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A spiral approach to solve the routing and spectrum assignment problem in ring topologies for elastic optical networks

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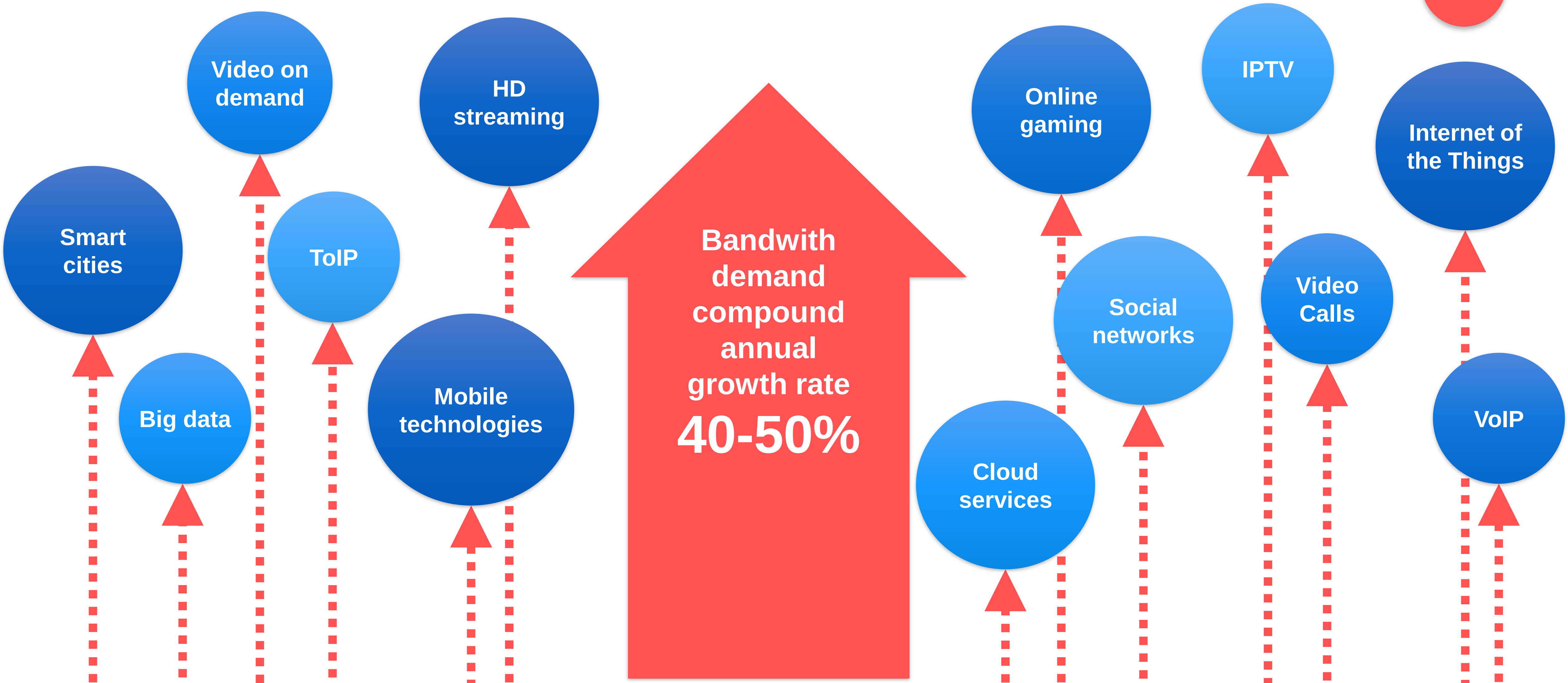
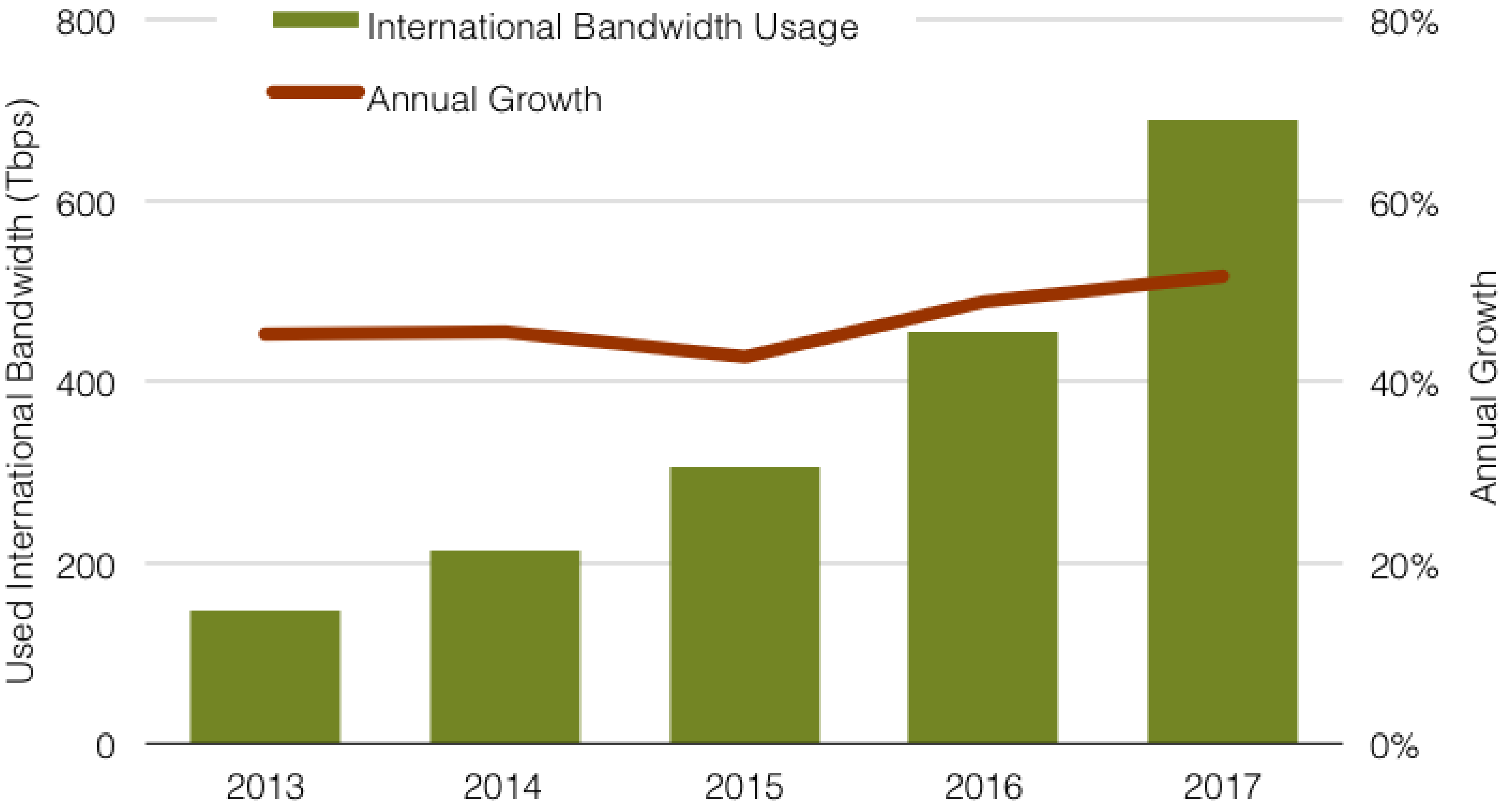
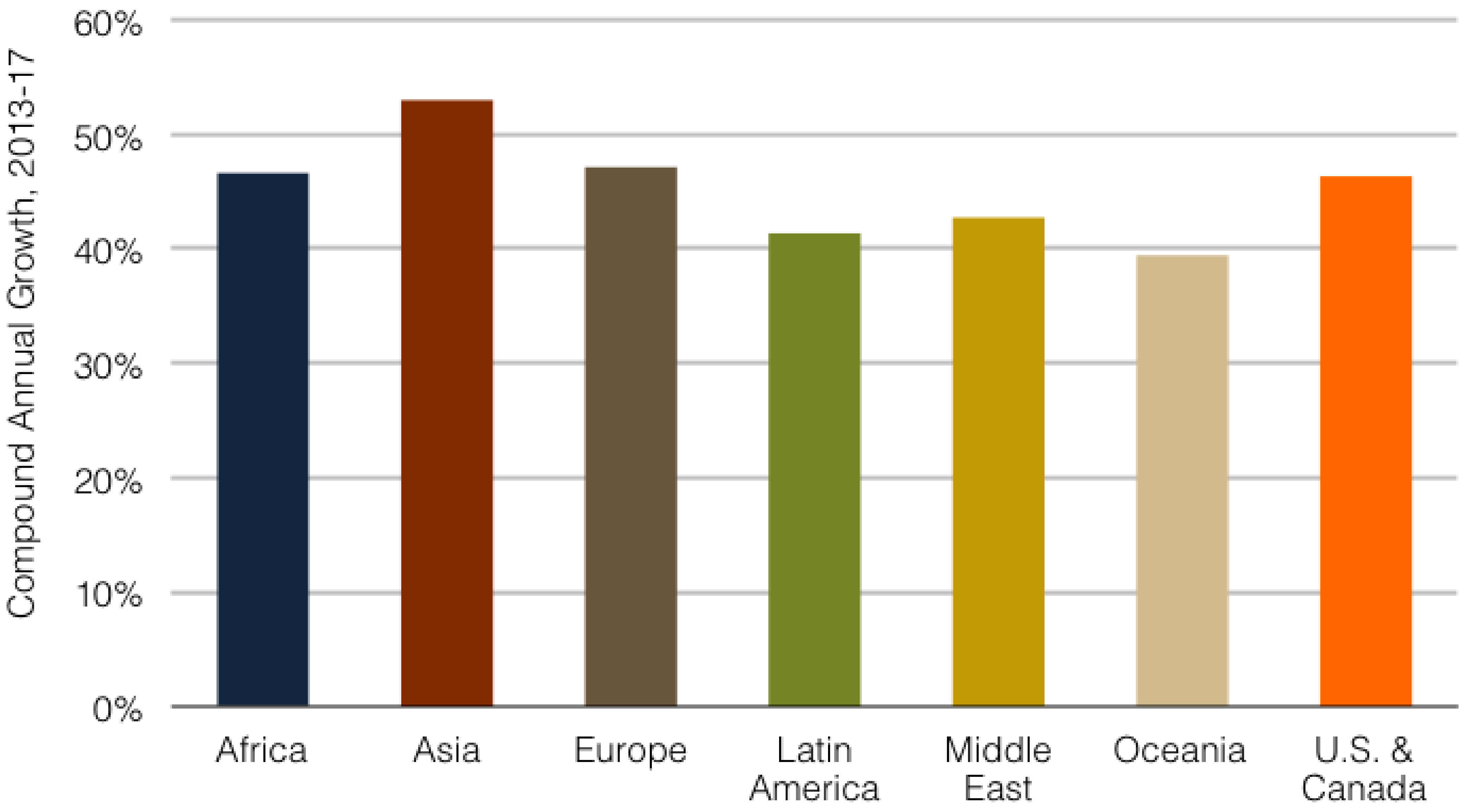
Bandwidth Demand





* https://www.telegeography.com/



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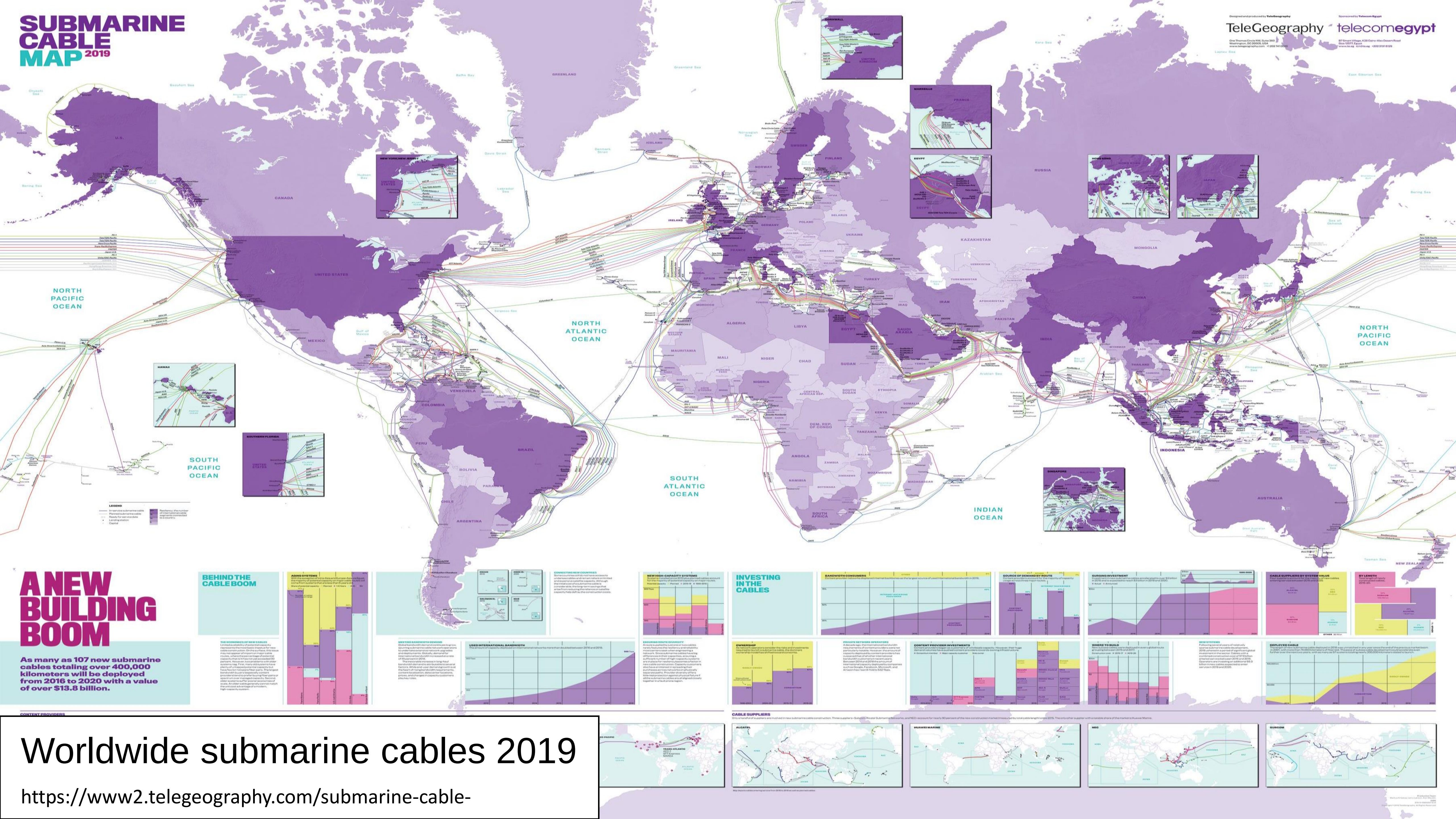

Worldwide submarine cables 2019

https://www2.telegeography.com/submarine-cable-

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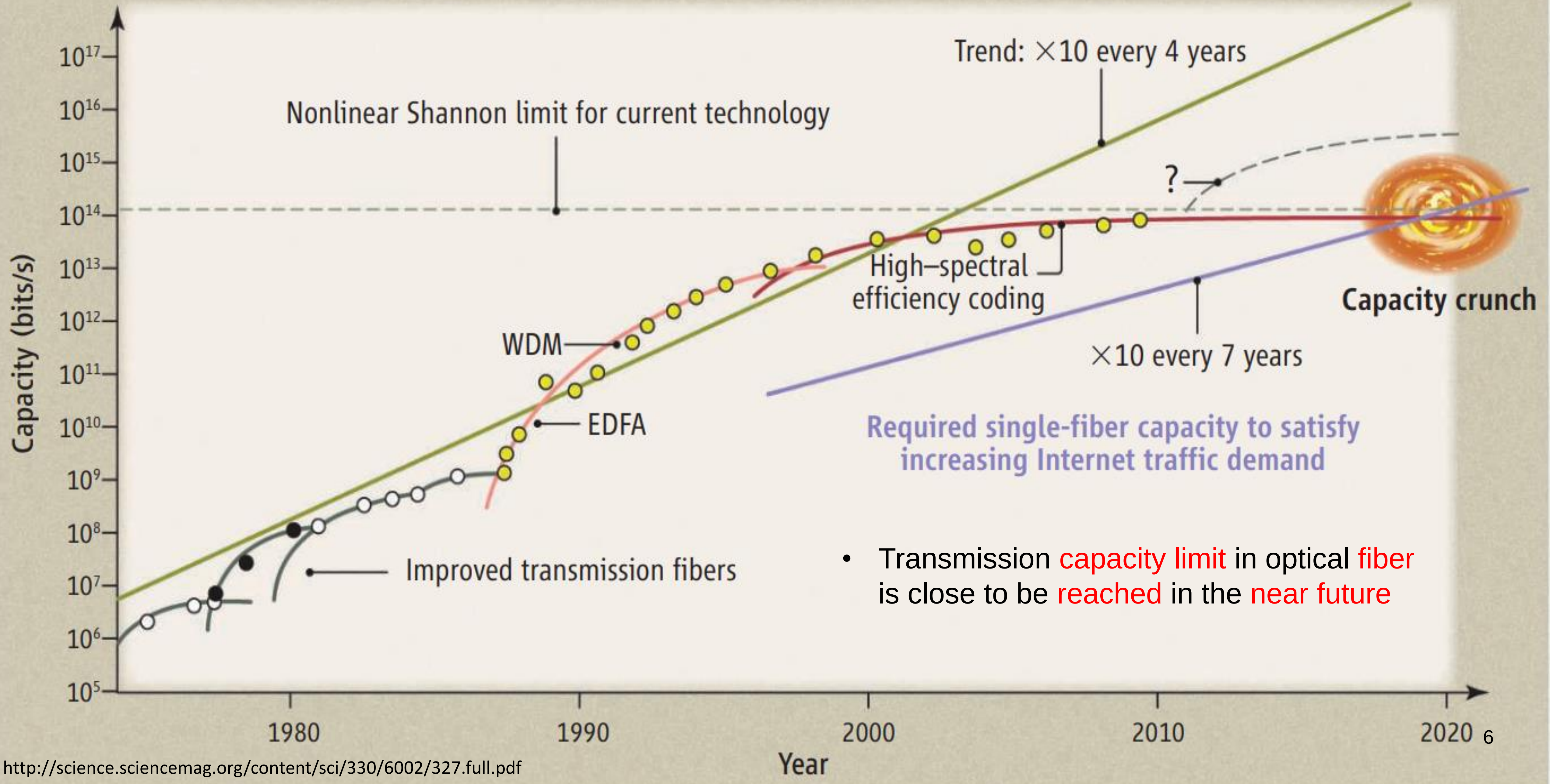
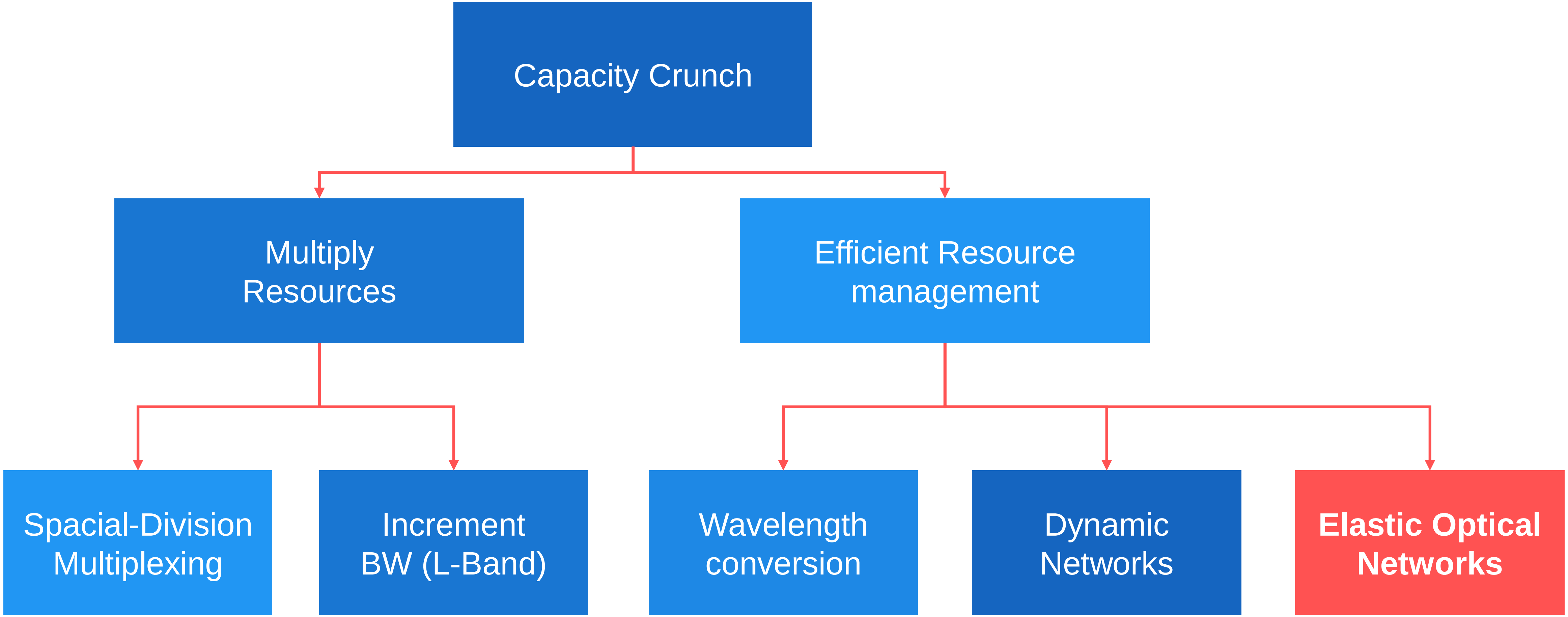


- Transmission capacity limit in optical fiber is close to be reached in the near future

http://science.sciencemag.org/content/sci/330/6002/327.full.pdf

Capacity Crunch Solutions



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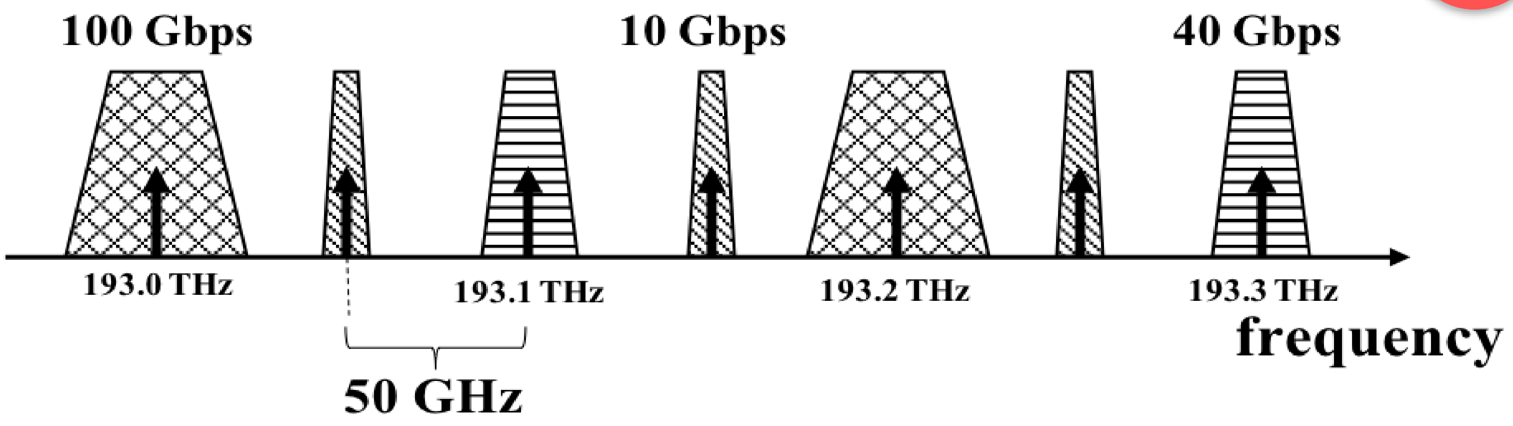
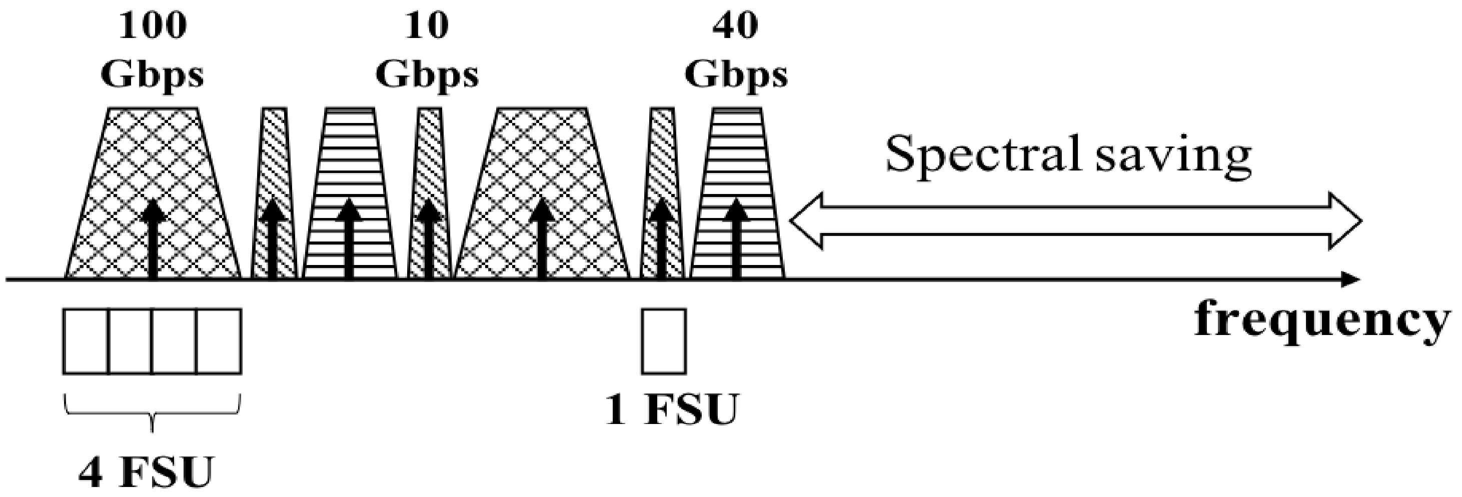
Elastic Optical Networks

Current optical spectrum configuration



Flexible Grid optical spectrum configuration



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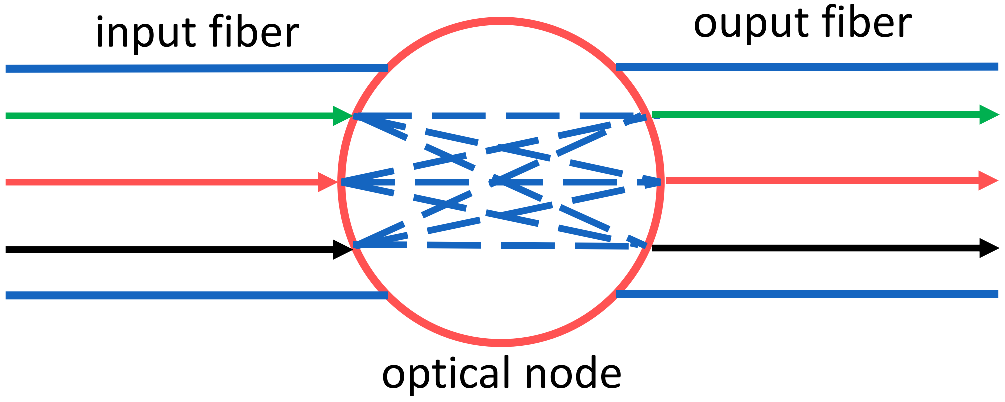
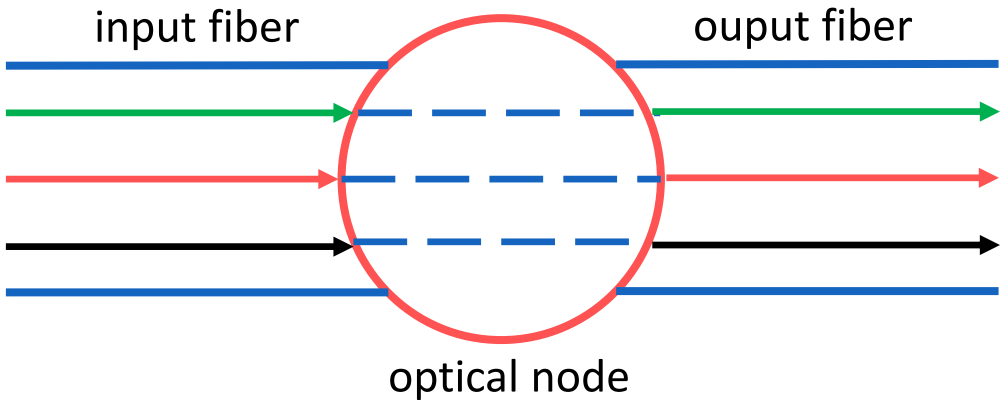
(No) Wavelength Conversion

Wavelength Conversion



- Optical node are capable to optically change the wavelength from input to output
- It allows users to use any wavelength available on their route links.
- Not commercially available

No Wavelength Conversion



- Input and output wavelength must be the same
- User paths must use same wavelength end-to-end

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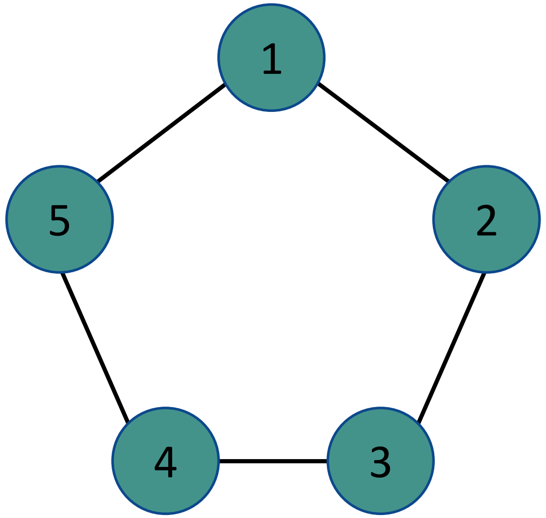
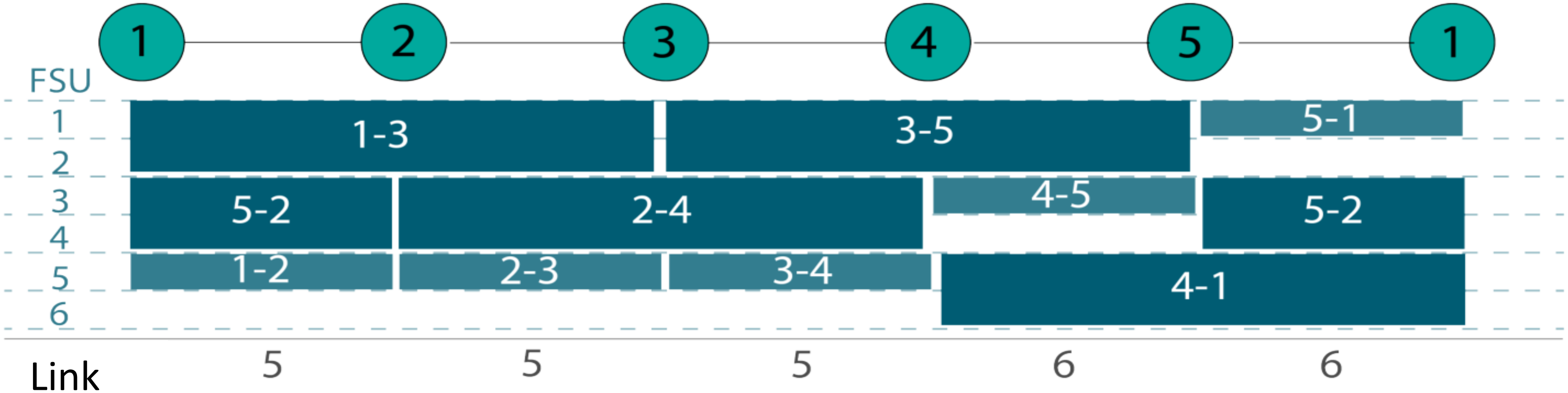
Routing and Spectrum Allocation

R (Routing) + *SA* (Spectrum Allocation) = *RSA* (Routing and Spectrum Allocation)



Clockwise



Link capacity

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Routing and Spectrum Allocation

We can solve it by optimization, but the problem is NP-Complete*

* Lopez, V. and Velasco, L., Elastic Optical Networks, Springer International 2016

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Routing and Spectrum Allocation

A standard heuristic solution is to solve the problem in stages

Routing → Spectrum Allocation

Routing
- Shortest Path
- Balancing
- K-Shortest Path

Spectrum Allocation
- First-Fit
- Best-Fit
- Random-Fit

Routing and Spectrum Allocation

A standard heuristic solution is to solve the problem in stages

Routing → Spectrum Allocation

QUESTION

¿Is the order important?

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Routing and Spectrum Allocation

A standard heuristic solution is to solve the problem in stages

Routing → **Spectrum Allocation**

Shortest Path
Balancing
K-Shortest Path

First-Fit with:

- Decreasing order of their route length
- Decreasing order of their bandwidth requirements.

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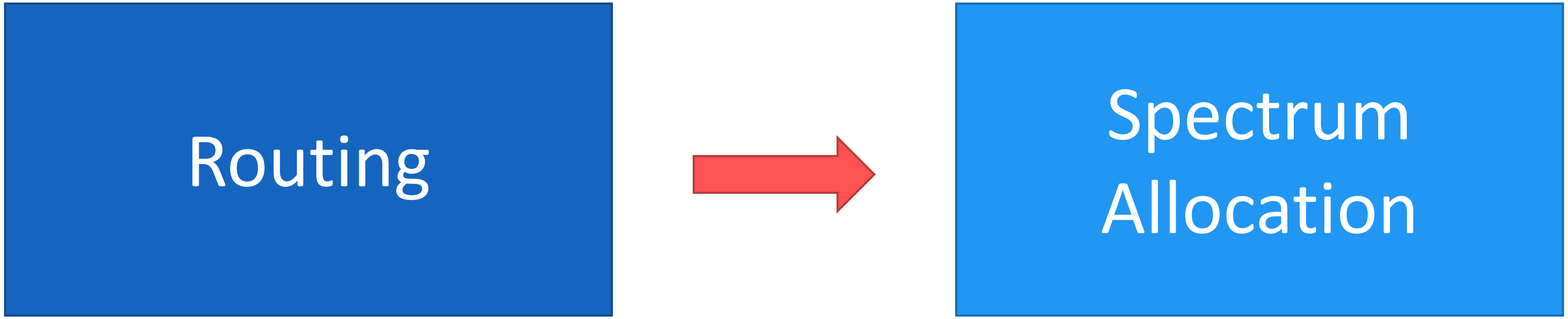
Routing and Spectrum Allocation

A standard heuristic solution is to solve the problem in stages



QUESTION

¿Is this enough?

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Routing and Spectrum Allocation

A standard heuristic solution is to solve the problem in stages

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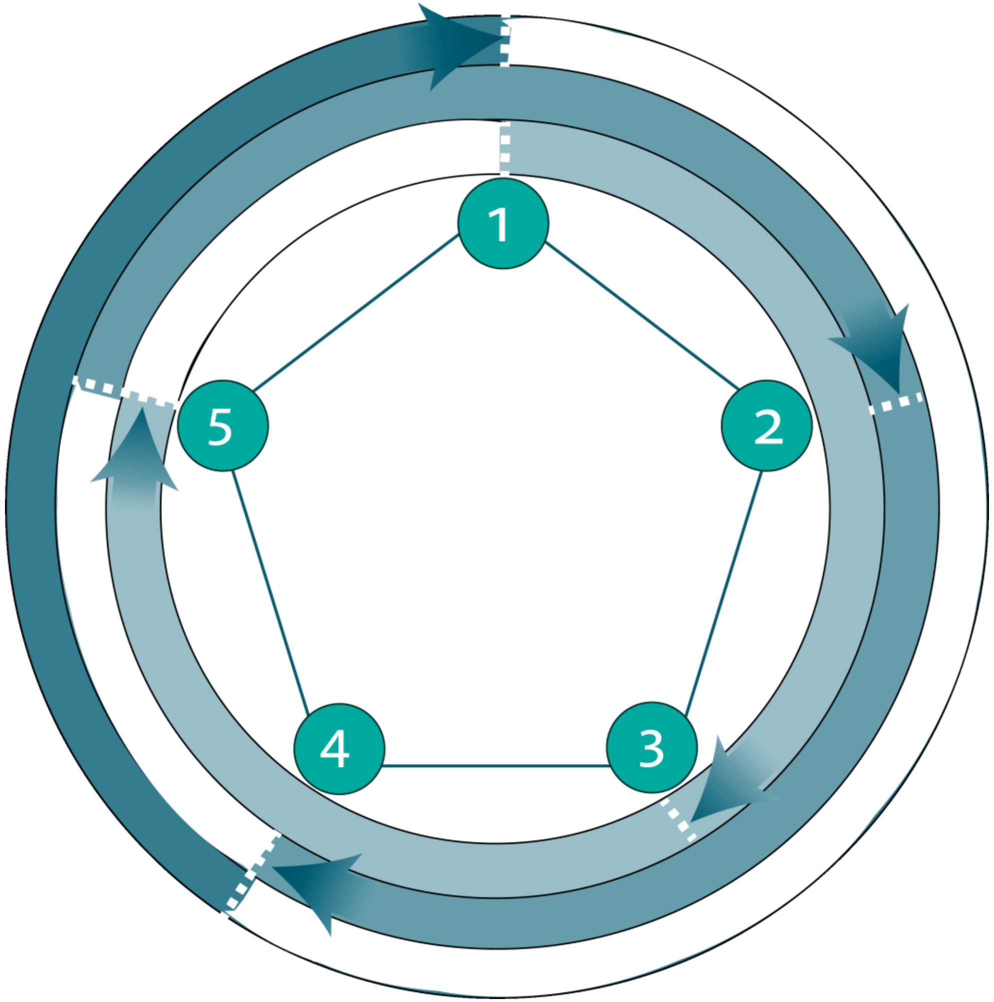
Spiral Strategy



Spiral Allocation

The ``Spiral'' concept seeks to assign the resources using the ring topology as an advantage, sorting and allocating the FSU to each user in spiral order.

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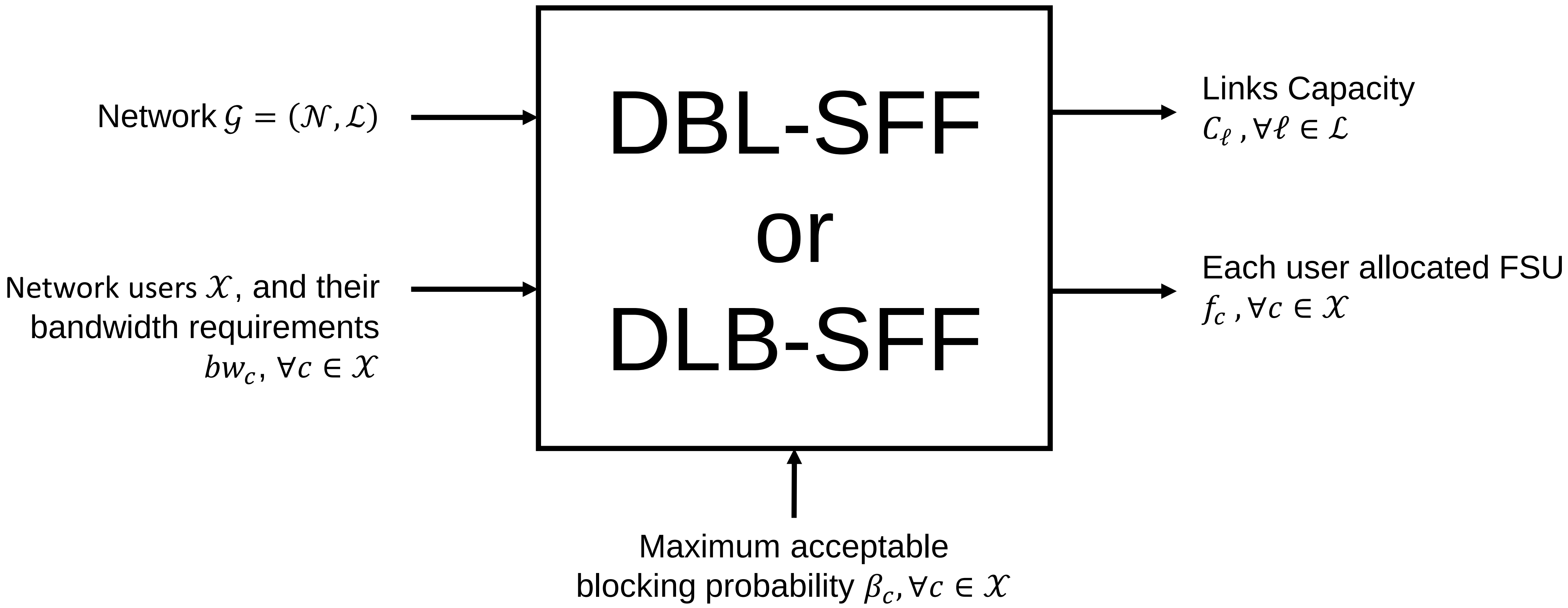
Routing and Spectrum Allocation diagram



DBL-SFF: Decreasing Bandwidth-Length – Spiral First-Fit
DLB-SFF: Decreasing Length-Bandwidth – Spiral First-Fit

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Routing and Spectrum Allocation

A standard heuristic solution is to solve the problem in stages

- Shortest Path
- Balance diameter routes

- Length over bandwidth
- Bandwidth over length
- Spiral Approach

- First-Fit

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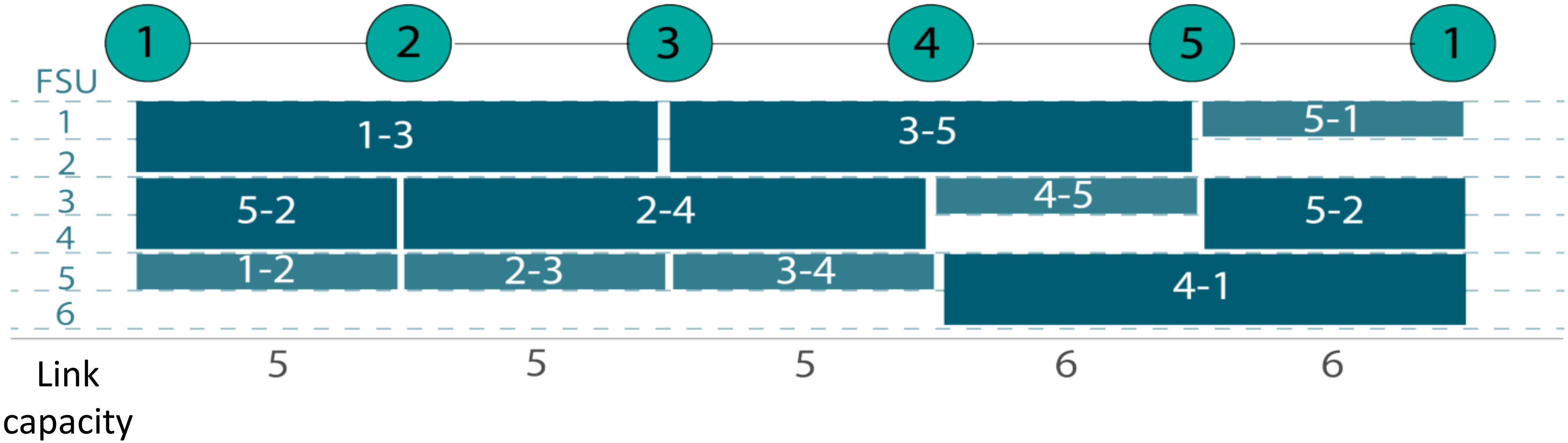
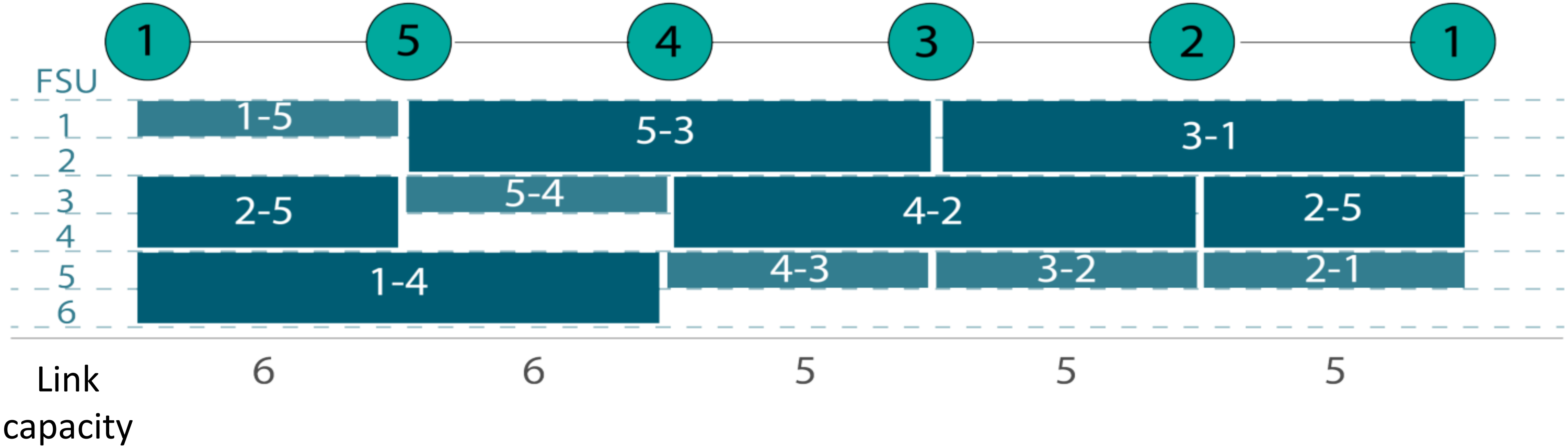
Example

Clockwise



Anti-clockwise



Numerical Examples

- Several sizes ring topologies
- Compared to First-Fit
- We measured the overall network capacity $\mathcal{C}_{net}$ as the sum of FSUs in all network links

$$\boldsymbol{\mathcal{C}_{net}} = \sum_{\forall \ell \epsilon \mathcal{L}} \boldsymbol{FSU_{\ell}}$$

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Numerical Examples

Nodes	Algorithm	C_{net}	FRC [%]	Time
6	Optimization (ILP)	114	0, 00	49,23
	SP-OA	118	3, 39	4,219
	DB-SFF	114	0, 00	0,000739
	DL-SFF	114	0, 00	0,001014
7	Optimization (ILP)	198	1, 01	997,5
	SP-OA	198	1, 01	58,01
	DB-SFF	212	7, 54	0,000918
	DL-SFF	214	8, 41	0,001252
8	Optimization (ILP)	353	0, 28	429916
	SP-OA	372[1]	3, 49[1]	21600
	DB-SFF	352	0, 00	0,001216
	DL-SFF	359	1, 95	0,001408
9	Optimization (ILP)	-	-	-
	SP-OA	-	-	-
	DB-SFF	572	5,59	0,001401
	DL-SFF	578	6, 57	0,001662

[1] Stopped at 6 hours

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Numerical Examples

Nodes	Algorithm	C_{net}	FRC [%]	Time
10	Optimization (ILP)	-	-	-
	SP-OA	-	-	-
	DB-SFF	657	5,78	0,001772
	DL-SFF	672	8, 04	0,002093
15	Optimization (ILP)	-	-	-
	SP-OA	-	-	-
	DB-SFF	2457	4,76	0,004051
	DL-SFF	2556	8, 45	0,004176
25	Optimization (ILP)	-	-	-
	SP-OA	-	-	-
	DB-SFF	13563	4,96	0,024687
	DL-SFF	13888	7,27	0,025282
50	Optimization (ILP)	-	-	-
	SP-OA	-	-	-
	DB-SFF	100822	2,87	0,21571
	DL-SFF	102307	4,43	0,212102

[1] Stopped at 6 hours

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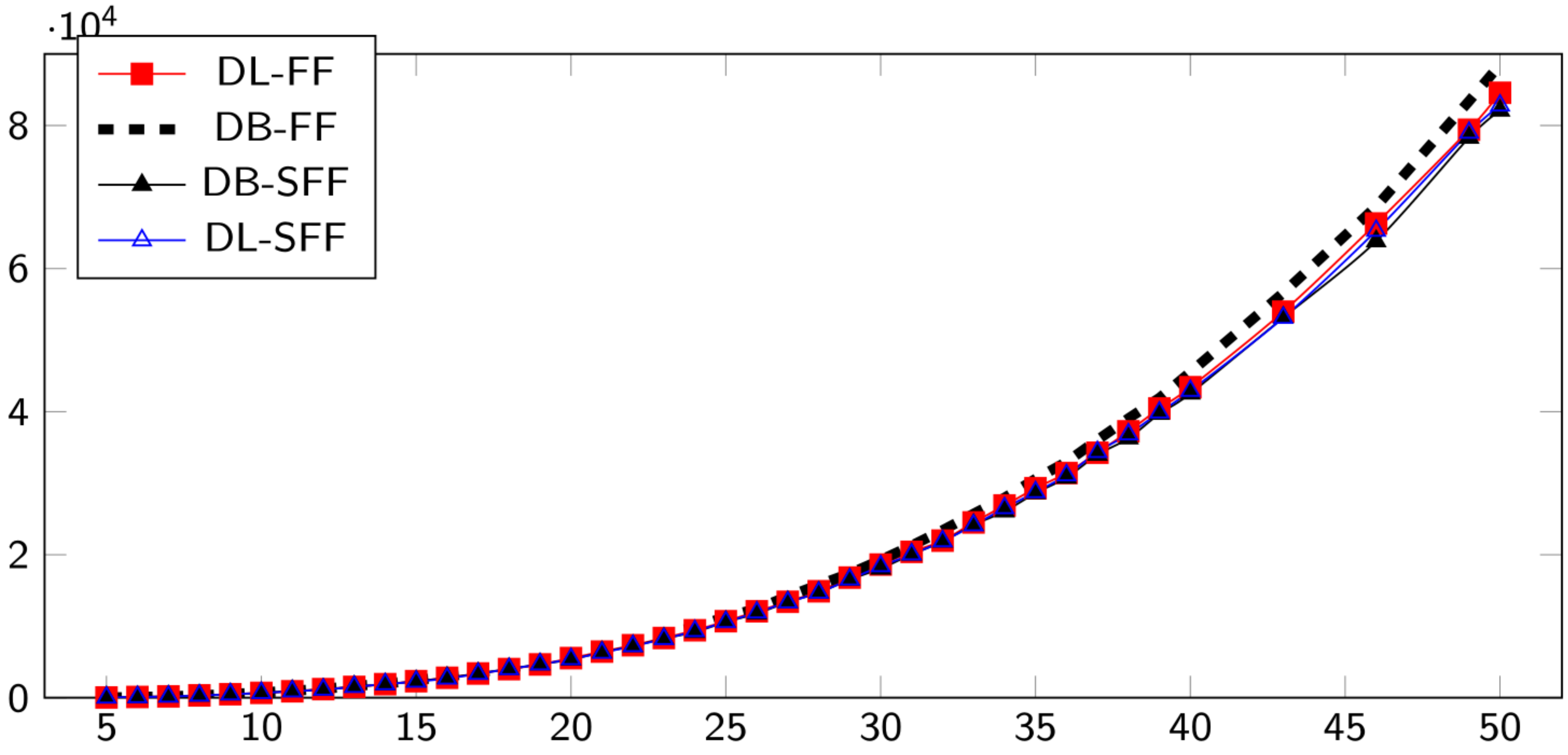
Numerical Examples



Network total capacity by amount of ring nodes

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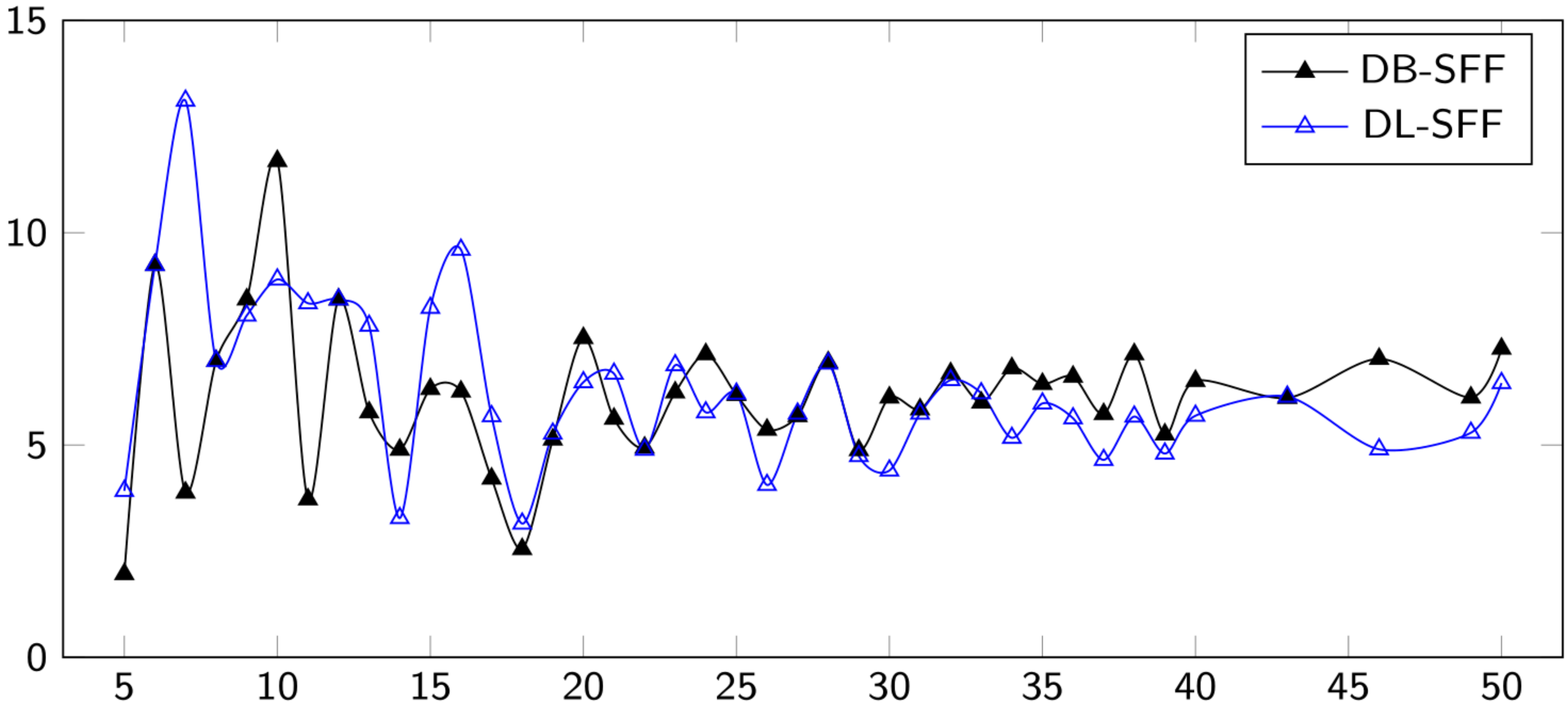
Numerical Examples



Percentual savings of network capacity obtained based on DB-FF

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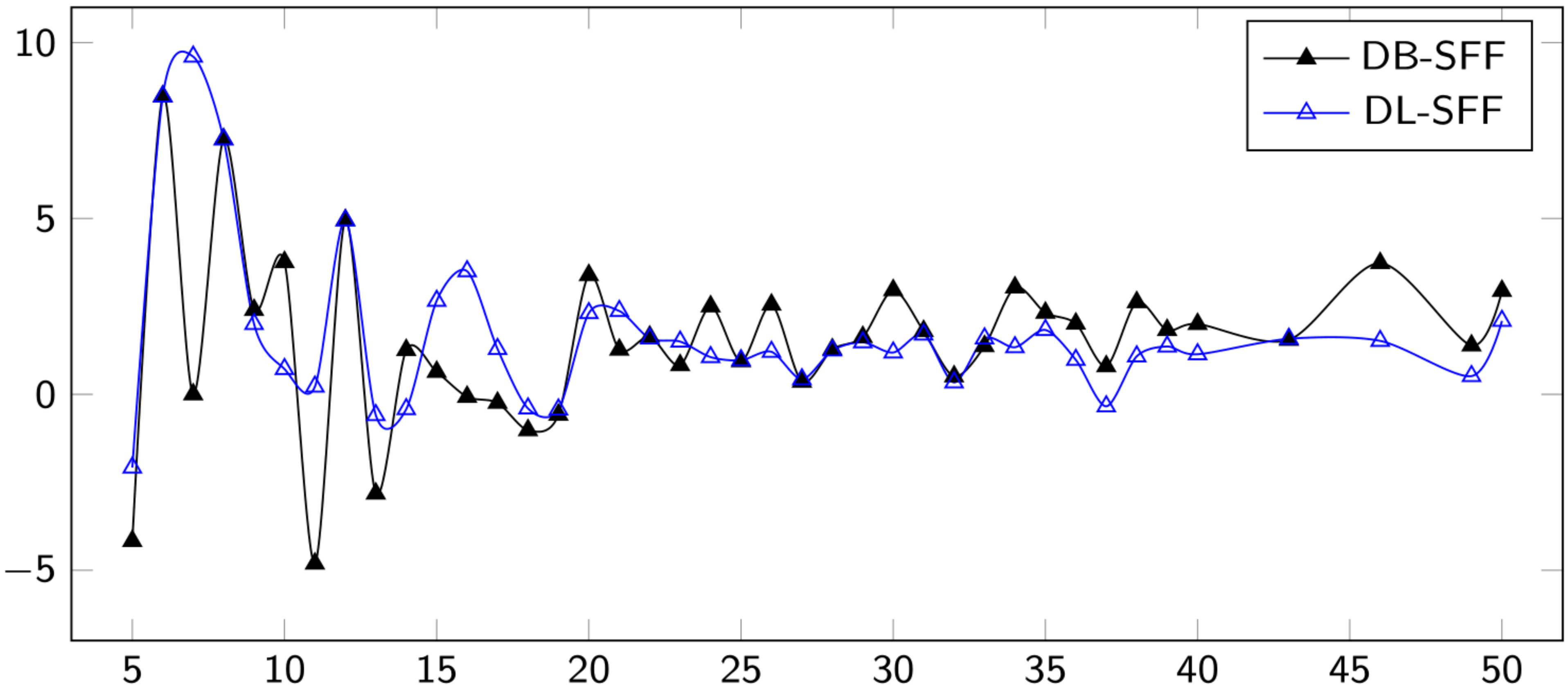
Numerical Examples



Percentual savings of network capacity obtained based on DL-FF

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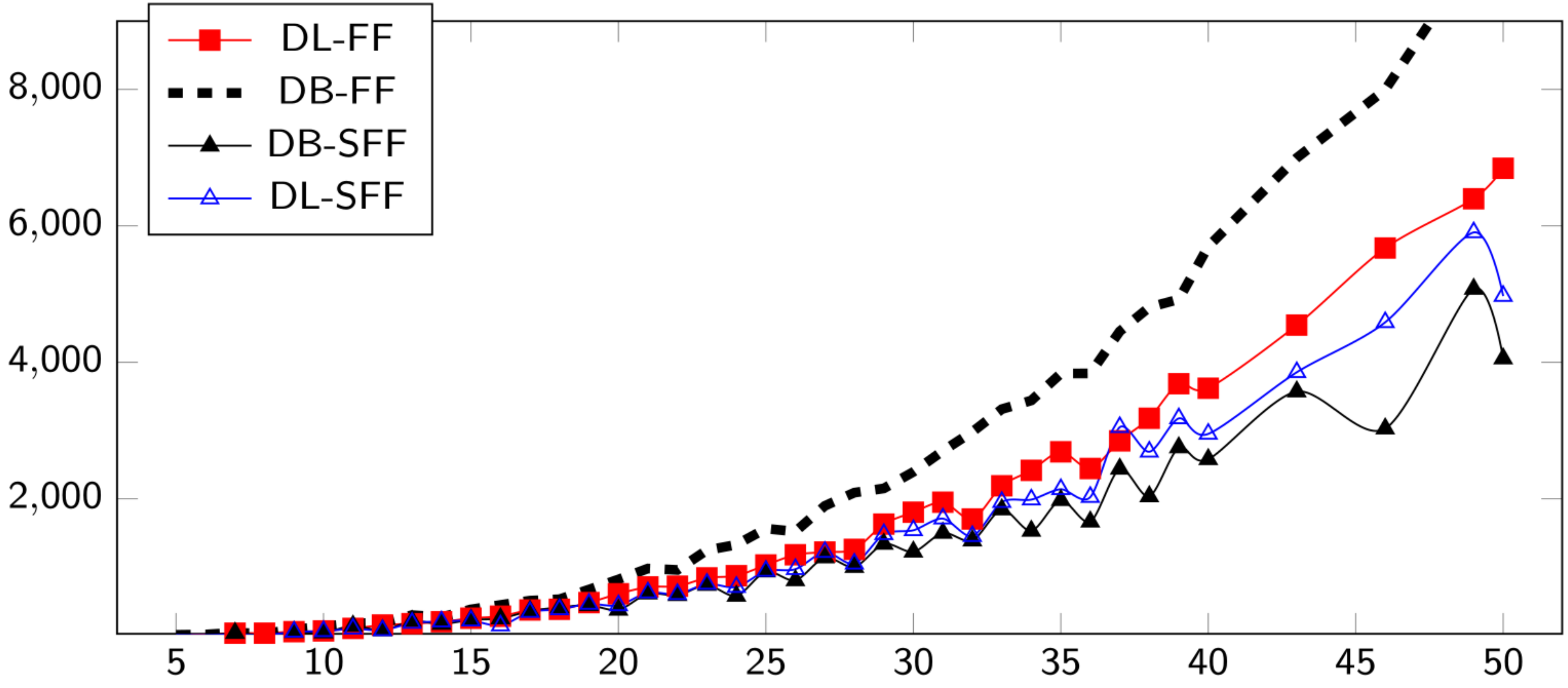
Numerical Examples



Amount of FSU fragmentated by the ring size

Final comments

- We present a novel method to solve the Routing and Spectrum Allocation on Elastic Optical Networks with Ring Topologies
  - Routes: Shortest Path + Balancing users
  - Wavelength Assignment: First Fit
  - Remarks the importance of an order policy: Spiral approach on Ring Topologies
- The optimization models obtain results only for small networks, with an execution time prohibitively high. Hence, a simulation technique is presented
- Our method has results close to optimal solutions and shows better results than the best strategies from the literature so far.
- Further work would be to solve the RSA problem on mesh network topologies and considering a dynamic network operation, adjusting the strategy of this work to said contexts.

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Questions?

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