Management and Control Aspects of Spectrum Sliced Elastic Optical Path Network (SLICE)

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Outline

1. Drivers
   • Adaptive spectrum allocation
   • Shifting grooming and multiplexing functionalities directly to optical domain
     in 100G era and beyond

2. SLICE concept and enabling technology
   • Spectrum-sliced elastic optical path network

3. Management and control aspects of SLICE
   • Definition of optical corridor
   • Introduction of optical frequency slot
   • Routing and spectrum assignment (RSA) algorithm
   • GMPLS signaling message extension

4. Summary
1. Drivers for Adaptive Spectrum Allocation and Grooming in Optical Domain
Driver for Adaptive Spectrum Allocation in 100G Era and Beyond

- For 400G/1T, rate- and distance-adaptive spectrum allocation is inevitable to achieve overall high SE
  - May not get the same mileage from the improvements in SE achieved through electrical multiplexing and grooming that we achieved before, especially for longer optical paths.

**So far**

<table>
<thead>
<tr>
<th>Optical reach</th>
<th>SE improvement</th>
<th>400G/1T</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.7 Gb/s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>43 Gb/s</td>
<td></td>
<td>448 Gb/s</td>
</tr>
<tr>
<td>112 Gb/s</td>
<td></td>
<td>448 Gb/s</td>
</tr>
<tr>
<td>&gt;</td>
<td>x 2.3</td>
<td>2 sub-carriers DP-16QAM</td>
</tr>
<tr>
<td>≈</td>
<td>x 1.3</td>
<td>4 sub-carriers DP-QPSK</td>
</tr>
<tr>
<td>&gt;</td>
<td>x 2.9</td>
<td>5 sub-carriers DP-16QAM</td>
</tr>
</tbody>
</table>

Driver for Shifting Grooming Directly to Optical Domain in 100G Era and Beyond

- Off-loading of transit traffic from core routers to energy-efficient and low-cost Layer 2 or Layer 1 switches in next generation 40G/100G networks
- Will electrical bypass still be feasible in 400G/1T era from viewpoints of energy consumption, cost, and footprint?
2. SLICE Concept and Enabling Technology

- Spectral resources on a given route
  - 70 GHz for path A
  - 30 GHz for path Z
SLICE Concept

- Introducing elasticity and adaptation into the optical domain
- Novel optical network architecture based on “elastic optical paths”
- Spectrum-efficient transport with flexible granular grooming in optical domain
- Adaptive allocation of right-sized bandwidth to an end-to-end optical path by “slicing off” the necessary spectral resources according to
  - actual user traffic volume or
  - physical conditions on the route, path length and node hops

Current optical path network

SLICE

ITU-T grid

Freq. slot ?

100 Gb/s, 500 km
100 Gb/s, 100 km
400 Gb/s, 500 km
40 Gb/s, 100 km
Rate-adaptive Spectrum Allocation

(a) Current wavelength-routed optical network

(b) Elastic optical path network
Distance-Adaptive Spectrum Allocation

- **Current optical networks:**
  - Worst-case design in terms of the transmission performance is employed for all optical paths
    - Longest path with multiple hops of nodes can be transmitted with sufficient quality
  - Most optical paths have large transport margins at the receiving end
- **Distance-adaptive SLICE:**
  - Utilize margins for shorter paths to save spectral resources (not to increase bitrate)
  - Shorter path: more spectrally efficient set of parameters (16-QAM and narrowest filter width)
  - Longer path: more robust set of parameters (QPSK and wider filter width)
SLICE Network Model

Bandwidth agnostic WXC in network core

Rate/format flexible transponder at network edge

Client node

Fiber
Rate and Format Flexible Transponder

• Introduce of coherent detection followed by DSP
  ✓ Optimizing 3 parameters provides required data rate and optical reach while minimizing spectral width
    • (Symbol rate) \times (Number of modulation levels) \times (Number of sub-carriers)

• Optical OFDM
  ✓ Provides compact spectrum comprising with sub-carries that satisfy orthogonal condition
  ✓ Optical multiplexing of orthogonal optical sub-carriers with a frequency spacing equal to the inverse of the symbol duration

• Evolution of photonic IC technology
Bandwidth Agnostic WXC

- Introduce bandwidth-variable WSS based on e.g. LCoS
- Required minimum spectrum window (optical corridor) is open at every node along optical path
  - Required width of optical corridor is determined by factoring in the signal spectral width and filter clipping effect accumulated along the nodes.

![Diagram of Bandwidth Agnostic WXC](image)

Variable bandwidth of BV-WSS

- Bandwidth agnostic WXC
3. Management and control aspects of SLICE
Explicit Spectral Resource Allocation: Optical Corridor

(a) Current wavelength-routed optical network

Grid spacing is fixed

allocated spectrum resources on the route are tied to the wavelength

Resource identifier:

$\text{f}_{\text{center}}$

(Wavelength)

Optical corridor:

Spectral window opened at every node along route

(b) Elastic optical path network

Width of the “optical corridor” and signal bit-rate, modulation format are independent parameters

Resource identifier:

$\text{f}_{\text{low}}$ and $\text{f}_{\text{high}}$
Optical Frequency Slot Concept

Current ITU-T frequency grid (G.694.1)

-8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8

| 12.5 GHz | 50 GHz | 37.5 GHz | 125 GHz |

Optical frequency slot: On the grid approach

-9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8

| 12.5 GHz | 50 GHz | 37.5 GHz | 125 GHz |

Optical frequency slot: Off the grid approach

Required a new slot numbering system, but is compatible with the current grids.

Wavelength labeling under standardization by IETF (CS: Channel Spacing, n: wavelength number)

CS: 2 (=50 GHz)
CS: 4 (=12.5 GHz)

Slot width: 12.5 GHz
(Start: 2, End: 7)

Intuitive, but not compatible with the current grids of 25 GHz, 50 GHz, and 100 GHz.
Routing and Spectrum Assignment (RSA) Algorithm: Creating Route List with Necessary Corridor width and Modulation Format

1. Create ordered list of a number of fixed routes for each source-destination pair at a given bit-rate
2. Calculate necessary corridor width (slot number) and modulation format for the route

Network topology, Physical parameters (bit-rate, length, loss, dispersion etc.)

Route list with necessary corridor width and modulation format

![Graph showing BER vs. Hop count for different frequencies and modulation formats]
Routing and Spectrum Assignment (RSA) Algorithm:
Allocating contiguous frequency slots

**Connection request**
(Source/Destination nodes, Bit rate)

3. Select a route from the list in sequence
(Transit nodes, number of slots, modulation format)

4. Search contiguous frequency slots available for every link on the route from a lower-numbered frequency slot

Contiguous frequency slots are available on the route?

Allocate contiguous frequency slots *(start slot, end slot)*

<table>
<thead>
<tr>
<th>s</th>
<th>d</th>
<th>Bit Rate</th>
<th>Route</th>
<th>No. slot</th>
<th>Mod. format</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>D</td>
<td>400G</td>
<td>A2B3C4D</td>
<td>7</td>
<td>28 G, 2 slots, 16QAM</td>
</tr>
</tbody>
</table>
Signaling Messages Extension Example

PATH message

| Label Request Object |
| Upstream Label Object |
| Explicit Route Object |
| Sender TSpec Object |

Parameters in objects

Switching type: spectrum switching capable

Label: (start slot, end slot)

Modulation format: (symbol rate, no. of sub-carriers, modulation level)

RESV message

| Label Object |
| Record Route Object |
| Flow Spec Object |

Switching type: spectrum switching capable

Label: (start slot, end slot)

Modulation format: (symbol rate, no. of sub-carriers, modulation level)
Elastic Optical Path Setup Procedure

Connection request arrives
Route and spectrum assignment calculation
Path setup signaling
Optical corridor with necessary width open
Optical channel with optimized format setup

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Summary

• For 100G and beyond, rate- and distance-adaptive spectrum allocation is inevitable to achieve overall high SE.

• SLICE provides a platform to achieve right-sized optical bandwidth allocation by introducing elasticity and adaptation into the optical domain.

• To operationalize SLICE,
  ✓ Explicit spectral resource allocation by using optical corridor and optical frequency slot concepts
  ✓ Efficient routing and spectrum assignment (RSA) algorithm
  ✓ Extended signaling messages are the keys.
Thank you!

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References


