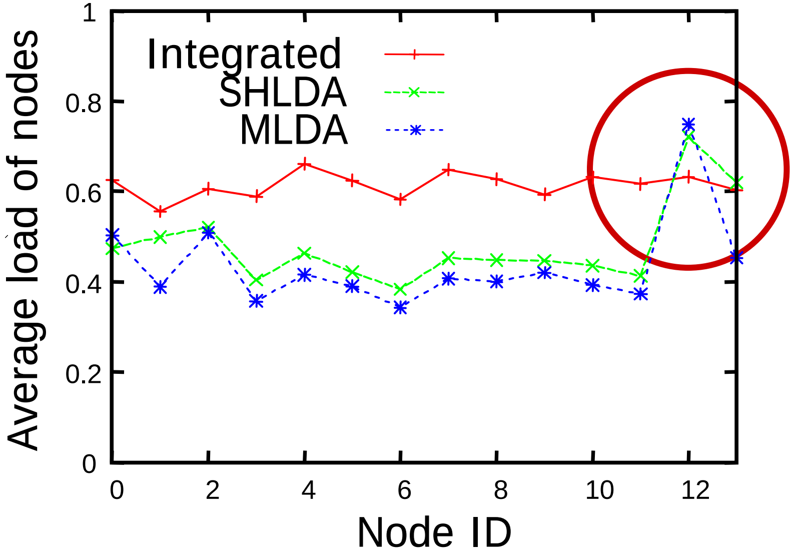


(a) Without traffic change NSFNET (b) With traffic change

- 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

11. R. Ramaswami and K. N. Sivarajan, "Design of logical topologies for wavelength–routed optical networks," *IEEE Journal on Selected Areas in Communications* **14**, pp. 840–851, June 1996.

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