Dynamic Routing and Spectrum Assignment in Co-Existing Fixed/Flex-Grid Optical Networks

Tanjila Ahmed

Agenda

- ➢Dynamic Routing and Spectrum Allocation in Mixed-grid network
- ➢Extension Ideas :

1. **Distance Adaptive Modulation Format**
2. Mixed Grid ROADM Architecture
3. Reduction of Fragmentation
4. Addition of Regenerators

Motivation

- Continuing attempts to squeeze more out of a single optical fiber, with technology advances

2.5 Gb/s → 10 Gb/s → 40 Gb/s → 100 Gb/s

- Find route, spectrum, bit rate, modulation format and FEC for a given demand, optimized in some way to meet key criteria, such as minimal blocking, minimum cost, reduced fragmentation and many other possible criteria.

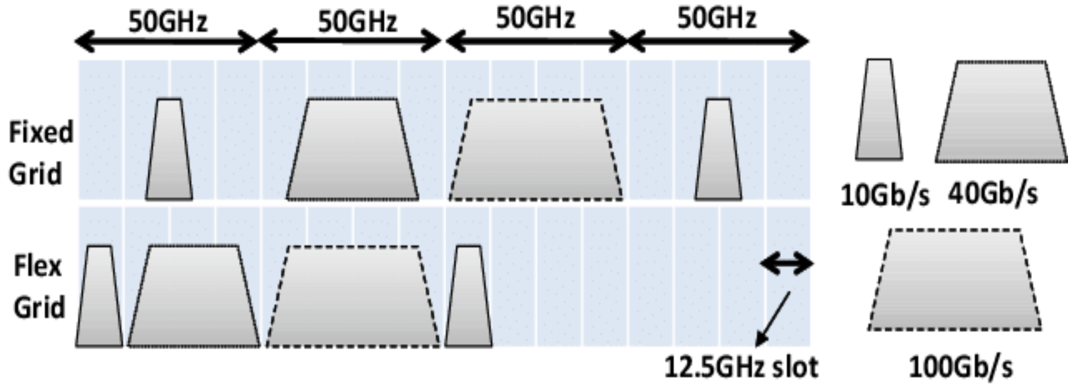


Image courtesy: [1]

Mixed Grid Topology

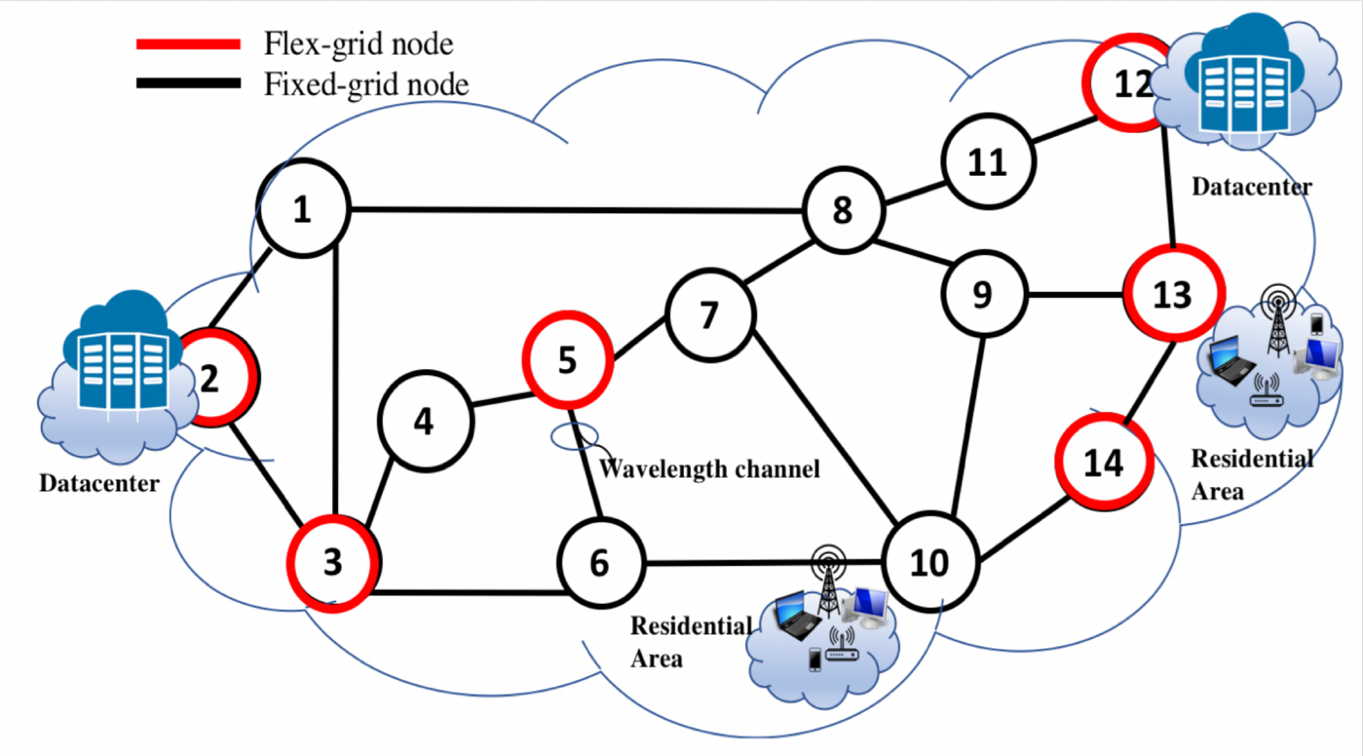


Fig.1 Co-existing fixed/flex-grid in NSFNet topology.

Table II: Traffic profiles.

Traffic Demand (Gb/s)	Profile 1	Profile 2	Profile 3
40	50%	20%	0%
100	30%	50%	40%
200	15%	20%	40%
400	5%	10%	20%

Spectrum Allocation in Mixed-grid Network

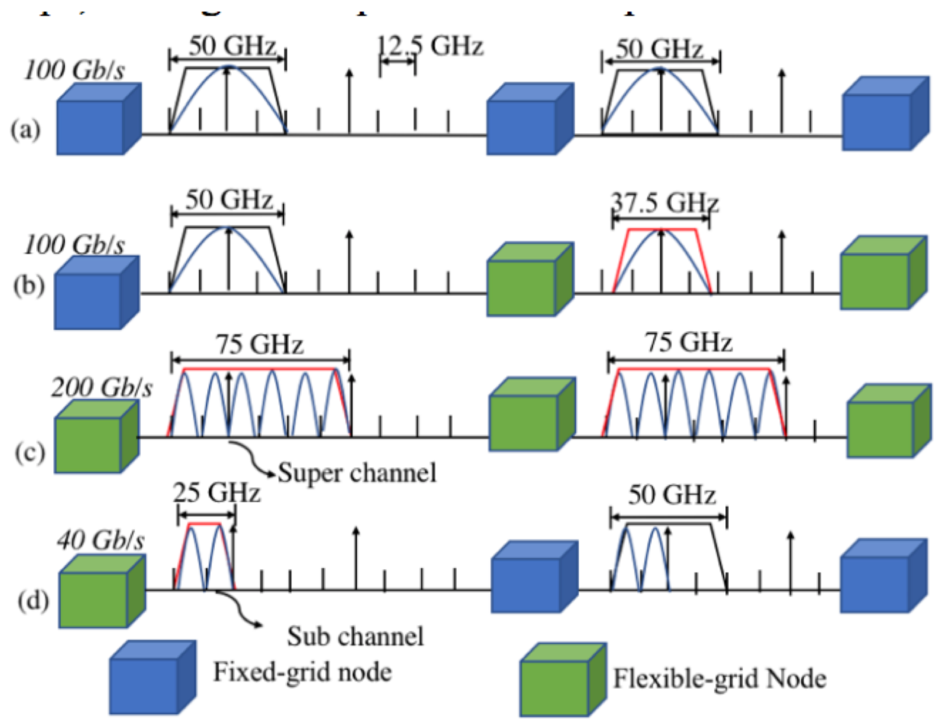


Fig. 2 Spectrum assignment in different mixed-grid scenarios.

Table I: Spectrum occupation for various bit rates.

Traffic Demand (Gb/s)	Fixed-Grid		Flex-Grid	
	Bandwidth (GHz)	#slots	Bandwidth gap (GHz)	#slots
40	50	1	25	2
100	50	1	37.5	3
200	100	2	75	6
400	200	4	125	10

Results in Terms of BBR

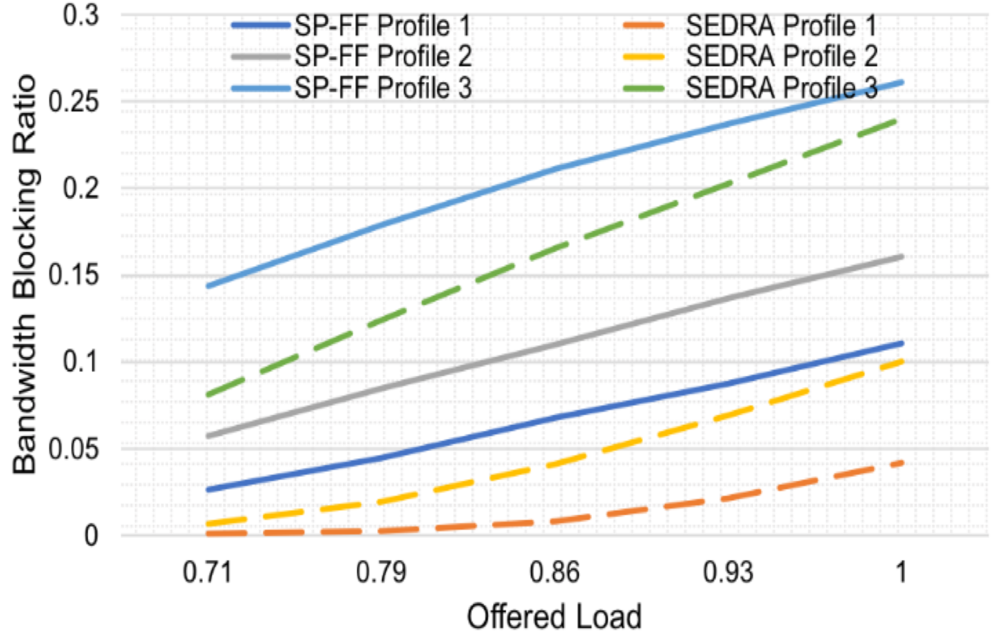


Fig. 3 Bandwidth blocking ratio vs. offered load for Uniform distribution.

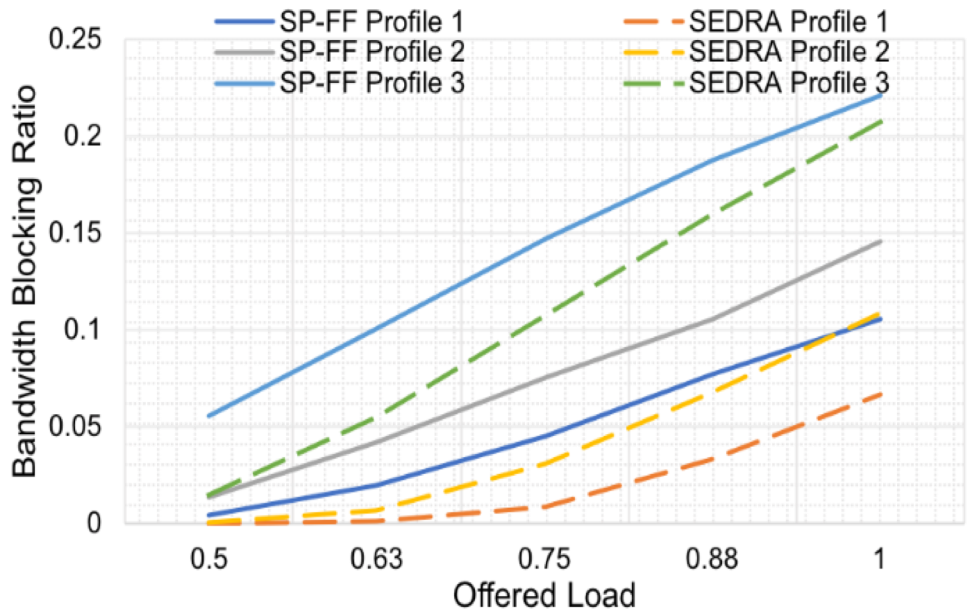


Fig. 4 Bandwidth blocking ratio vs. offered load for Poisson distribution.

Elastic Optical Network

Rate adaptive Super-channels

Multicarrier Higher Order Modulation

Flexible Center Frequency spacing

Flexible Spectrum Granularity

Distance Adaptive Modulation Format [2]

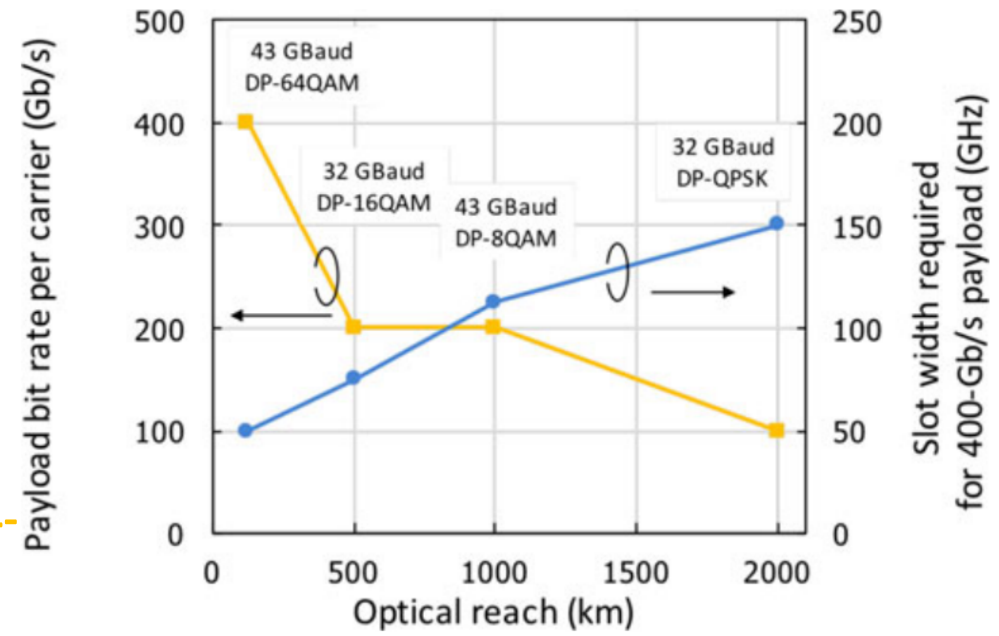
1 extra bit can be assigned to the symbol of each sub channel at the expense of roughly a 50 % reduction in optical reach

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

Observation :

1. Higher order modulation such as 8-QAM, 16-QAM or 64-QAM bit rate can be increased from 100 Gbps to 200 and 400 Gbps for shorter optical path.

2. Required slot width for 400 Gbps can be decreased from 150 GHz to 50 GHz.



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

Modulation Format Comparison [3]

Baud Rate Is maintained at around 28–32 Gbaud

TABLE I
MODULATION FORMAT COMPARISON

Modulation Format	Total Data Rate	Indicative OSNR*
DP-BPSK	50 Gb/s	9 dB
DP-QPSK	100 Gb/s	12 dB
DP-8QAM	150 Gb/s	16 dB
DP-16QAM	200 Gb/s	18.6 dB
DP-32QAM	250 Gb/s	21.6 dB
DP-64QAM	300 Gb/s	24.6 dB

*For indication purposes—actual values depend on type of FEC, launch power and other transmission parameters.

High OSNR requirement, implying that long distance transmission is not possible

low OSNR requirement, implying that relatively long distance transmission is possible

An increase in network capacity above the baseline DP-QPSK level will then be possible if a higher QAM than QPSK is within this OSNR limit.

Fixed Grid (DP-QPSK)

- 100 Gb/s bitrate comprises Baud rate of 28–32 Gbaud (which includes 25 Gbaud data plus and 12% overhead dependent on the type of FEC used), two transverse light polarizations and QPSK coherent modulation providing a total of 2 bits per symbol.

- Given that the current DP-QPSK coherent modulation has a spectrum of up to about 32 GHz, the additional 18 GHz within a 50 GHz slot is potentially wasted in the fixed grid environment. Reduction from 50 to 37.5 GHz (in flex-grid) gives an immediate improvement in point to point capacity of 33%.

Benefit of Flex-grid [3]

Following would all be capable of a data throughput of 100 Gb/s (after allowing for a 12% FEC overhead):

1) DP-QPSK at 28 Gbaud.
2) DP-8QAM at 18.6 Gbaud.
3) DP-16QAM at 14 Gbaud.
4) DP-32QAM at 11.2 Gbaud.
5) DP-64QAM at 9.4 Gbaud.

Lower Baud rate occupies lower spectrum which is achievable in flex-grid only.

The advantage of this is that the input bitrate is fixed to 100 Gb/s.

Network Capacity Increase [3]

Elastic modulation is highly network size dependent.

TABLE III
NETWORK CAPACITY BENEFITS FOR ELASTIC TRANSCEIVERS AND FLEXGRID ON DIFFERENT SIZE NETWORKS

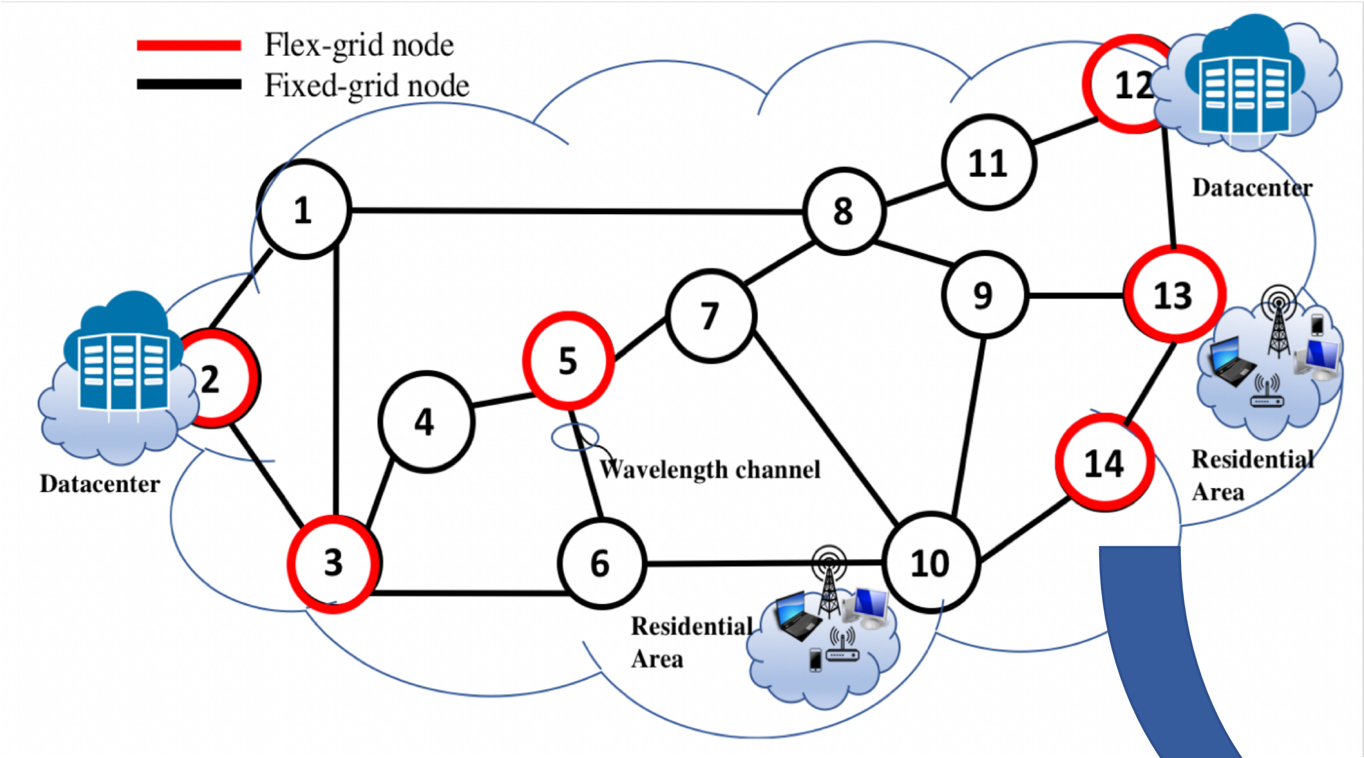
	% increase for elastic transceivers	% increase for 12.5 GHz flexgrid	% overall increase for elastic transceivers on flexgrid
BT UK	91	38	163
PAN EUROPE	55	32	106
USA ABILENE	29	37	75

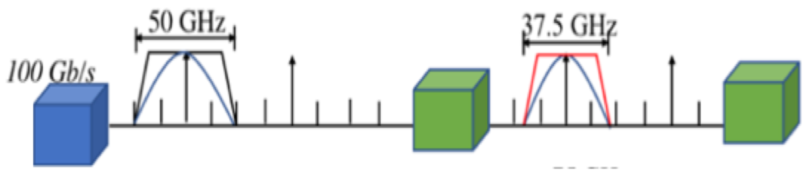
- For the BT UK case 1.91 × 1.38 = 2.64 which is very close to 163%)—showing that these advantages are broadly independent on each other. The modulation format optimization increases the bits per hertz for a given spectral slice and the flexgrid optimization increases the number of spectral slices available.
- These are substantial gains and would provide several years of additional growth for a network.

Optical Reach

Gbps	Reach (km)						
Baud Rate	14 GBaud			28 Gbaud		45 GBaud	61GBaud
Frequency (GHz)	18.75	25	31.25	37.5	50	50	
40 Gbps							
100 Gbps	1100(16 QAM)	1200(16 QAM)		(DP-QPSK)	1400(8 QAM)		
200 Gbps			495 (16 QAM)	540(16 QAM)	630(16 QAM)		
400 Gbps							

Modulation Format for Mixed-Grid





Reference

1. Imran, Muhammad, Prince M. Anandarajah, Aleksandra Kaszubowska-Anandarajah, Nicola Sambo, and Luca Potí, "A survey of optical carrier generation techniques for terabit capacity elastic optical networks," *IEEE Communications Surveys & Tutorials* 20, no. 1 (2018): 211-263.
2. Jinno, Masahiko et.al, "Elastic Optical Networking: Roles and Benefits in Beyond 100-Gb/s Era," *Journal of Lightwave Technology* 35, no. 5 (2017): 1116-1124.
3. Lord, Andrew, Paul Wright, and Abhijit Mitra. "Core networks in the flexgrid era." *Journal of Lightwave Technology* 33, no. 5 (2015): 1126-1135.