Traffic Analysis and Network Protection in Photonic Switched Optical Metro-Access Networks

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Traffic Analysis and Network Protection in Photonic Switched Optical Metro-Access Networks

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BRASIL
Flight Plan

- Objectives & Introduction
- Topologies and Optical Nodes
- Basic theory
- Simulation plan
- Results & Discussion
- Conclusion

Objectives and Motivation

This work looks at:

- Network Performance analysis and link failure sensitivity using Photonic Switching (OBS/OPS types), for Metro-Access networks;
- Innovative topology configurations are considered
- Analytic and Simulation approaches are realised;
- New results appear!

And we see new technologies bringing new functionalities to the Optical Layer, more efficiently – indicating savings in network (usage) time & energy.
For core networks WDM (OCS) is definitively established;

For Metro-Access, in order to avoid (unnecessary) O/E conversions, OPS/OBS technologies are attractive solutions within WDM channels, to offer granularity and capacity, with significant reduction of network latency and energy consumption;

Important aspects are service survivability and network protection under link failure (the most common case is a single failure at a time..);

We look at traffic analysis and network protection in OBS/OPS networks having mesh topologies and ring topologies; the usual tree topology for access networks (EPON/GPON) is not considered because it is incompatible with asynchronous traffic assumed here;

Performance metrics are based on network capacity, average number of hops (ANH) and packet loss fraction.

Each node is \((P \times P)\), \(P=2, 3, 4\), plus add/drop ports; modified MS;

- Uni- and bidirectional links;
- \(N=m^2\) nodes;
- Regular when \(m\) even;
- Quasi-regular when \(m\) odd;

Each node is \((2 \times 2)\), plus add/drop ports;

- Uni- and bidirectional links;
- the New Ring is to be compared with the 2x2 MS network;
- connectivity is one to next \((N+1)\) and previous \((N-2)\) neighbours;
Optical Network Node & Packet

- **Optical Node** includes:
  - 2, 3, 4 inputs and outputs, plus add/drop
  - header processing
  - bufferless at optical layer, but includes FDL (fiber delay line)

- **Optical Packet/Burst**:
  - Header: final destination;
  - Payload: digital content (data, video, voice)
  - asynchronous operation;
  - concatenation at arrival (solvable problem)

Routing Protocols

- **Store and Forward (SF)** – packets are held and sent only through the shortest path to destination; minimize ANH, but has an impact on delay and latency. (*instrumental in the analytic computations*).

- **Deflection Routing (DR)** – packets are sent to the network, without regard to path; contention is resolved by deflection to available port; deflections avoid packet loss, latency is minimized, but ANH always increases. (*instrumental in network traffic simulation*).
Basic Theory

- Network capacity:
  \[ C_c = \frac{P \cdot N \cdot S}{H} \]
- Link failure alters capacity as:
  \[ C_c = \frac{(P \cdot N - m) \cdot S}{H} \]
- Performance factor:
  \[ F_p = \frac{C_c}{H} \]

Note: ANH is recalculated after failure, disconsidering the missing links

Results >>

Analytic Results

<table>
<thead>
<tr>
<th>Topology</th>
<th>Link failure</th>
<th>Capacity</th>
<th>( \Delta C ) (%)</th>
<th>Number of hops</th>
<th>( \Delta H ) (%)</th>
<th>Factor of performance</th>
<th>( \Delta P ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Msq-4</td>
<td>3.1</td>
<td>22.34</td>
<td>21.13</td>
<td>3.12</td>
<td>2.014</td>
<td>3.125</td>
<td>3.31</td>
</tr>
<tr>
<td>Msq-5</td>
<td>4.1</td>
<td>27.28</td>
<td>26.52</td>
<td>3.78</td>
<td>2.93</td>
<td>3.127</td>
<td>3.28</td>
</tr>
<tr>
<td>Msq-10</td>
<td>5.1</td>
<td>38.13</td>
<td>37.21</td>
<td>2.91</td>
<td>2.85</td>
<td>3.547</td>
<td>2.94</td>
</tr>
<tr>
<td>Msq-20</td>
<td>6.3</td>
<td>48.47</td>
<td>47.61</td>
<td>1.77</td>
<td>1.71</td>
<td>1.781</td>
<td>1.80</td>
</tr>
<tr>
<td>Msq-40</td>
<td>8.5</td>
<td>22.34</td>
<td>20.85</td>
<td>9.46</td>
<td>2.01</td>
<td>3.132</td>
<td>6.34</td>
</tr>
<tr>
<td>Msq-75</td>
<td>15.18</td>
<td>27.28</td>
<td>25.52</td>
<td>7.68</td>
<td>2.91</td>
<td>1.317</td>
<td>3.26</td>
</tr>
<tr>
<td>Msq-75</td>
<td>15.18</td>
<td>38.13</td>
<td>37.43</td>
<td>1.60</td>
<td>1.59</td>
<td>1.781</td>
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</tr>
</tbody>
</table>

### Analytic Results

- **Topology Ring / SF protocol / more and less used links**

<table>
<thead>
<tr>
<th>Topology</th>
<th>Link failure</th>
<th>Capacity</th>
<th>Without</th>
<th>With</th>
<th>ΔC (%)</th>
<th>Number of hops</th>
<th>Without</th>
<th>With</th>
<th>ΔH (%)</th>
<th>Factor of performance</th>
<th>Without</th>
<th>With</th>
<th>Δf (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ring 9</td>
<td>2, 3</td>
<td>20</td>
<td>17.89</td>
<td>10.53</td>
<td>2.25</td>
<td>2.75</td>
<td>5.98</td>
<td>8.89</td>
<td>7.53</td>
<td>13.24</td>
<td>10.53</td>
<td>8.89</td>
<td>7.53</td>
</tr>
<tr>
<td>Ring 16</td>
<td>3, 1</td>
<td>24.02</td>
<td>22.86</td>
<td>7.27</td>
<td>3.33</td>
<td>3.52</td>
<td>4.47</td>
<td>7.31</td>
<td>6.04</td>
<td>11.25</td>
<td>7.27</td>
<td>4.47</td>
<td>3.33</td>
</tr>
<tr>
<td>Ring 9</td>
<td>7, 8</td>
<td>20</td>
<td>17.00</td>
<td>15.00</td>
<td>2.25</td>
<td>2.5</td>
<td>11.11</td>
<td>8.89</td>
<td>6.80</td>
<td>21.30</td>
<td>15.00</td>
<td>8.89</td>
<td>6.80</td>
</tr>
<tr>
<td>Ring 16</td>
<td>13, 16</td>
<td>24.02</td>
<td>21.89</td>
<td>8.87</td>
<td>3.33</td>
<td>3.54</td>
<td>6.31</td>
<td>7.21</td>
<td>6.18</td>
<td>14.28</td>
<td>8.87</td>
<td>6.31</td>
<td>7.21</td>
</tr>
</tbody>
</table>

- **Traffic Simulation plan**

Software: Network Simulator 2 (NS-2)

- Routing Protocol Deflection Routing (DR);
- Packets: 500 bytes (2µs);
- Transport UDP / const. Bit-rate CBR;
- Bit-rate: 2.5 Gb/s;
- every node generates uniform traffic to every other node;
- Packets per round: 2 x 10^5 (200000) ;
- Uni- and bidirectional link connections.
**Traffic Simulation Results**

**Average N Hops for MS(2x2); MS(3x3); and Ring Uni- and Bidirect.:**

with and without single link failure

**Mesh MS-type (2x2) and (3x3)**

**Ring Uni- and Bidirect.**

<table>
<thead>
<tr>
<th>Link load</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>2x2</td>
<td>6</td>
<td>7.5</td>
<td>9</td>
<td>10.5</td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>15</td>
<td>16</td>
<td>17</td>
</tr>
<tr>
<td>3x3</td>
<td>8</td>
<td>9.5</td>
<td>11</td>
<td>12.5</td>
<td>14</td>
<td>15</td>
<td>16</td>
<td>17</td>
<td>18</td>
<td>19</td>
</tr>
</tbody>
</table>

**Partial Conclusions:**
- ANH for mesh is always smaller than for equivalent ring;
- Mesh is more robust, “insensitive” to single failure;
- Mesh unidirect. is better,… Ring bidir. is better

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**Traffic Simulation Results**

**Packet loss fraction (PLF) for Mesh MS-16 (PxP) 2, 3, 4 ;**

with/without link failure

<table>
<thead>
<tr>
<th>Link load</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>2x2</td>
<td>0.05</td>
<td>0.1</td>
<td>0.15</td>
<td>0.2</td>
<td>0.25</td>
<td>0.3</td>
<td>0.35</td>
<td>0.4</td>
<td>0.45</td>
<td>0.5</td>
</tr>
<tr>
<td>3x3</td>
<td>0.02</td>
<td>0.04</td>
<td>0.06</td>
<td>0.08</td>
<td>0.1</td>
<td>0.12</td>
<td>0.14</td>
<td>0.16</td>
<td>0.18</td>
<td>0.2</td>
</tr>
<tr>
<td>4x4</td>
<td>0.01</td>
<td>0.02</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
<td>0.06</td>
<td>0.07</td>
<td>0.08</td>
<td>0.09</td>
<td>0.1</td>
</tr>
</tbody>
</table>

**Partial Conclusions:**
- PLF is smallest for 3x3 due to largest number of different connections;
- mesh with higher PxP is more robust, and less sensitive to single failure;
- but 2x2 is cheaper …
Partial Conclusions:
- PLF is better for Uni- due to larger number of different connections;
- Ring is always sensitive to link failure;
- Uni- and bidir. have similar installation costs …

Traffic Simulation Results

Packet loss fraction (PLF) for Ring-16 (uni- and bidirect.) with/without link failure

Ring-16 (uni-) and (bidir)

Ring-16 (bidir.)

Ring-16 (uni-)

Traffic Simulation Results

Simulation and modelling are excellent tools to experiment with in network planning and evaluation;

Innovative variations of mesh and ring with various interconnections of optical nodes in OPS/OBS networks offer better performance and robustness (protection to data traffic), without necessarily impacting on installation costs;

it is observed that optical nodes that have a larger number of different connections (PXP optical ports) to other nodes demonstrate improved performance; and should be used in more congested locations.

Last – but not least! – optimized Mesh networks once again demonstrate higher performance and robustness than Ring (and tree)…

details of installation and operation must be further discussed for actual installations (preferred Metro-Access level) !!
I. B. Martins; F. Rudge Barbosa; L. H. Bonani; E. Moschim


