Dynamic Routing and Resource Allocation in a Elastic Optical Network Using Learning Algorithms

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Motivation

- Advent of cloud computing era : bandwidth intensive and dynamic new applications and services
- Transformation from rigid and homogeneous to flexible and heterogeneous network is needed
- Metro/Core optical Networks are requiring 100 Gb/s and beyond line rate
- Elastic optical Network increases flexibility and adaptability in terms of dynamic traffic demand
- A simple, scalable and robust routing and spectrum allocation technique is required to handle massive traffic
- Most research works provide either mathematical or heuristic solutions for RSA which is non-scalable and non-optimum or complex respectively.
- We are proposing prediction model which can learn and make prediction on data without explicitly being programmed to solve RSA problem in a EON.

Novelties of Elastic Optical Network

- Rate adaptive Super-channels
- Multicarrier Higher Order Modulation
- Flexible Center Frequency spacing
- Distance Adaptive Modulation
- Flexible Spectrum Granularity

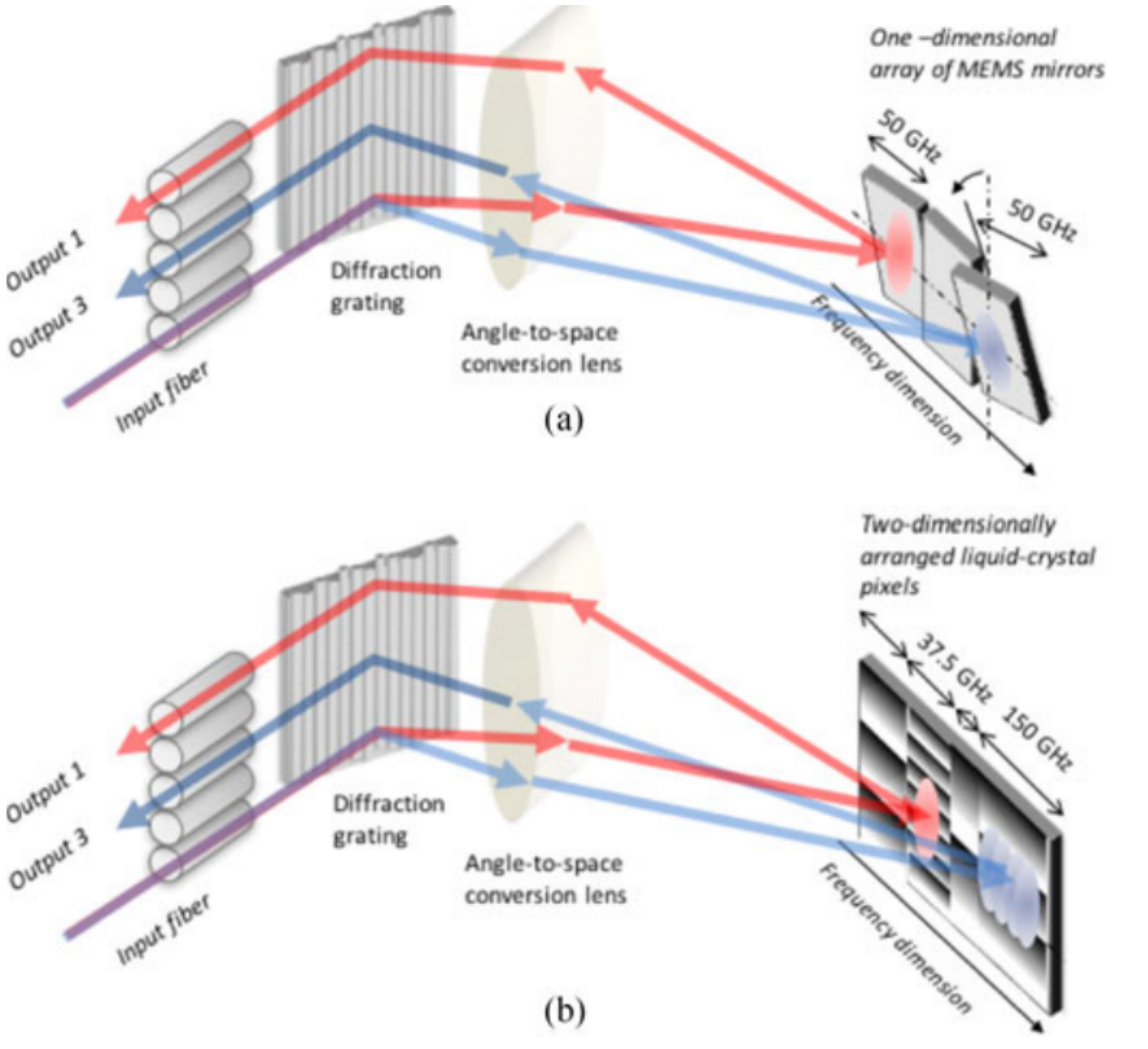
Enabling Technology for Elastic Optical Network

Bandwidth Variable Transponder: 3 types of software defined superchannel transponder design

1. Multi-rate multi reach
2. Multi rate constant reach
3. Constant rate multi reach

Super Channel : Using the superchannel technology, line rates beyond 100 Gb/s are feasible without any electrical bandwidth bottleneck. The line rate can be easily adjusted to traffic demands by simply varying the number of sub-channels or the bit per symbol for each sub-channel.

Wavelength Selective Switch : Since superchannels in EONs occupy various spectrum widths, ROADM switching bandwidths should be adjustable to their spectrum width to achieve spectrally efficient routing and grooming. This can be done with bandwidth variable WSSs based on a LCoS spatial light modulator



ïg. 3. Generic view of how the WSS works. (a) MEMS based WSS with a ixed passband width. (b) LCoS based WSS with variable passband widths.

[1] Jinno, Masahiko. "Elastic Optical Networking: Roles and Benefits in Beyond 100-Gb/s Era." *Journal of Lightwave Technology* 35, no. 5 (2017): 1116-1124

Fragmentation

- For example, a released 400 Gb/s 16-quadrature amplitude modulation (QAM) connection typically leaves seven empty slots of 12.5 GHz. If four of these slots are re-occupied by a 100 Gb/s DP-QPSK signal, it results in three fragmented slots.
- The fragmentation problem is addressed by either trying to alleviate fragmentation or, more effectively, performing a defragmentation process. The alleviation of fragmentation is generally based on enhanced RMLSAs, which define the optimum spectral position of new requests taking into account.
- the defragmentation process improves the spectrum utilization by taking active measures on the established traffic (e.g., rerouting and/or reallocating of spectrum resources), with the goal of reducing the unusable spectrum gaps. There are two options to perform defragmentation: • Reroute optical paths with or without spectrum slot reassignment. • Reassign spectrum slots maintaining the same optical path routing

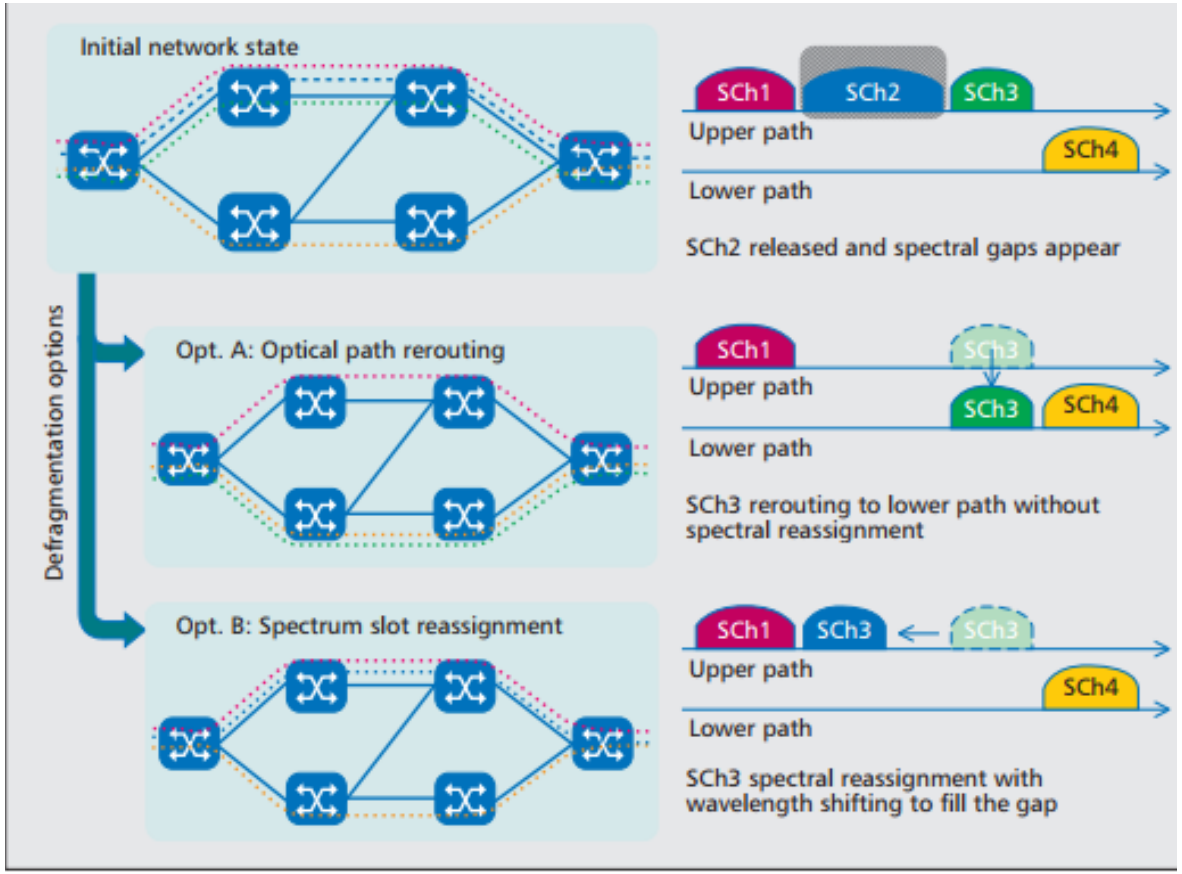


Figure 4. Network example describing the two defragmentation options of optical path rerouting and spectrum slot reassignment when one SCh (SCh2-dashed line) is released.

[2] Klonidis, Dimitrios, Filippo Cugini, Ori Gerstel, Masahiko Jinno, Victor Lopez, Eleni Palkopoulou, Motoyoshi Sekiya, Domenico Siracusa, Gilles Thouénon, and Christophe Betoule. "Spectrally and spatially flexible optical network planning and operations." *IEEE Communications Magazine*53, no. 2 (2015): 69-78.

Distance Adaptive Transmission

- In [1] authors showed that, one more bit can be assigned to the symbol of each sub channel at the expense of roughly a 50 % reduction in optical reach

{ Higher modulation format
Higher Spectral Efficiency
Higher Data rate } = { Lower Slice width
Lower Optical Reach/Distance }

Observation :
1. By using higher order modulation such as 8-QAM, 16-QAM or 64-QAM bit rate can be increased from 100 GB/s to 200 and 400 GB/s for shorter optical path.
2. Required slot width for 400 Gb/s can be decreased from 150 GHz to 50 GHz.

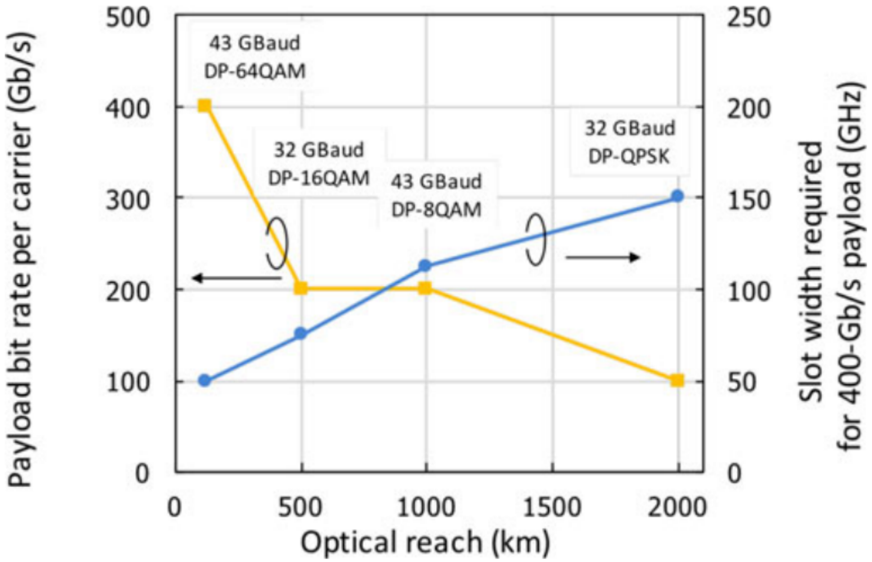


Fig. 7. Payload bit rate per carrier and slot width reduction for 400-Gb/s payload as a function of required optical reach.

[1] Jinno, Masahiko. "Elastic Optical Networking: Roles and Benefits in Beyond 100-Gb/s Era." *Journal of Lightwave Technology* 35, no. 5 (2017): 1116-1124.

Routing and Spectrum Allocation (RSA)

- Spectrum Contiguity constraint : Finding Contiguous frequency slot along the optical route
- Dynamic online process of resource allocation
- Minimize required spectral resource
- Minimize CAPEX & OPEX
- Maximization of energy efficiency

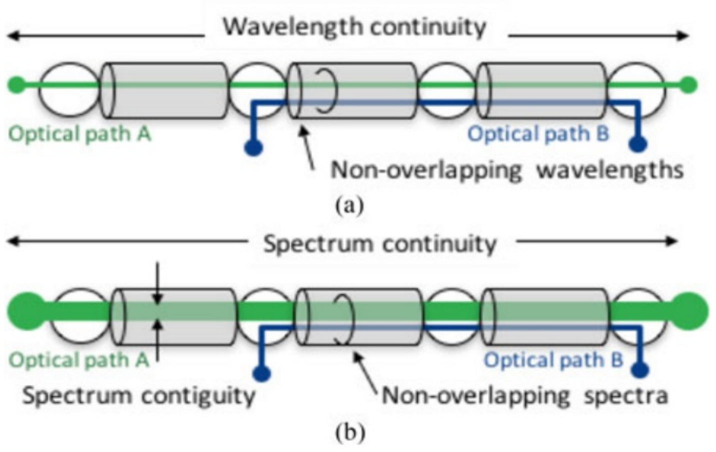
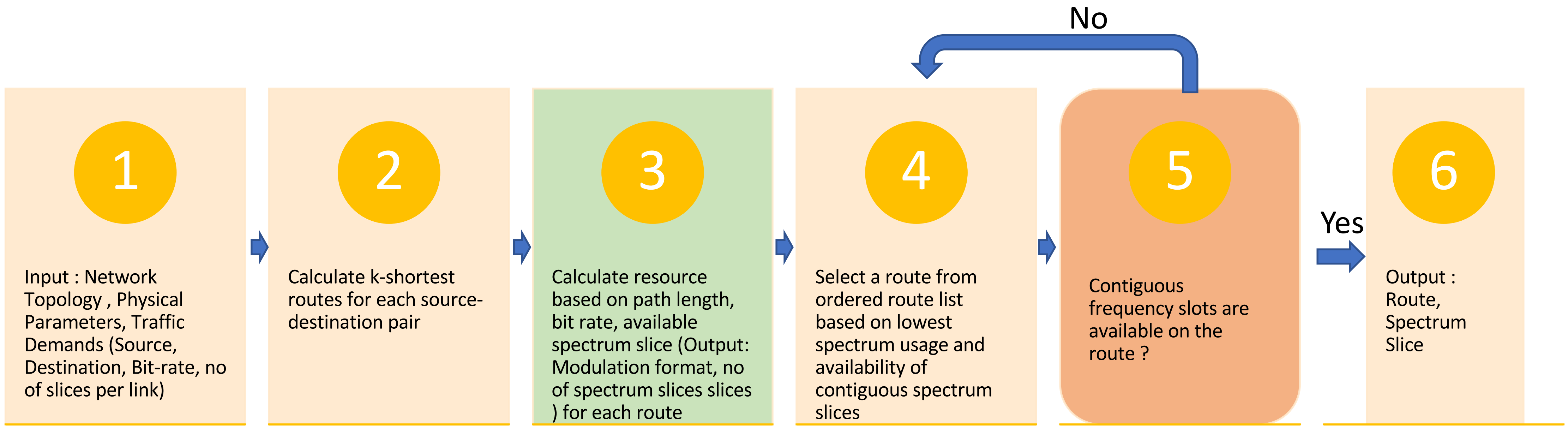


Fig. 4. Constraints that must be considered when calculating routes and wavelengths/spectra to accommodate optical paths. (a) Conventional WDM network. (b) Elastic optical network.

[1] Jinno, Masahiko. "Elastic Optical Networking: Roles and Benefits in Beyond 100-Gb/s Era." *Journal of Lightwave Technology* 35, no. 5 (2017): 1116-1124.

Routing and Spectrum Allocation (RSA)



Distance Adaptive Transmission

Table 1. Modulation format, number of required slices and transceivers (in brackets) as a function of path length for bit-rate 400 Gb/s.

Path length	Transmission reach of BPSK				
	2000 km	4000 km	6000 km	8000 km	10000 km
500 km	MF: 8-QAM Slices: 10 Transceivers: 3	MF: 16-QAM Slices: 7 Transceivers: 2	MF: 16-QAM Slices: 7 Transceivers: 2	MF: 32-QAM Slices: 7 Transceivers: 2	MF: 32-QAM Slices: 7 Transceivers: 2
1000 km	MF: QPSK Slices: 13 Transceivers: 4	MF: 8-QAM Slices: 10 Transceivers: 3	MF: 8-QAM Slices: 10 Transceivers: 3	MF: 16-QAM Slices: 7 Transceivers: 2	MF: 16-QAM Slices: 7 Transceivers: 2
2000 km	MF: BPSK Slices: 25 Transceivers: 8	MF: QPSK Slices: 13 Transceivers: 4	MF: QPSK Slices: 13 Transceivers: 4	MF: 8-QAM Slices: 10 Transceivers: 3	MF: 8-QAM Slices: 10 Transceivers: 3

Table 1 shows the selection of a MF and, in consequence, the number of required spectrum slices and transceivers for a demand with bit-rate 400 Gb/s and various values of the path length (transmission distance).

- Let EON supports 6 Modulation Formats : BPSK,QPSK,8-QAM, 16-QAM, 32-QAM, 64-QAM
- **Half Distance Rule :** the transmission reach of MF(m+1) is calculated as a half of the reach of MF m. Where represents particular MF.
- Usually smaller geographical networks gain more benefit from employing higher order modulation formats

[3] Walkowiak, Krzysztof, Mirosław Klinkowski, and Piotr Lechowicz. "Influence of modulation format transmission reach on performance of elastic optical networks." In *Transparent Optical Networks (ICTON), 2017 19th International Conference on*, pp. 1-4. IEEE, 2017.

Routing and Spectrum Allocation (RSA)

3

Calculate resource based on path length, bit rate, available spectrum slice (Output: Modulation format, no of spectrum slices slices) for each route

1. Machine Learning Classifier Feature Selection :

- Path length(Optical Reach) between source and destination, D
- Bit rate of the traffic demand, B
- Available spectrum through all the links of the route, F
- Transmission reach of BPSK
- Source
- Destination

2. For a particular set of these features a specific Modulation format and corresponding spectrum slices is selected.

3. Use a training dataset with all possible instances to train the ML classifier such as Random Forest, Random Tree.. Etc.

Routing and Spectrum Allocation (RSA)

Example of training data set :

- Source, Destination, Path length, Bit Rate, Available Spectrum, transmission reach of BPSK, Modulation Format, Slices
- 1,7,500 Km, 400 Gb/s, 500 GHz, 2000 km, 8-QAM , 10
- 1,7,1000 Km, 400 GB/s, 500 GHz, 2000 km, QPSK, 13

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Next Steps..

- Data Generation (Training + Test data)
- Simulation for different network topology US 26 (avg link length 754 km), DT 14 (avg link length 182 km)
- Including fragmentation aware RSA