COST Action 272
“Packet-Oriented Service Delivery via Satellite”

*Capacity Dimensioning of Intersatellite Links in Constellation Networks Using Optical WDM Networking*
*TD-01-___-S*

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Introduction: Optical Transport Network (OTN)

- The OTN is formed by assigning separate wavelength channels to dedicated pairs of satellites and one (or more) continuous path(s) between them, so-called LightPath.

Objectives:
- Simplify the routing.
- Reduce queuing delays at some intermediate nodes.
- Reduce the processing load for the on-board processor.
The OTN Topology

- Origin-Destination Connection
- LightPath
- Inter-Satellite Link

Wavelength-Division Multiplexing

The same wavelength (Lightpath) could be used if different routes have the same destination satellite.

On-board Wavelength Routing

Connectivity and Technology Options

- Single-Hop Logical Connectivity
- Multiple-Hop Logical Connectivity
- Double-Hop Logical Connectivity

• Dedicates a complete wavelength to each Origin-Destination connection (i.e. Lightpath).
Connectivity and Technology Options

- Single-Hop Logical Connectivity

- Multiple-Hop Logical Connectivity
  - Reduction number of wavelengths.
  - Imperative in large constellations.
  - Reuses wavelengths.

- Double-Hop Logical Connectivity
  - Particular case of MH-Connectivity.
  - It maintains a high degree of connectivity at optical level.
  - Increase of the network resources utilization.
  - Reduce the number of maximum wavelengths per ISL.
Routing Selection

Objectives:

- To increase the network resources utilization splitting the traffic.
- To choose the shortest paths to reduce the queuing, routing, switching and propagation delays.
- Use the regular structure of satellite network.

Routing Selection

- Deterministic Routing Selection
  - M1 - Approach
  - M2 - Approach

- Optimized Routing Selection
  - Full Optimization

Use "Matrix-route" (the shortest route) for the whole Origin-Destination traffic.
Routing Selection

- Deterministic Routing Selection
  - M1 - Approach
  - M2 - Approach

- Optimized Routing Selection
  - Full Optimization

A “Mirror Route” is used to split the whole traffic in a percentage 50%:50% (Equal sharing).

- The shortest-hop group for each Origin-Destination traffic is used.
- The optimizer finds an optimum sharing traffic between the routes.
Routing in Optical Satellite Networks

Alternate Path (The Mirror Route for M2 - Approach)

- M2 - Reduced Approach
- M2 - Standard Approach
- M2 - Extended Approach

- If the number of intermediate nodes is larger in the Mirror Route, only the first route is used.

Routing in Optical Satellite Networks

Alternate Path (The Mirror Route for M2 - Approach)

- M2 - Reduced Approach
- M2 - Standard Approach
- M2 - Extended Approach

- First Route and Mirror Route are disjoint.
Routing in Optical Satellite Networks

Alternate Path (The Mirror Route for M2 - Approach)

- M2 - Reduced Approach
- M2 - Standard Approach
- M2 - Extended Approach

- Neighbour satellites are used as Mirror Route.
- Double-Hop connectivity is not viable.

Constellations under Study

- The constellations under study:
  - **Meonet** - Walker Constellation 15 / 3 / 1 - Inclination 54°
    - MEO Constellation
  - **Celestri** - Walker Constellation 63 / 7 / 5 - Inclination 48°
    - LEO Constellation

- Both are Delta-constellations to avoid the seam edge.
- Inter-orbit links permanently available.
Traffic Scenarios

• Generic scenarios (Bidirectional and Symmetric traffic):
  • T1: Deterministic traffic.
  • T2: Traffic with uniform distribution.
  • T3: Decreasing traffic distribution.

• “Realistic” traffic:
  • T4
  • T5

Traffic Scenarios

• Generic scenarios:
  • T1
  • T2
  • T3

• “Realistic” traffic: Traffic generation depending on terrestrial parameters.
  • T4: Smooth distributed traffic on the Earth.
  • T5: Peaky traffic in some specific zones on the Earth.
## Results

- The worst case link load is drastically reduced combining M2 approach, single-hop and the optimizer.

### Worst Case Intra-link Load

<table>
<thead>
<tr>
<th>Traffic Scenario</th>
<th>Traffic (c.u.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1 Approach</td>
<td></td>
</tr>
<tr>
<td>M2-Reduced (Equal Sharing)</td>
<td></td>
</tr>
<tr>
<td>M2-Standard (Equal Sharing)</td>
<td></td>
</tr>
<tr>
<td>M2-Extended (Equal Sharing)</td>
<td></td>
</tr>
<tr>
<td>M2-Extended (Full Optimization)</td>
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### Worst Case Inter-link Load

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</table>

- The optimizer uniform the traffic between intra-links and inter-links.
Results

Comparison of M2 approaches.
- M2 Reduced gives a better delay and reduces the number of Lightpaths per ISL.
- M2 Standard and M2 Extended give a better traffic distribution.

<table>
<thead>
<tr>
<th></th>
<th>M1</th>
<th>M2 Reduced</th>
<th>M2 Standard</th>
<th>M2 Extended</th>
</tr>
</thead>
<tbody>
<tr>
<td>max # bidirect. LPs/intra-ISL (single-hop)</td>
<td>9</td>
<td>18</td>
<td>19</td>
<td>21</td>
</tr>
<tr>
<td>max # bidirect. LPs/inter-ISL (single-hop)</td>
<td>5</td>
<td>10</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>total # of LPs/network</td>
<td>105</td>
<td>210</td>
<td>210</td>
<td>210</td>
</tr>
<tr>
<td>max # bidirect. LPs/intra-ISL (double-hop)</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>max # bidirect. LPs/inter-ISL (double-hop)</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Worst case alter. path delay in close sat.</td>
<td>0</td>
<td>65ms</td>
<td>330ms</td>
<td>295ms</td>
</tr>
</tbody>
</table>

Routing Approach - M2 Standard

Comparison of M2 Standard (equal sharing) and M2 Standard (full optimization).

<table>
<thead>
<tr>
<th>Space-based traffic scenario</th>
<th>Ground-based traffic scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14 (MB)</td>
</tr>
<tr>
<td>WCL load, max</td>
<td>9.6</td>
</tr>
<tr>
<td>ISL load, mean</td>
<td>9.5</td>
</tr>
<tr>
<td>average ISL utilization (no OTN)</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

Routing Approach - M2 Standard-FD (Full Optimization)
Conclusions

• Some different kinds of alternative routing have been compared. The selection depends of the network design.

• Combining the optimizer and M2 approach gives us large benefits.

• It seems interesting to join in the future the optimizer, M2 approach and double-hop optical connectivity to get a better results.