Management & Control Issues in Spectrum-Sliced Elastic Optical Network (SLICE)

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Outline

1. Concept of spectrum-sliced elastic optical path network, SLICE
   - Increase agility and flexibility
   - Automatically provide any-to-any, appropriate optical bandwidth, appropriate time

2. Enabling technologies and experimental demonstrations
   - Bandwidth variable transponder and wavelength-crossconnects
   - Elastic variation of optical path 40 Gb/s to over 400 Gb/s

3. Management & control issues to be addressed
What Is “SLICE”? 

- Optical network architecture based on “elastic optical path”
  - SLICE: Spectrum-sliced elastic optical path network architecture
- Spectrum-efficient transport with flexible granular grooming in optical domain
- Dynamic allocation of right-size bandwidth to an end-to-end optical path by “slicing off” the necessary spectral resources.
What Is “Elastic Optical Path”?

- Alternative to the rigid bandwidth allocation
- Elastic optical path “expands and contracts” according to traffic or user request.

Conventional “rigid” optical path
Bandwidth “fixed, rigid”

Proposed “elastic” optical path
Bandwidth “expanding and contracting”
Spectrum Assignment and Benefits of SLICE

Conventional optical path network

Efficient and scalable accommodation of various bandwidths in SLICE

Sub-wavelength
Multiple data rate
Super-wavelength
Elastic variation
SLICE Key Technologies and Network Model

- Bandwidth-variable OFDM format
  - High spectral efficiency and the flexible rate
  - Optical multiplexing of orthogonal optical sub-carriers with a frequency spacing of the inverse symbol duration.

- Bandwidth-variable wavelength cross-connects (WXC)
  - Necessary bandwidth in nodes along the optical path

Sub-carrier

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Fiber

BV transponder at the network edge

Client node

BV WXC in the network core

OFDM: Orthogonal Frequency Division Multiplexing
Functional View Example of SLICE Transponder

- PDUs extracted, mapped to G.709 OTN frame or its possible extension, and transformed into optical OFDM signal.
- Inter-frame byte removed for efficient utilization of network bandwidth.
- Tailoring of spectral width by allocating appropriate number of optical sub-carriers.
Implementation Example of Bandwidth-Variable WXC

- Performs self-routing of incoming optical signal
- Optical bandwidth of self-routing window is contiguously configured
- Bandwidth-variable Wavelength Selective Switches (WSSs) are utilized in B&S configuration
  - Add-and drop
  - Grooming routing
Bandwidth Variable WSS

- Incoming optical signals with differing optical bandwidths and center frequencies can be routed to any of the output fibers.

- Variable optical bandwidth functionality
  - Spatial phase modulator technology such as LCoS
SLICE Experimental Configuration

- B&S type WXC that comprises LC-based WSSs
- With variable bandwidth of integral multiple of 50 GHz
- Add/drop, multicast

Optical OFDM/DPSK signal generator

WSS-based signal distributor

Optical OFDM demux
DPSK demodulator
BERT

189.9 190 190.1 190.2 190.3
Optical Frequency (THz)

Intensity (dB)
Multiple Rate Optical Path Accommodation

![Diagram showing level versus optical frequency with labels α, β, γ, δ, θ for different rates and Q values for different subcarriers.](image)
Bandwidth Expansion of Elastic Optical Path

![Diagram showing bandwidth expansion and Q dB graph]

- Path 1
- Path 2 (speed 8x)

- Q > 16.5 dB
- FEC limit
- Bandwidths: 440 Gb/s, 390 Gb/s, 340 Gb/s, 290 Gb/s, 240 Gb/s, 190 Gb/s, 140 Gb/s, 90 Gb/s, 40 Gb/s
Networking Level SLICE Technology Challenges

- Flexible spectrum allocation and signaling scheme
- Routing and non-uniform spectrum allocation algorithm
- Framing of elastic optical path and OA&M overhead implementation
- Protection and restoration scheme utilizing unique bandwidth variation feature
- Optical link capacity adjustment scheme
  
  *etc.*
Requirements in Spectrum Allocation

• Conventional ITU-T frequency grid, anchored to 193.1 THz, supporting channel spacing varying from 12.5 GHz to 100 GHz
• Requirements
  – Efficient accommodation of sub-wavelength, super-wavelength, and mixed rate traffic volume
  – Independent of signal format
  – Future proof for various new possible data rates
  – Intuitive for network designers and operators
Spectrum Allocation and Labeling Example

Frequency grid (ITU-T G.694.1)

Wavelength label in PATH message (drafr-ietf-ccamp-gmpls-g-694-lambda-label-04)

Frequency slot example

Assigned spectrum range

Signal spectra

Filter guard-band

100 Gb/s
60 Gb/s
300 Gb/s

Slot width: 6.25 GHz
L: 3, H: 14

100 GHz
50 GHz
25 GHz
12.5 GHz

ex. 6.25 GHz

f = 193.0 THz
n = -1

f = 193.1 THz
n = 0

f = 193.2 THz
n = 1

Grid: 1
CS: 1
n: 1

Grid: 1
CS: 2
n: 2

Grid: 1
CS: 3
n: 4

Grid: 1
CS: 4
n: 8

n = 0

n = 1

n = 2

n = 4
Routing and Spectrum Assignment (RSA)

- Conventional Routing and Wavelength Assignment (RWA)
  - Wavelength continuity constraint

- Routing and Spectrum Assignment (RSA)
  - Spectrum continuity constraint
  - Bandwidth continuity constraint
  - Non-uniform spectrum width
  - Possible variation of spectrum width according to traffic flow volume
Framing Example of Elastic Optical Path

- PDUs mapped onto \( n \) out of \( N \) OTUk channels in OTN PHY.
- By adjusting the number of OTUk channels, the necessary logical bandwidth is allocated to client signal.
- \( n \) OTUk channels are sent to OFDM transmitter block.
Highly Survivable Restoration with Bandwidth Squeezing

- Squeeze bandwidth of failed working optical path if insufficient bandwidth in detour to ensure minimum connectivity at the expense of bandwidth.
Summary

• Spectrum sliced elastic optical path network, SLICE
  – Key for bringing increased agility and flexibility into optical transport networks
  – Provide any-to-any connectivity with appropriate optical bandwidth at right time.
• Technology challenges related to management & control issues
  – Flexible spectrum allocation scheme and signaling
  – Routing and non-uniform spectrum allocation algorithm
  – Enhanced protection and restoration utilizing unique bandwidth variation feature
• SLICE will introduce a new degree of freedom and open up a more significant role for optical transport networks
Thank you!

Spectral resources on a given route

70 GHz for path A
30 GHz for path Z