Virtual Fiber Configuration Method
for Dynamic Lightpath Establishment
in Large-Scaled WDM Networks

Graduate School of Osaka University
Advanced Network Architecture Laboratory
Shinya Ishida
s-isida@ist.osaka-u.ac.jp
Contents

• Growing WDM networks
  – Topology of large-scale WDM networks
  – Influence of the power-law connectivity

• Our solution
  – Quasi-static lightpath
  – Virtual fiber
  – Degree-based virtual fiber configuration

• Evaluations

• Conclusion and future work
Growing WDM networks

• Rapid increase of the Internet’s traffic volume
  – WDM technology

• Growth of WDM networks
  – Interconnections by GMPLS and ASON
  – A large-scale WDM network will be constructed

• Performance of a large-scale WDM network
  – What topology?
    • Random mesh network (used in traditional studies on WDM)
    • Another
Topology of the Internet

- **AS level topology of the Internet**
  - Power-law connectivity
    - Most nodes have a few connections
    - Some nodes have lots of connections (hub nodes)

**Power-law connectivity**
The probability $p(k)$ that a node is connected to $k$ other nodes is proportional to $k^{-r}$ ($r$ is constant).
Topology of large-scale WDM networks

• BA (Barabási-Albert) model
  – Incremental growth
    • Nodes join a network one by one
  – Preferential attachment
    • High-degree nodes are likely to be connected with new nodes

• Large-scale WDM networks
  – Nodes join incrementally
  – Links are added selfishly
    • No coordinators for the entire networks
    • Limits of costs for equipments

Power-law connectivity
Influence of power-law connectivity

- Unbalanced load
  - Many lightpaths through hub nodes
  - Blocking probability is increased

\[ L_e: \text{Number of node pairs whose lightpaths go through a link } e \]

Simulation model:
- Links are bi-directional
- Routing is Shortest hop routing
- No wavelength conversion
Our solution

- Changing topologies logically
  - Enhancement of network equipments is expensive
  - Link state based routings increase overheads

<table>
<thead>
<tr>
<th>Solution</th>
<th>Merits</th>
<th>Demerits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enhancement of network equipments such as fibers and OXCs</td>
<td>Any other architectures are not required</td>
<td>Costs for installing and managing network equipments become high</td>
</tr>
<tr>
<td>Using a link state based routing</td>
<td>Wavelength resources are highly utilized against dynamic changes of traffic pattern</td>
<td>Overheads for distributing link state information and updating routing tables are increased</td>
</tr>
<tr>
<td>Changing topologies by configuring virtual fibers</td>
<td>Any more resources are not needed and a routing has not to be changed</td>
<td>Flexibility of wavelength utilization is limited</td>
</tr>
</tbody>
</table>
Quasi-static lightpath

- Setup static lightpaths in advance
  - Regard static lightpaths as logical links
  - Reserve and release wavelengths of logical links as wavelengths of physical links

- Moderate the affect of the wavelength continuity constraint
Virtual fiber

- Cut-through operation
  - Setup quasi-static lightpaths for all of the wavelengths

- Degrees of intermediate nodes are reduced
  - Routes of some lightpaths have to be changed
Degree-based virtual fiber configuration

- Reduce degrees of hub nodes by cut-through
  - Some lightpaths are diverted from hub nodes
  - Loads for links around hub nodes are distributed

Outline of degree-based virtual fiber configuration method

Step 1: Set the degree threshold $th$. Go to Step 2.
Step 2: Find a node $n_0$ having maximum degree $d_{max}$. If $d_{max} > th$, go to Step 3. If not, go to Step 5.
Step 3: Select such two adjacent nodes of $n_0$, $n_1$ and $n_2$, that the sum of their degrees is maximum. Go to Step 4.
Step 4: Cut through $n_0$ from $n_1$ to $n_2$. Go to Step 2.
Step 5: Quit configuring virtual fibers.
Evaluations

• Compare blocking probabilities
  – for the cases with and without virtual fiber configurations

  – Simulation model
    • Maximum degree: 88
    • Propagation delay: 0.1 msec (uniform)
    • Processing delay: 0
    • Lightpath setup requests: Poisson arrival
    • Holding times: Exponential distribution (rate 1.0 sec)
Comparison of blocking probability

- Our method reduces more than one order of magnitude of blocking probability
- Optimal threshold depends on arrival rate
  - Main factor for blocking probability changes

![Graphs showing distribution of $L_e$ and blocking probability](image)
Comparison of topological property

- Virtual fiber configuration
  - Average link load is increased
  - Variance of link load is reduced

- Main factor changes according to arrival rate
  - Average link load when the arrival rate is low
  - Maximum link load when the arrival rate is high

Properties of each topology

<table>
<thead>
<tr>
<th>Topology</th>
<th>Power-law</th>
<th>64</th>
<th>48</th>
<th>32</th>
<th>16</th>
<th>8</th>
<th>Random</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average distance</td>
<td>3.99</td>
<td>4.15</td>
<td>4.33</td>
<td>4.47</td>
<td>5.09</td>
<td>5.92</td>
<td>5.06</td>
</tr>
<tr>
<td>Average $L_e$</td>
<td>998.89</td>
<td>1046.0</td>
<td>1107.1</td>
<td>1166.0</td>
<td>1406.9</td>
<td>1787.1</td>
<td>1222.5</td>
</tr>
<tr>
<td>Maximum $L_e$</td>
<td>25120</td>
<td>12905</td>
<td>11863</td>
<td>11786</td>
<td>9993.0</td>
<td>8745.0</td>
<td>3442.0</td>
</tr>
<tr>
<td>Minimum $L_e$</td>
<td>15</td>
<td>48</td>
<td>62</td>
<td>55</td>
<td>117</td>
<td>325</td>
<td>414</td>
</tr>
</tbody>
</table>
Conclusion and future work

• Conclusion
  – Future large-scale WDM networks
    • Power-law connectivity
    • Hub nodes decline the performance of blocking probability
  – Virtual fiber configuration method
    • Investments and complicated routing are not required
    • Balances link load by logically reducing degrees of hub nodes
    • Reduces the blocking probability by more than one order of magnitude

• Future work
  – A way to determine the optimal threshold in advance
Thank you