Optical Node Architecture and Hitless Spectrum Defragmentation for Flexible Grid Optical Networks

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Outline of This Talk

- **Flexible optical node architecture**
  - employing software-defined modulation-flexible universal transceivers
  - for beyond 100G flexible grid optical networks.

- **Hitless spectrum defragmentation**
  - using synchronous bandwidth-variable WSS control
  - for in-service resource optimization.
Flexible Grid Optical Networks

- Beyond 100G, e.g. 400G or 1T, will require more than 50GHz spectrum
- Super-channel transmission – multiple sub-carriers packed tighter for higher spectral efficiency, managed/operated as single entity
  - fixed or variable data rate (n x R Gb/s), flexible channel bandwidth (m x slotBW GHz), design for adaptive reach (modulation format)
- Flexibly adjust spectrum/bandwidth, data rate and reach to match traffic demands – minimize overall resource usage in the network

Software-controlled switching between short- and long-haul modes on a single transceiver

16QAM

Universal transceiver

Flexible optical switch node

Software-controlled adjustment of transmission routes and wavelength slot on an optical switch node
Universal Transceiver

- Programmable modulation format (DP-QPSK, DP-16QAM, etc.)
  - DP-QPSK – 100Gb/s
  - DP-16QAM – 200 Gb/s, same hardware supporting 2x capacity, higher spectral efficiency, lower reach
  - Reduce sparing for service providers

- Super-channel for 400 Gb/s
  - Nyquist filtering – spectrum shaping to allow tighter packing of sub-carriers
  - 2x SC DP-16QAM
  - 4x SC DP-QPSK
Conventional Optical Node Architecture (using dedicated transponders)

Type 1: 100G dedicated transponder
- **100G DP-QPSK**

Type 2: 400G dedicated transponder
- **400G (DP-QPSK) x 4**

Type 3: 400G dedicated transponder
- **200G DP-16QAM x 2**
Flexible Optical Node Architecture
(pool of universal transceivers)

Flexible node architecture requires ~20% less transceivers compared to conventional node architecture.
Spectrum Defragmentation

 Signals can occupy different number of slots, the uneven usage of slots causes spectrum fragmentation.

 e.g. a departed 400 Gbps signal leave 7 empty slots, 4 of which may be re-occupied by a 100 Gbps signal, leaving 3 “fragmented” slots unusable by any signal.

 Hitless Spectrum Defragmentation

 The network ‘retunes’ the signals occupying the neighboring slots of a departed signal to fill the ‘gap’

 e.g. the signal occupying the slots above the empty slots always ‘fall down’ to fill the empty slots.

 The transponders and all devices (such as flexible grid ROADMs) along the signal path ‘retune’ into the new slots.

 This defragmentation method supports any topology and works with any routing and spectrum assignment algorithm.

Illustration of Spectrum Defragmentation

(a) Without defragmentation
(b) With defragmentation

Fragmented spectrum

Increased usable spectrum as a result of defragmentation
Defragmentation Demonstration Using Real-time Coherent Receiver

- Four ROADM nodes with flexible grid (A-D).
- Continuous wavelength sweep-capable tunable LDs (Tx and LO).
- Synchronous WSSs operation with wavelength sweep of signal.

Experimental Demonstration

- Continuous wavelength sweep (over entire C-band) and real-time BER.
- Wavelength sweep in steps of 20 pm (2.5 GHz) width every 100 ms.

Wavelength sweep for spectrum defragmentation without service disruption is successfully demonstrated.
Key Performance Metrics for Continuous Wavelength Sweep Defragmentation

- How to tune the wavelength of tunable lasers?
  - The faster you can tune, the less amount of wavelength sweeping time.

- How to control the passband of bandwidth-variable wavelength selective switches (BV-WSS)?
  - Sequential BV-WSS control or Synchronous BV-WSS control.

(a) Sequential BV-WSS control
(b) Synchronous BV-WSS control
Comparison of BV-WSS Control Methods

■ Sequential BV-WSS control
  ■ The sweeping time is proportional to the product of # of vacated slots and # of signal layers.
  ■ It may take quite long time if the departed signal vacates many slots and there are many layers of signals need to be retuned.

■ Synchronous BV-WSS control
  ■ The sweeping time is proportional to the sum of # of vacated slots and # of signal layers.
  ■ The overall sweeping time can be significantly reduced.
    • It also relaxes the hardware requirement on tuning speed of lasers, BV-WSSs, etc., enabling practical and cost-effective defragmentation solutions.

■ Synchronous BV-WSS control enables more successful defrag operations than Sequential BV-WSS control.
  ■ Under the same wavelength sweep speed and traffic condition.
Blocking Rate Performance

- Reference – 400G over current network using inverse multiplexing (4x100G)
- 400G Super-channel with adaptive modulation – 85% higher load
- Spectrum defragmentation improves network capacity by additional ~15%
Offered load = 100 Erlangs

- Achieved close-to-ideal blocking performance for 1000 s mean holding time with 100 ms/2.5 GHz sweep speed (in our experiment)
Summary

- Presented a flexible optical node architecture employing software-defined modulation-flexible shared universal transceivers to enable beyond 100G transport and in-service resource optimization in flexible grid optical networks.

- Spectrum defragmentation with realistic wavelength sweep speed of 1 s/2.5 GHz step yields up to 15% higher load than the case without defragmentation for connections with holding times on the order of hours.

- The hitless spectrum defragmentation technique can be implemented in an existing NMS, or be incorporated in a future Software-Defined Optical Network (SDON) paradigm.

- Pave the way to the deployment of practical and efficient flexible grid optical networks.
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