Same as the slides used at the PI meeting 2019@Chicago

Resilience in Next-Generation Intelligent Optical Networks

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Hiroshi Hasegawa, Nagoya University
Masahiko Jinno, Kagawa University

1st Annual PI Meeting, Tokyo
October 26, 2018

Outline

- ✓ Ge Same as the slides used at the PI meeting 2019@Chicago

- ✓ Proposed Research
  - Survivable and Scalable OXC Node Architecture (Nagoya Univ.)
  - Highly Survivable Protection Schemes for Trustworthy Optical Networks (Kagawa Univ.)
  - Trustworthy Connection Resource Management (George Washington Univ.)

- ✓ Collaboration Plan & Time Table

Same as the slides used at the PI meeting 2019@Chicago

General Background & Project Goals

Background

Extreme Same as the slides used at the PI meeting 2019@Chicago

Cisco VNI (Visual Network Index)

- 127 times/16 years (2006-2021)
- 3.2 times (average), 4.6 times (peak) / 5 years (2016-2021)

Broadband connection speed: x2 faster (2016-2021)
Emerging applications: 5G, UHDTV(up to 144Gbps)
Cloud based services

ICT based society

In Japan

- +29.7% /year (2017-2018)

Optical networks

- Only optical networks can carry the huge traffic. (10+Tbps/fiber, 1000fibers/cable)
- Offloading from wireless to fiber (ex. 5G, Radio over Fiber (RoF))
- Optical channel capacity: 10Gbps, 40Gbps, 100Gbps ⇨ 200Gbps, 400Gbps, 1Tbps…
- "Channel capacity enhancement < Traffic growth" : More fibers on each link

⇨ Large scale optical nodes with many components

Almost constant revenue

Scalability & CAPEX

Failures

- Disasters: earthquakes, typhoons, tsunami…
- Random failures: # of failures will increase as components in a network will be more.
- Connection disruption has huge impact on our ICT based society.

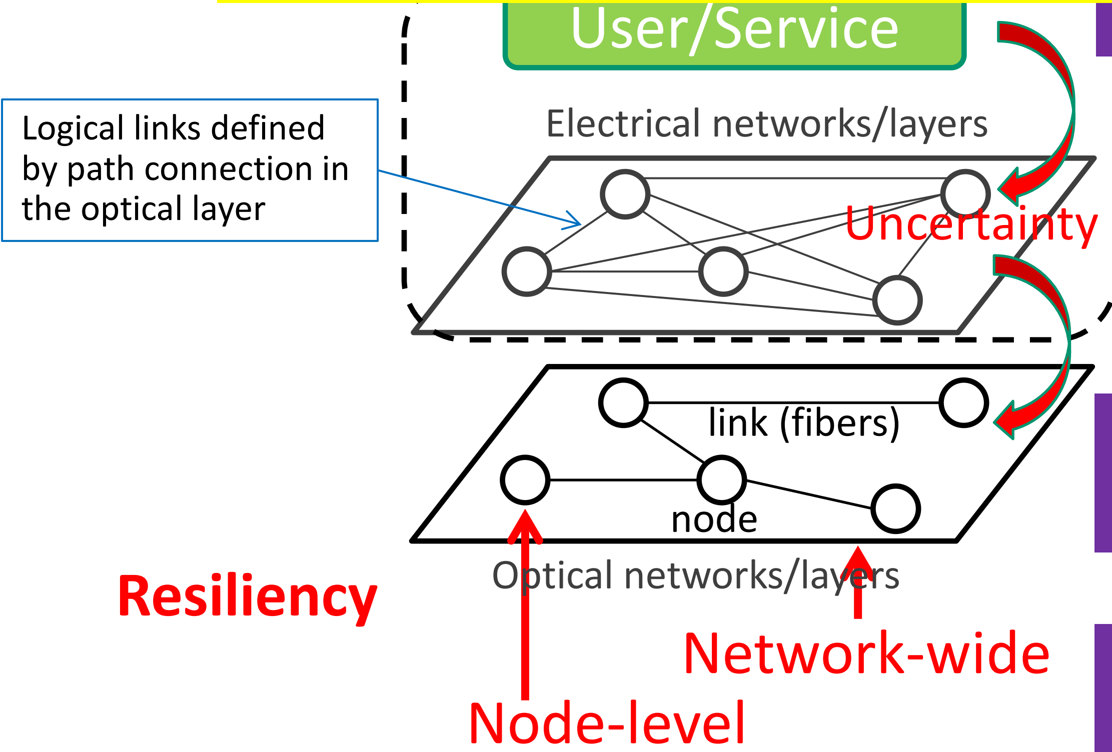
Resiliency / Trustworthyness

Tools

- Recent advancement of machine learning.
- Specialized software and hardware (ex. Google's TPU).

Trustworthy & "profitable" optical networks

Same as the slides used at the PI meeting 2019@Chicago



Resource allocation

- Traffic/connection demand
- Service Level Agreement
- **Revenue**

Redundancy in networks
Advanced transmission

Cost-effective, scalable, & parallel hardware

Essentially difficult and complex problem

- Optical network design problem is **NP complete** even if we omit the resiliency requirement.
- Trade-offs between CAPEX reduction and resiliency level.
- Revenue is defined in the upper layer and CAPEX (i.e. cost) in the lower layer.

Project Goals

1. De Same as the slides used at the PI meeting 2019@Chicago es.

2. Hybrid protection/restoration frameworks for the robustness against multiple node/link failures.

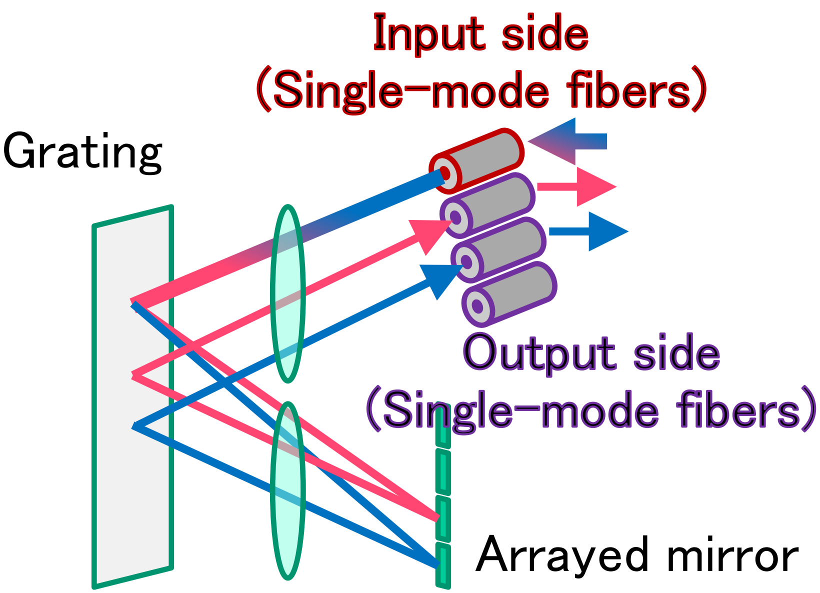
3. Fine-grained connection-level availability (as opposed to network-level survivability) management.

Survivable and Scalable OXC Node Architecture

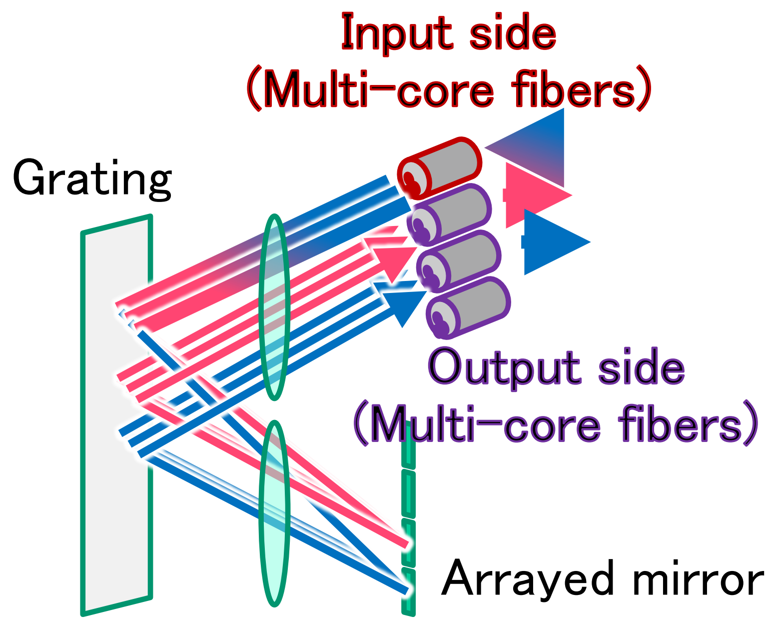
Hiroshi Hasegawa (Nagoya University)

Spatially-jointed switching @ WSSs

MEMS-based WSS

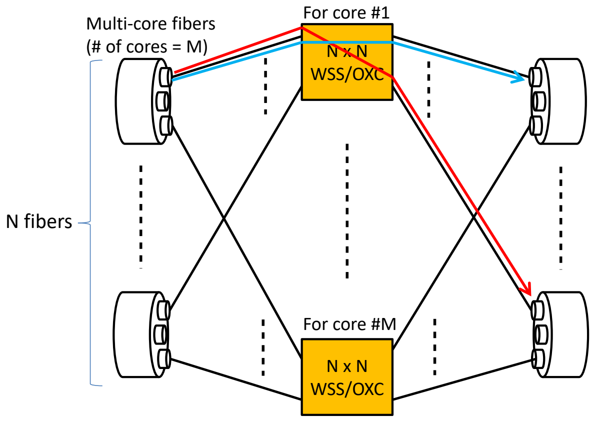


Spatially-jointed switching mode

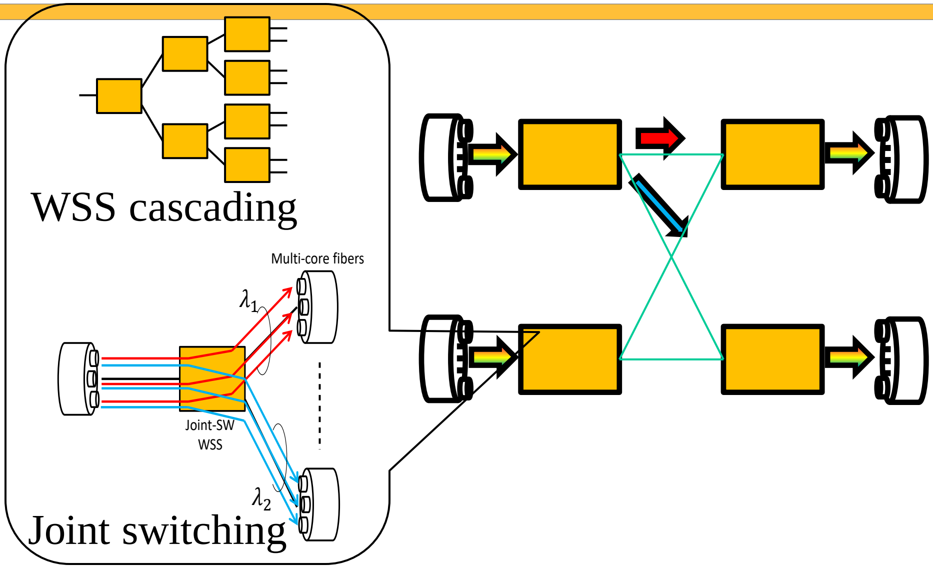


- A WSS can be shared by # of cores.
- The WSS degree will be small. For example, a 1x20 WSS can be used as a 7-core 1x2 joint switching WSS.
- The WSS cascading will be inevitable which substantially increases the number of WSSs.

Conventional SDM node architectures



Core-wise switching node
[F. Moreno-Muro et.al. JOCN2017]



Spatially-jointed switching node

- # of WSSs/core ≥ 1
- Very good routing performance. Comparable to impractical WSS-based node with the full mesh inter-connection.

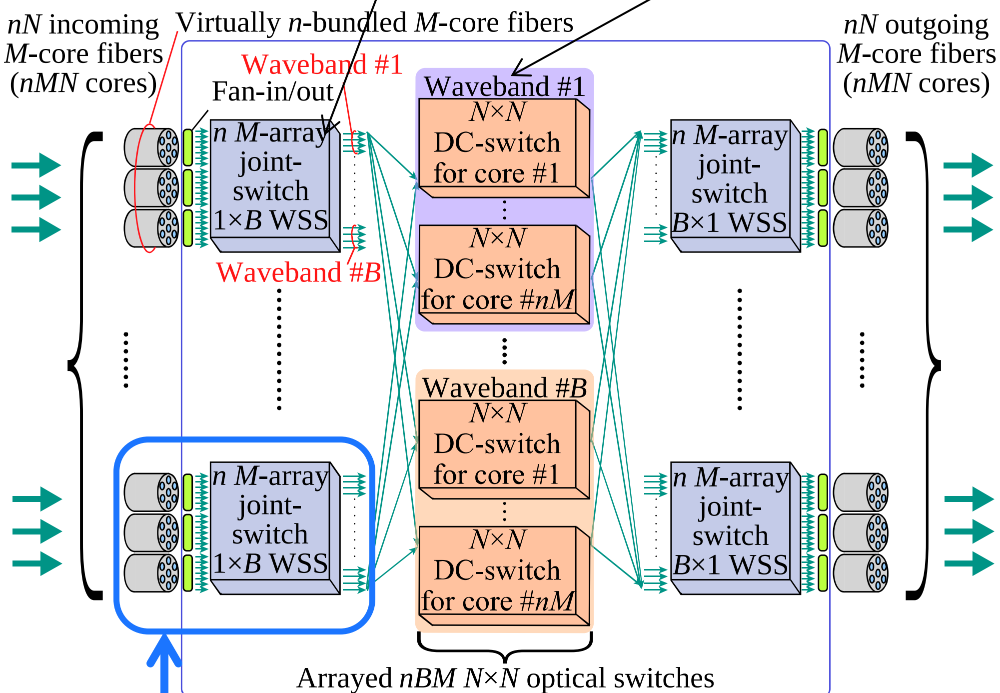
- # of WSSs/core ≥ 1/# of cores/MCF
- Suffered from insufficient WSS degree. The number of WSSs will steeply increase by the WSS cascading.
- Relatively poor routing performance

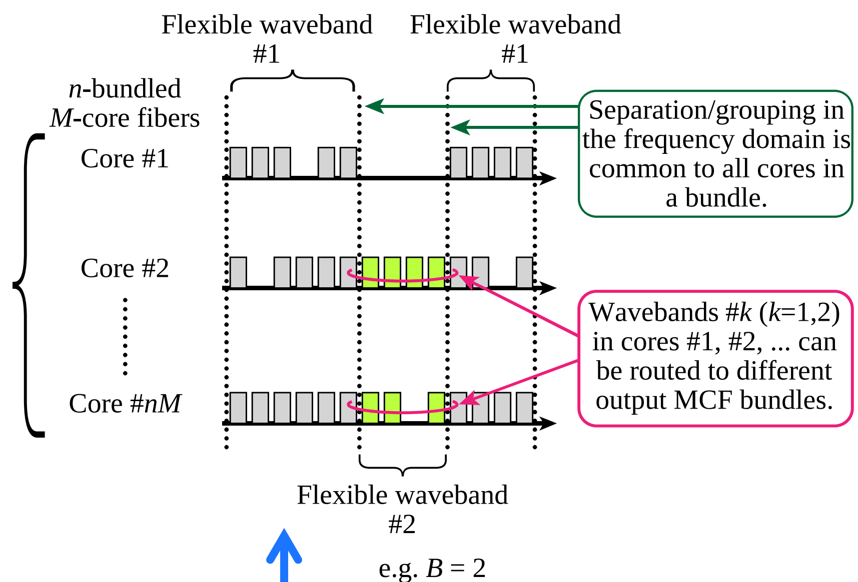
There was no proposal that achieves "# of WSSs/core = 1/# of cores/MCF" and comparalbe routing performance to WSS-based node.

Spatially-jointed flexible waveband routing node architecture

Path grouping and routing are separated and implemented with different devices.

Flexible waveband routing at JUNO1





Spatially-jointed switching at WSSs

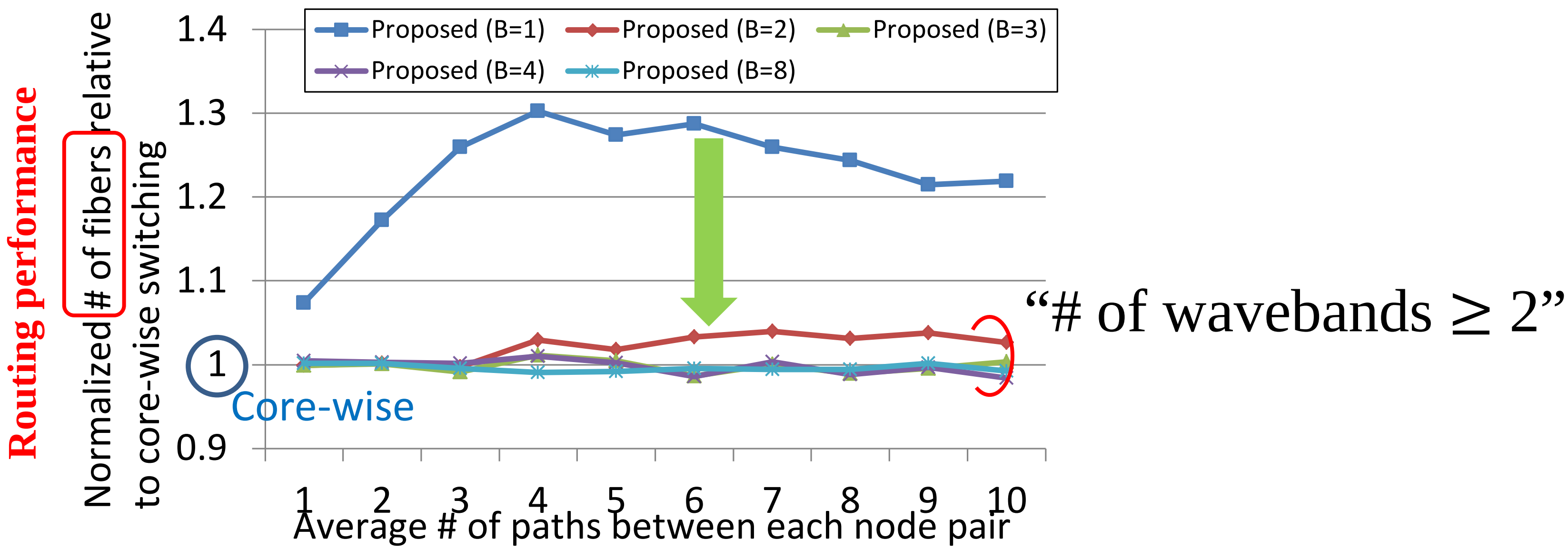
- Cost-effectiveness: "# of WSSs << # of cores"
- Scalability: Increasing the number of arrayed WSSs.
- Reliability: Minimized WSS numbers.

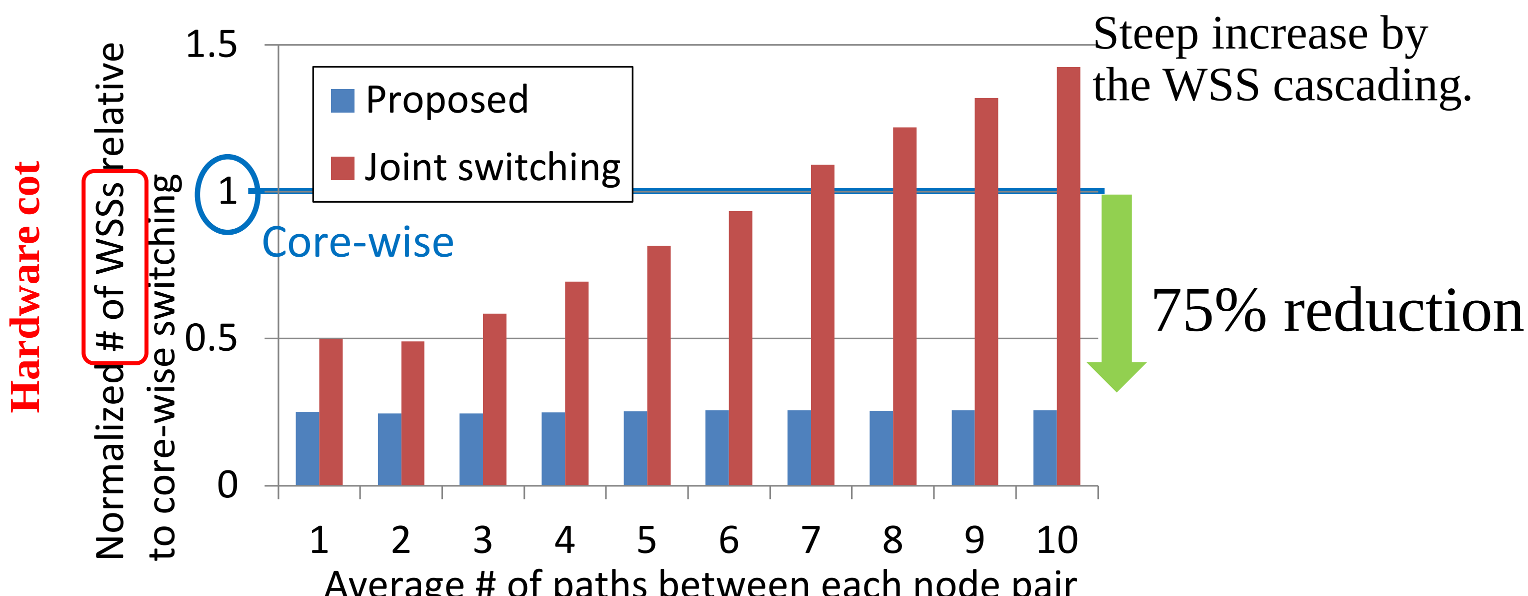
Spatially-jointed flexible wavebanding

- Wavebanding: Common to all cores.
- Routing wavebands: independent.
- # of wavebands in a core: small

This property enables the use of spatially-joint switching mode.

Results @ 5x5 mesh with 4-core MCFs



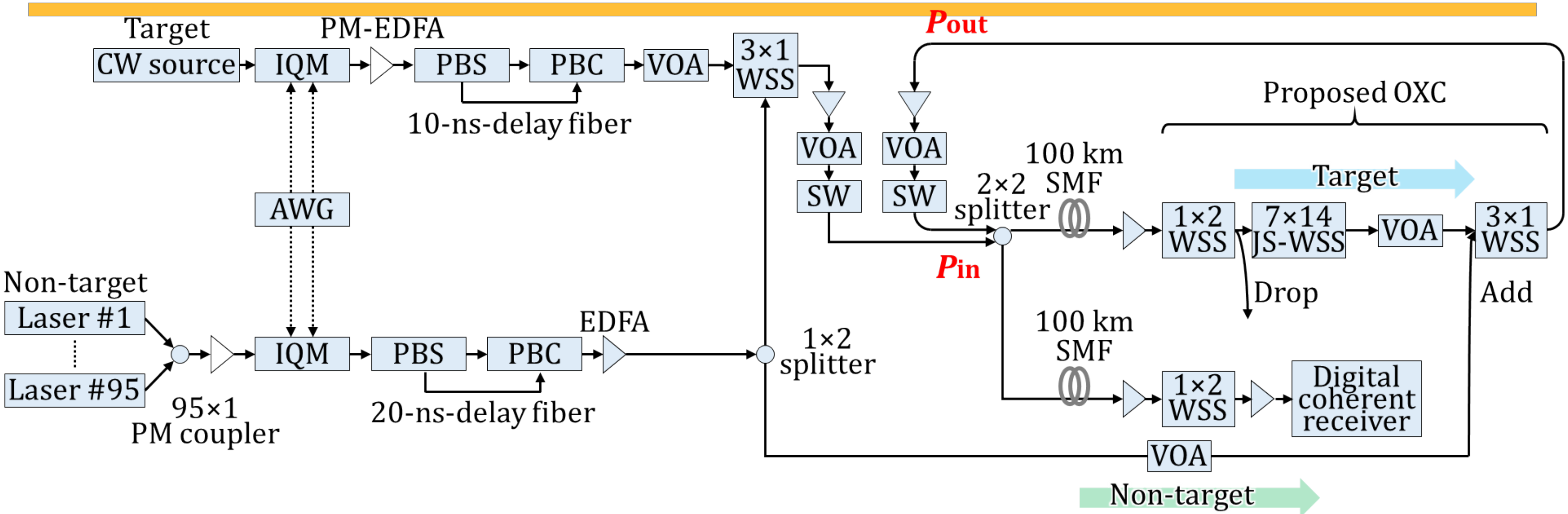


THE GEORGE WASHINGTON UNIVERSITY WASHINGTON, DC

NAGOYA UNIVERSITY

KAGAWA UNIVERSITY

Transmission experiments



IQM	IQ modulator	WSS	Wavelength selective switch
AWG	Arbitrary waveform generator	SW	Switch
PM-EDFA	Polarization maintain erbium-doped fiber amplifier	EDFA	Erbium-doped fiber amplifier
PBS	Polarization beam splitter	SMF	Single mode fiber
PBC	Polarization beam coupler	JS-WSS	Joint-switch wavelength selective switch
VOA	Variable optical attenuator		

400Gbps × 64 × 84 = **2.15Pbps**

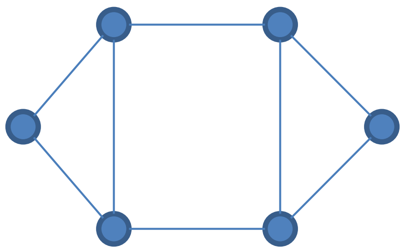
64: # of paths/fiber

84: # of ports of the cross-connect

Best student paper award@ONDM2020, Best paper award@ICP2020

Machine-Learning based Network Control

How to parametrize the state of an optical network?



“# of fibers” x “# of slots”=1024

- 6 nodes/ 16 unidirectional links
- # of frequency slots: 64, # of fibers/link: 1

# of frequency slots = 352 (C-band), # of fibers on each link = 1

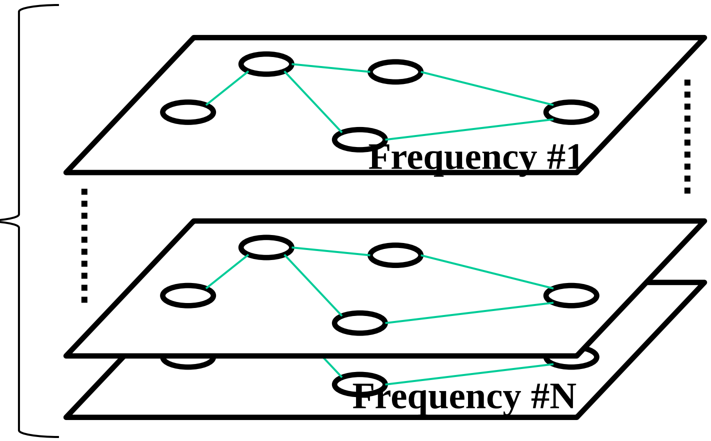
Topologies	# of nodes	# of links	Size of state vector
5x5 regular mesh	25	40	28160
USA (USNET)	24	43	30272
Pan-European (COST239)	19	37	26048
Japan (JPN25)	25	43	30272

The control of typical optical networks would be intractable.

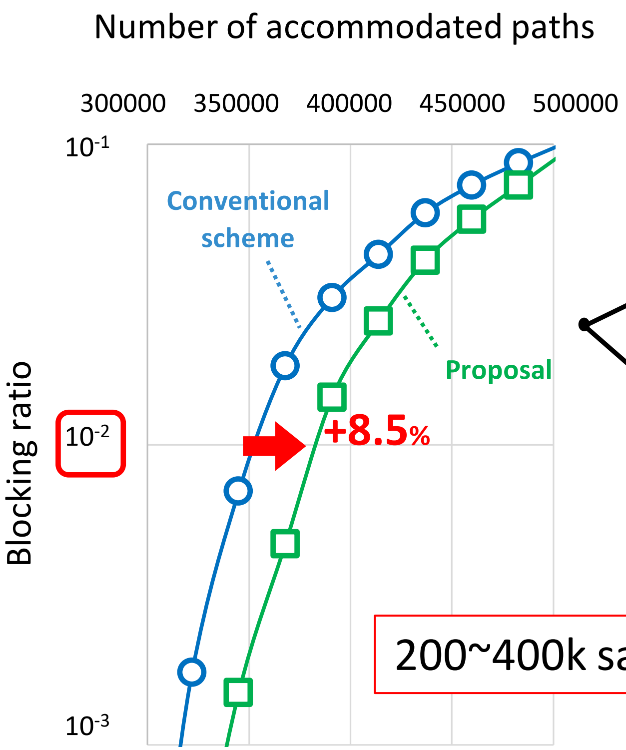
Proposed Control Algorithm @ Fixed grid

Our strategy [R. Shiraki et.al. ICTON2019]
Estimate the “value” of each wavelength layer independently and sum up all values.

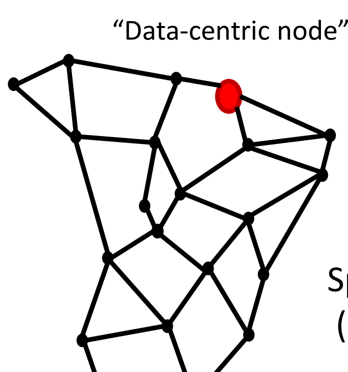
Topologies are identical.



a DWDM network (fixed-grid)



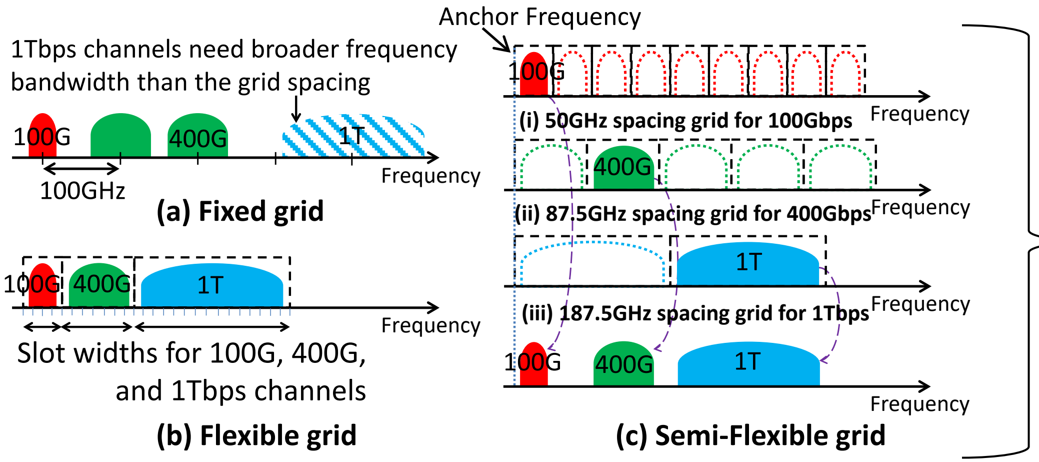
200~400k samples



Spanish Telefónica network
(21 nodes, 70 unidirectional links with multiple fibers)

Best student paper award@ICTON2019

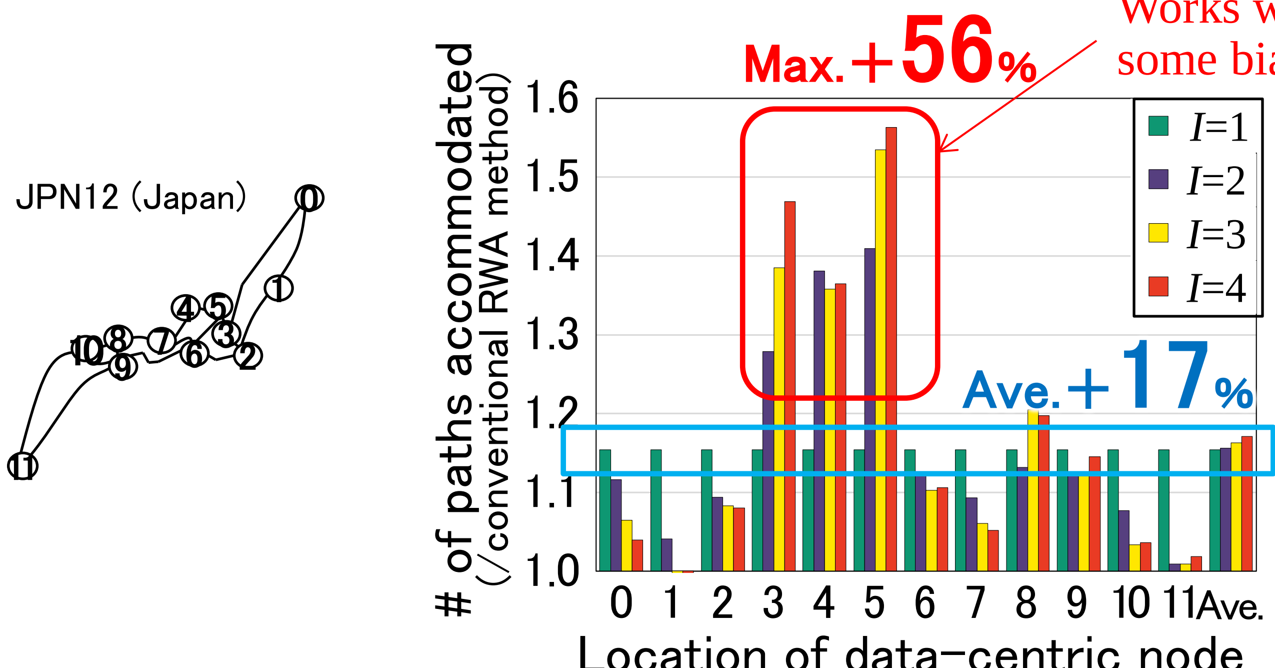
Proposed Control Algorithm @ Flexgrid



[Z.Shen et.al. ECOC2013]

- The "value" at each grid position is estimated in the same way and then combined.
- The use of semi-flexible grid automatically mitigates the frequency slot fragments.

[R. Shiraki et.al. OFC2020]



Works well especially for some biased traffic.

Traffic enhancement factor for the selected node

Substantial improvement for the uniform traffic.