



UNIVERSIDAD TECNICA
FEDERICO SANTA MARIA

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

Nicolas Jara, Jesenia Salazar, Reinaldo Vallejos.
Universidad Santa María,
Valparaíso, Chile.

July 29 – 31, 2019
Prague, Czech Republic

SIMULTECH 2019

9th International Conference on Simulation and Modeling

Methodologies, Technologies and Applications

30-07-2019

Bandwidth Demand

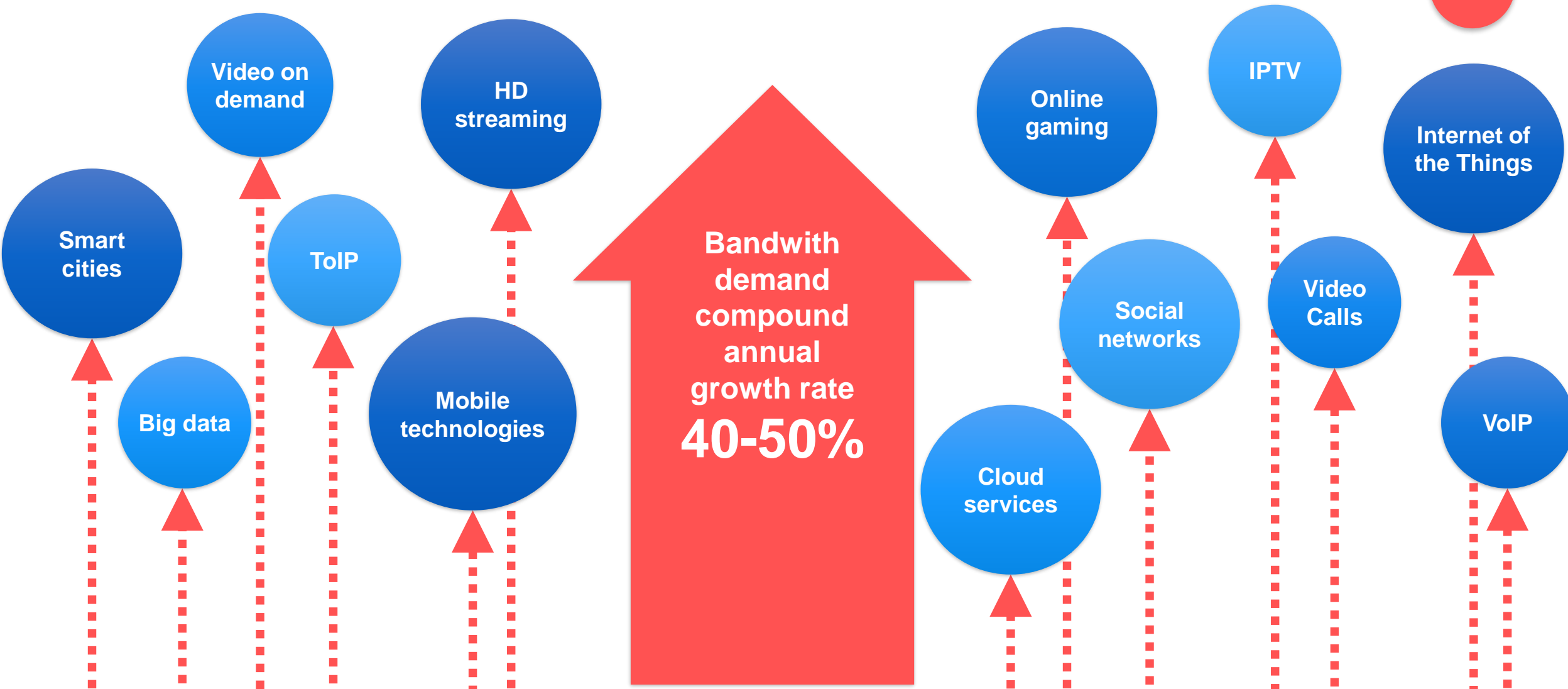
INTRODUCTION

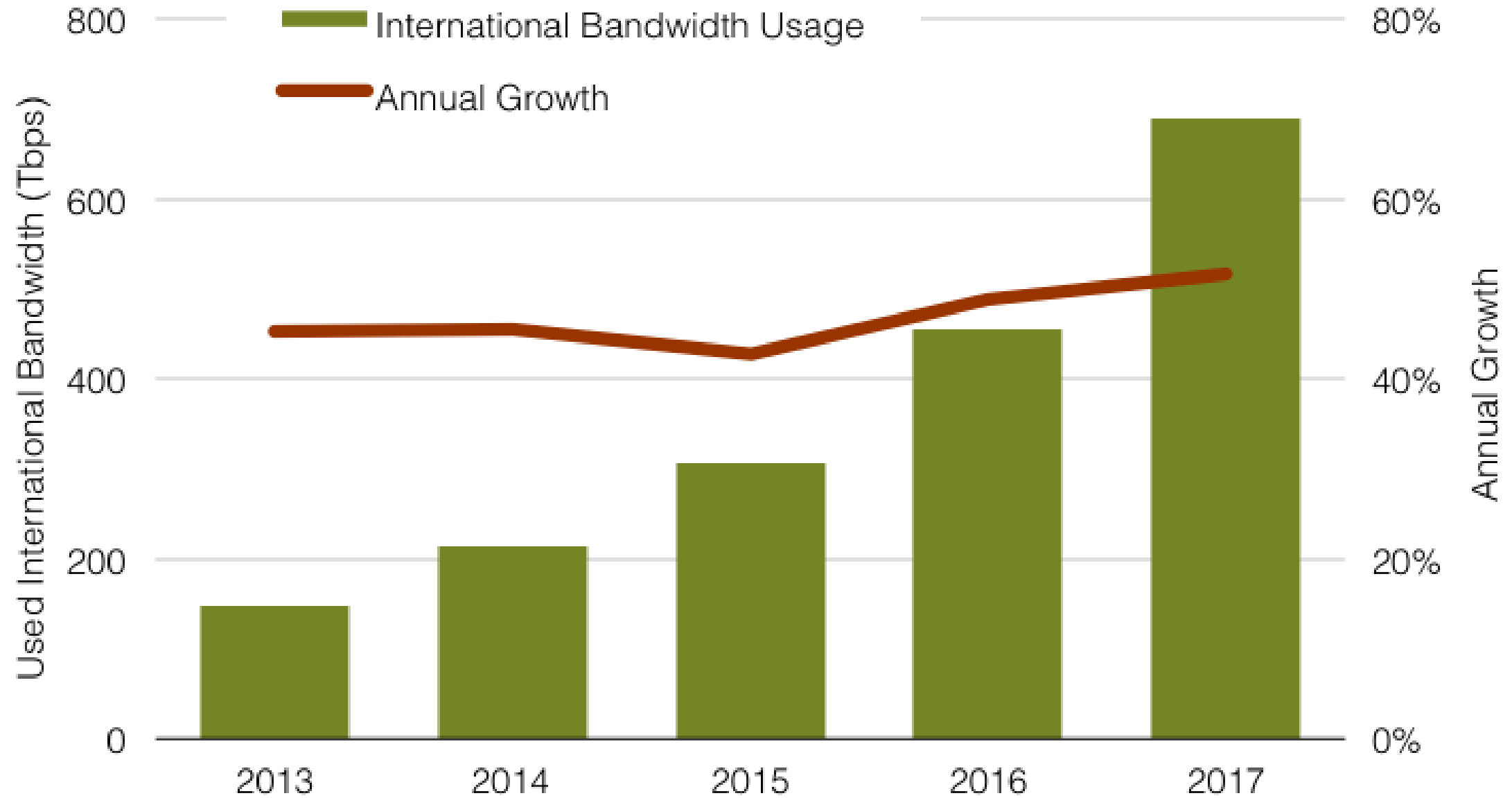
NETWORK AND TRAFFIC

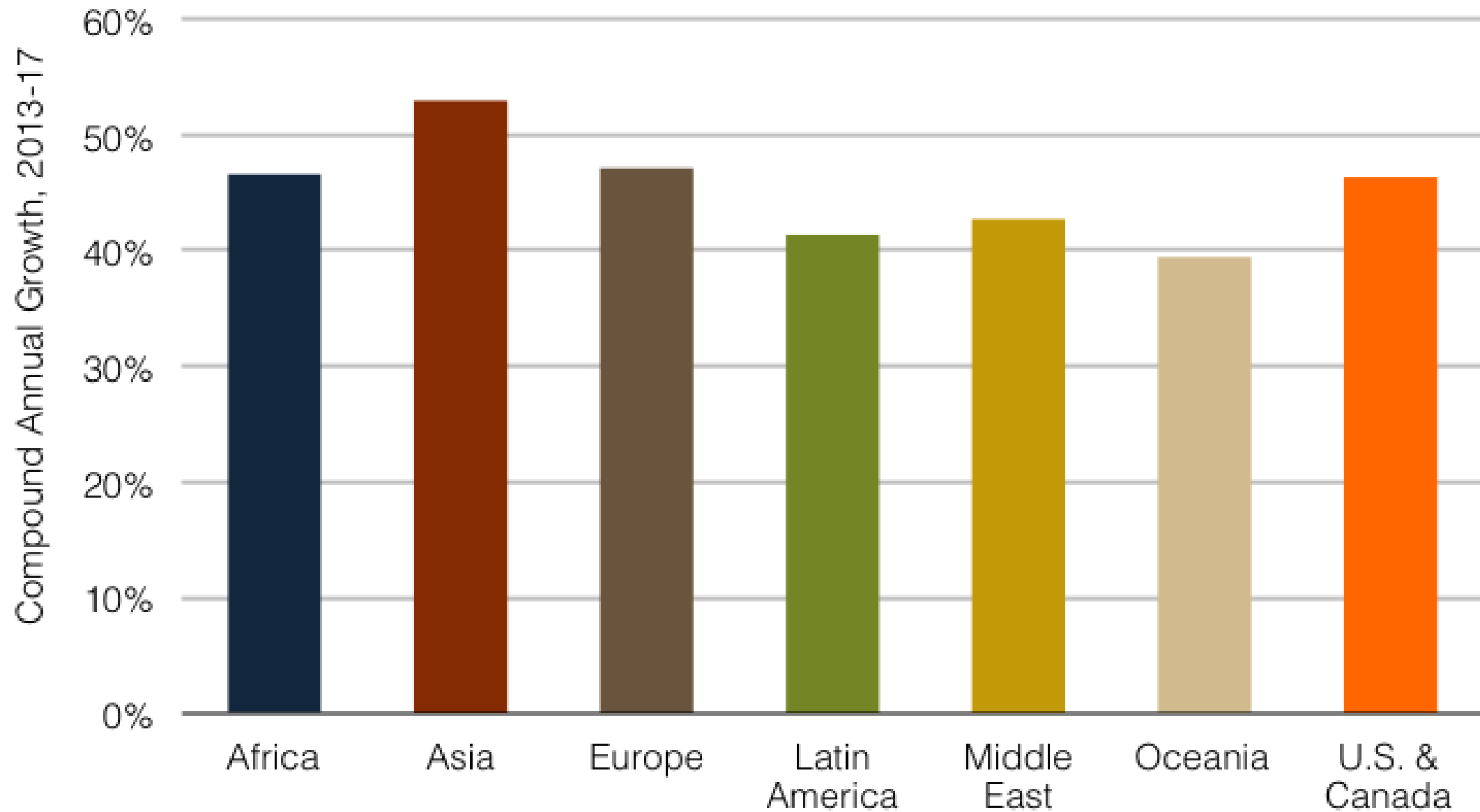
RSA

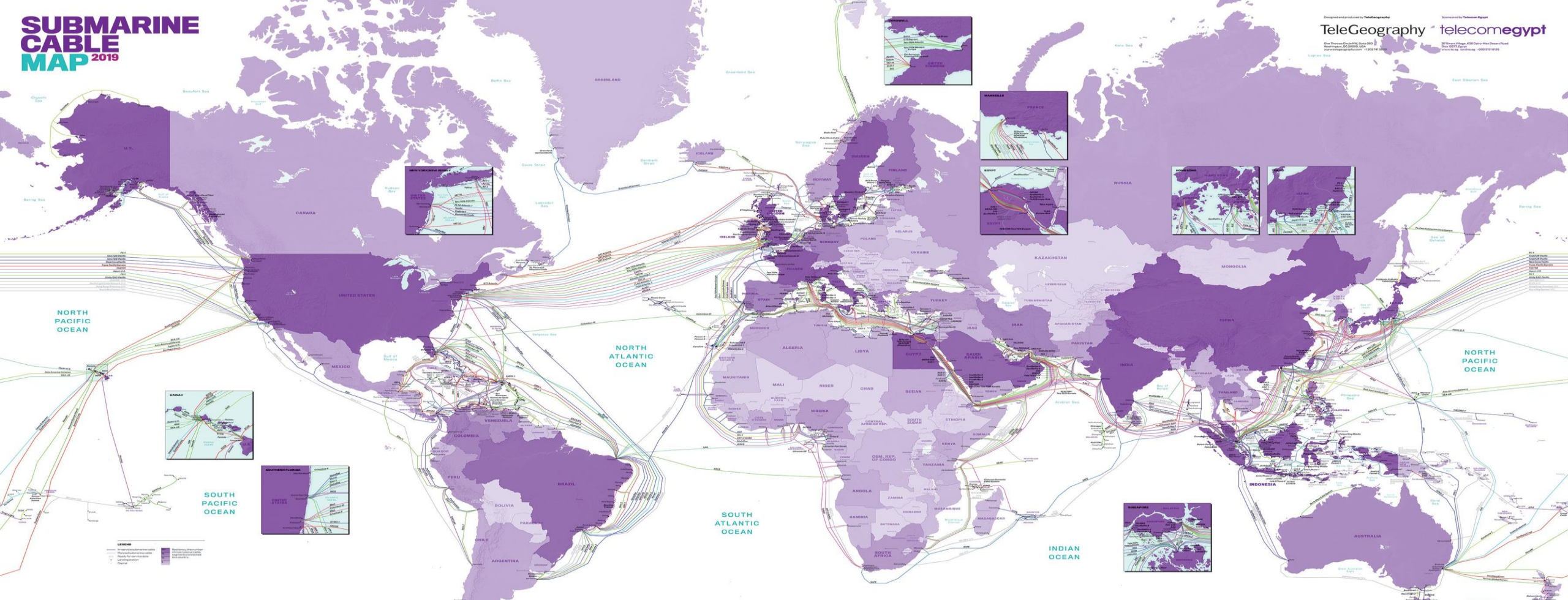
EXAMPLES

2







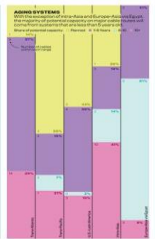


A NEW BUILDING BOOM

As many as 107 new submarine cables totaling over 400,000 kilometers will be deployed from 2016 to 2020 with a value of over \$13.8 billion.

BEHIND THE CABLE BOOM

THE ECONOMY OF NEW CABLES
 The economic benefits of new submarine cables are significant. They provide a more direct and efficient route for data, reducing latency and increasing bandwidth. This is particularly important for cloud services, video streaming, and financial markets. New cables also create jobs in construction, engineering, and operations.



NEW CABLE SYSTEMS

New cable systems are being designed to meet the growing demand for bandwidth and lower latency. These systems often feature higher capacity fibers and more advanced routing capabilities. Key examples include the EAS-SEA cable connecting East Africa, Asia, and Southeast Asia, and the AFRICA-EUROPE cable connecting Africa and Europe.

NEW CABLES IN CONSTRUCTION

Several new submarine cables are currently under construction. These include the EAS-SEA cable, the AFRICA-EUROPE cable, and the MEXICO-CENTRAL AMERICA cable. The completion of these cables will significantly expand the global submarine cable network.

NEW CABLES IN PLANNING

Several new submarine cables are in the planning stage. These include the MEXICO-CENTRAL AMERICA cable, the AFRICA-EUROPE cable, and the EAS-SEA cable. The completion of these cables will significantly expand the global submarine cable network.

NEW CABLES IN OPERATION

Several new submarine cables are already in operation. These include the EAS-SEA cable, the AFRICA-EUROPE cable, and the MEXICO-CENTRAL AMERICA cable. The completion of these cables will significantly expand the global submarine cable network.

INVESTING IN THE CABLES

Investment in submarine cables is increasing as demand for bandwidth grows. Major players in the industry include TeleGeography, Telecom Egypt, and other global telecommunications companies. The investment is focused on building new cables and upgrading existing ones.

MARKET OVERSIGHT

Market oversight is essential for ensuring the stability and security of the submarine cable network. This involves monitoring cable health, managing capacity, and addressing any potential threats to the network. TeleGeography provides comprehensive market oversight services.

PRIVATE NETWORK OPERATORS

Private network operators are playing an increasingly important role in the submarine cable market. They are investing in new cables and upgrading existing ones to meet the needs of their customers. This includes major players like AT&T Intellectual Property and Verizon Communications.

CONTENT PROVIDER INVESTMENT

Content providers are investing in submarine cables to improve their service quality and reduce costs. This includes major players like Netflix, Amazon, and Google. By investing in cables, they can ensure that their content is delivered quickly and reliably to their users.

FINANCING INVESTMENT

Financing investment is a key challenge in the submarine cable market. Building new cables is a capital-intensive activity that requires significant upfront investment. However, the long-term benefits of new cables make them an attractive investment opportunity.

NEW CABLES TO BUILD

Several new submarine cables are planned for construction in the coming years. These include the EAS-SEA cable, the AFRICA-EUROPE cable, and the MEXICO-CENTRAL AMERICA cable. The completion of these cables will significantly expand the global submarine cable network.

NEW CABLES IN OPERATION

Several new submarine cables are already in operation. These include the EAS-SEA cable, the AFRICA-EUROPE cable, and the MEXICO-CENTRAL AMERICA cable. The completion of these cables will significantly expand the global submarine cable network.

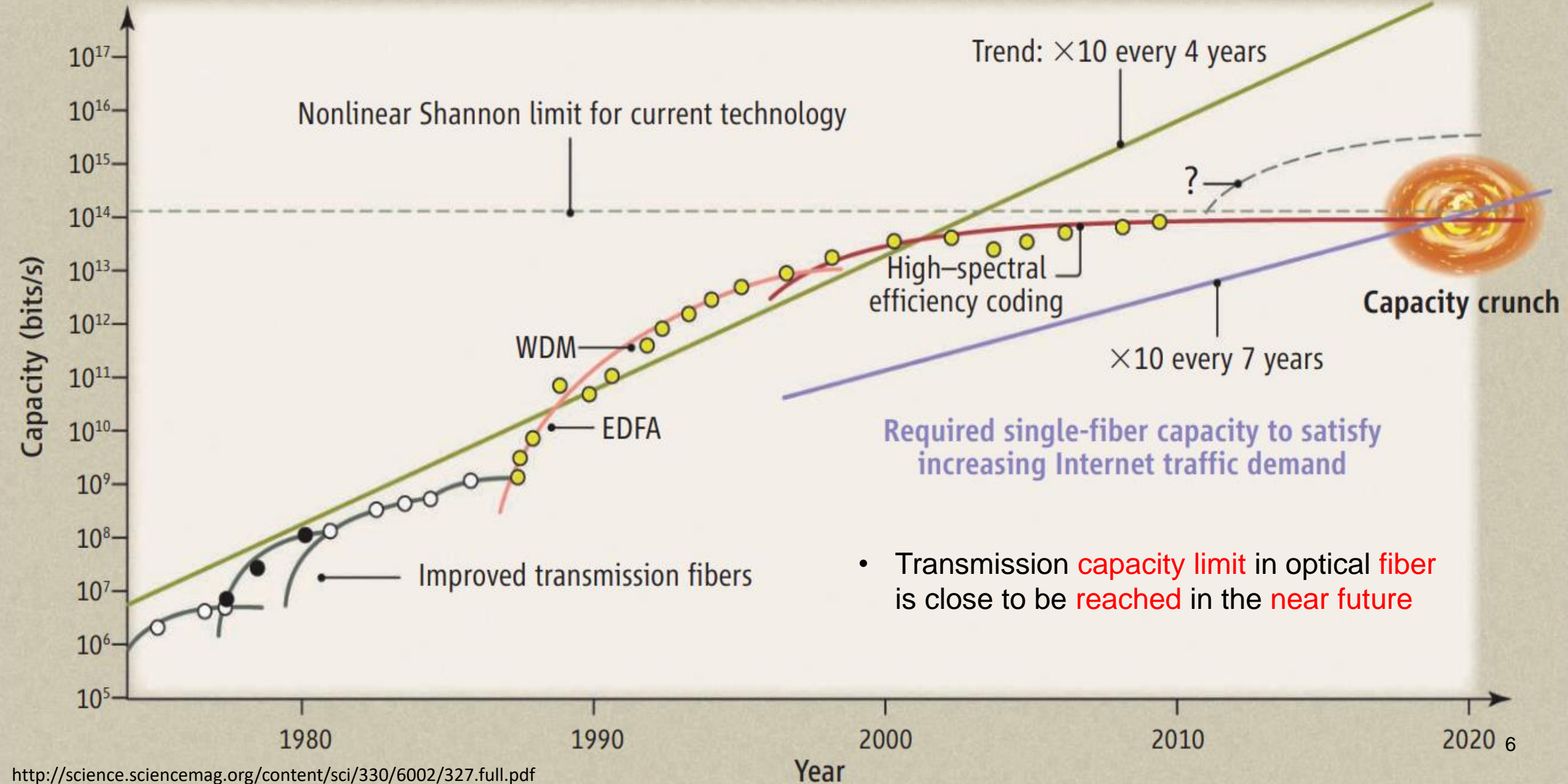
EMPLOYED CABLE

The number of employed cables is growing as demand for bandwidth increases. This is particularly true in the Asia-Pacific region, where the number of cables has increased significantly in recent years. The growth in employed cables is a key indicator of the health of the submarine cable market.

Worldwide submarine cables 2019

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





Capacity Crunch Solutions

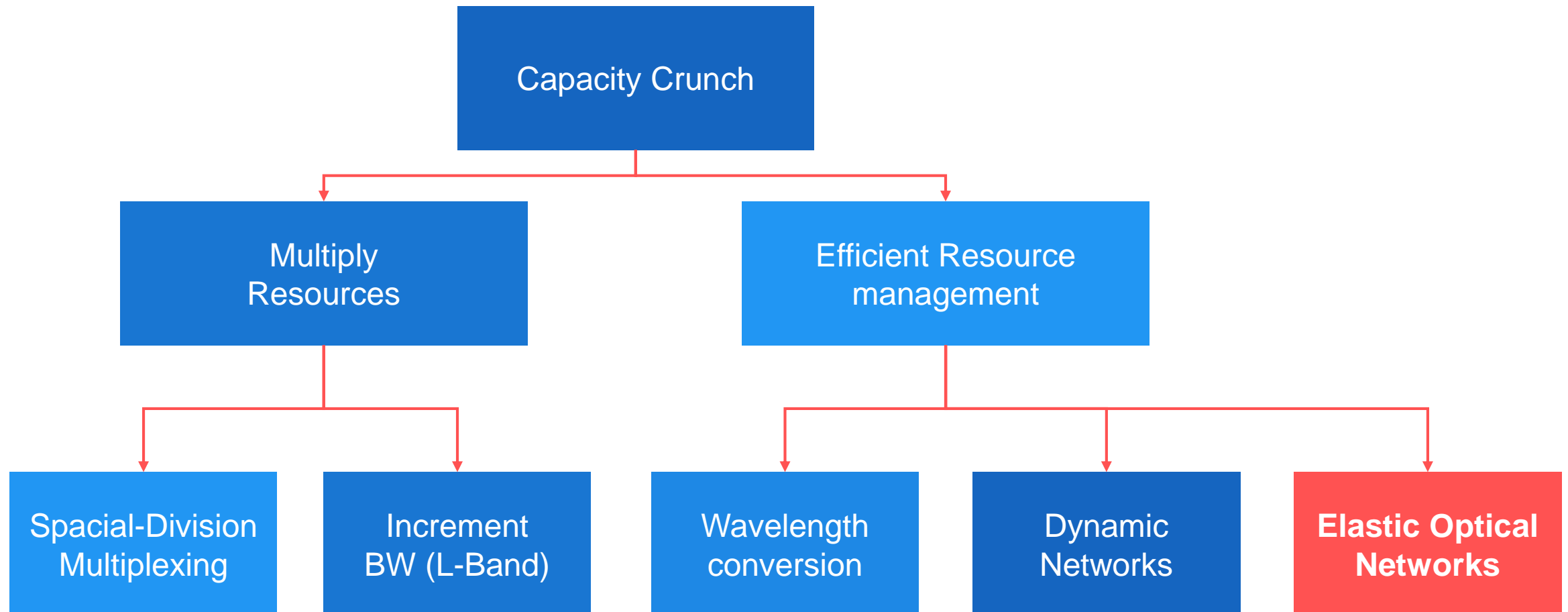
INTRODUCTION

NETWORK AND TRAFFIC

RSA

EXAMPLES

7



Elastic Optical Networks

INTRODUCTION

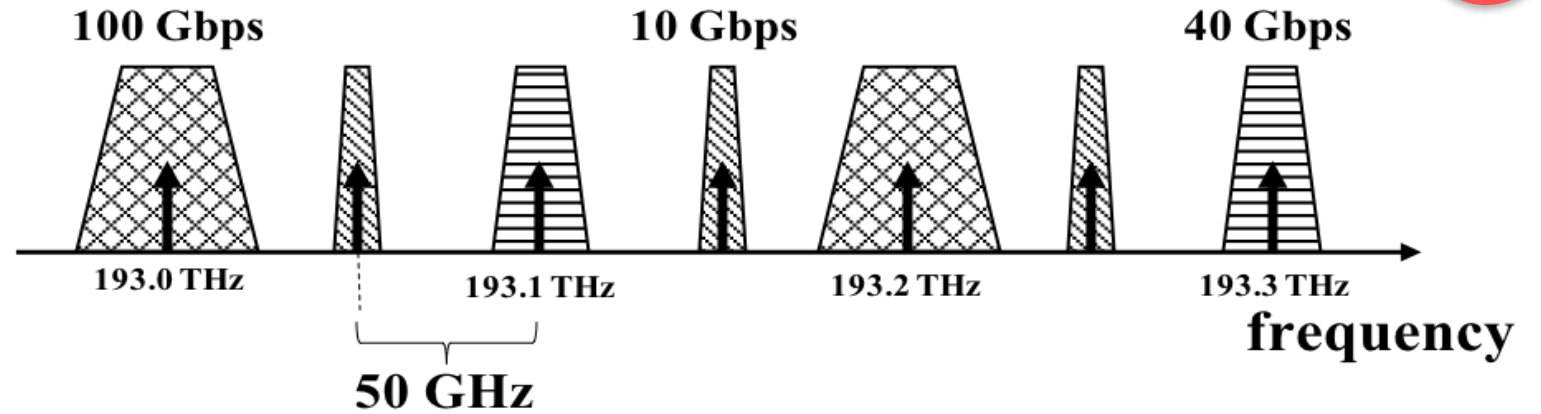
NETWORK AND TRAFFIC

RSA

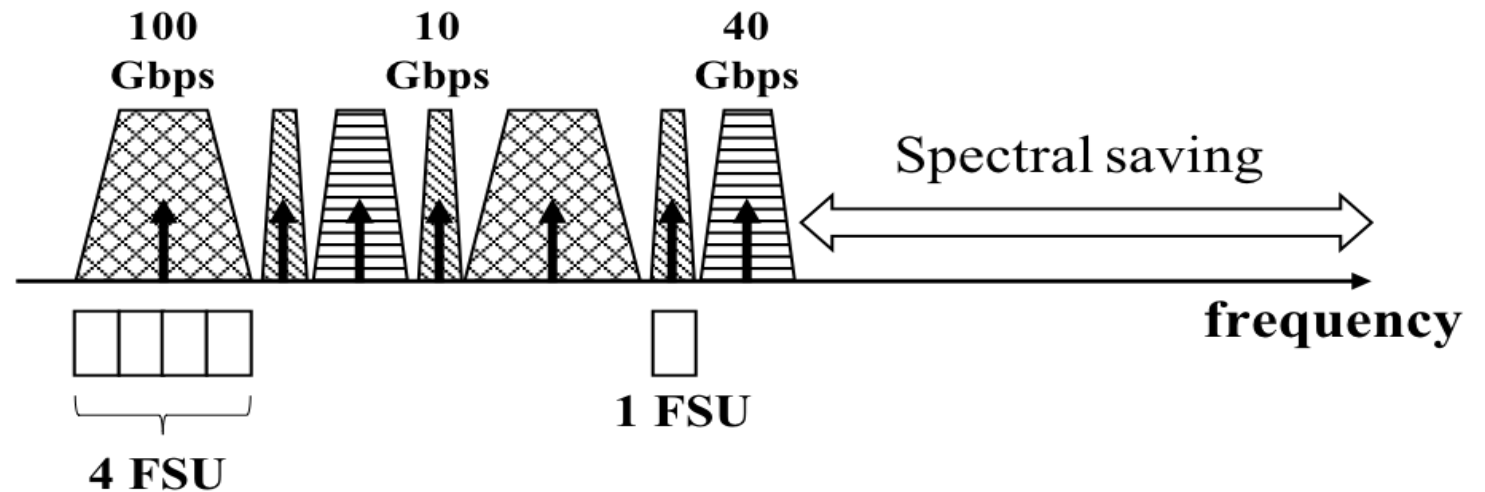
EXAMPLES

8

Current optical spectrum configuration



Flexible Grid optical spectrum configuration



(No) Wavelength Conversion

INTRODUCTION

NETWORK AND TRAFFIC

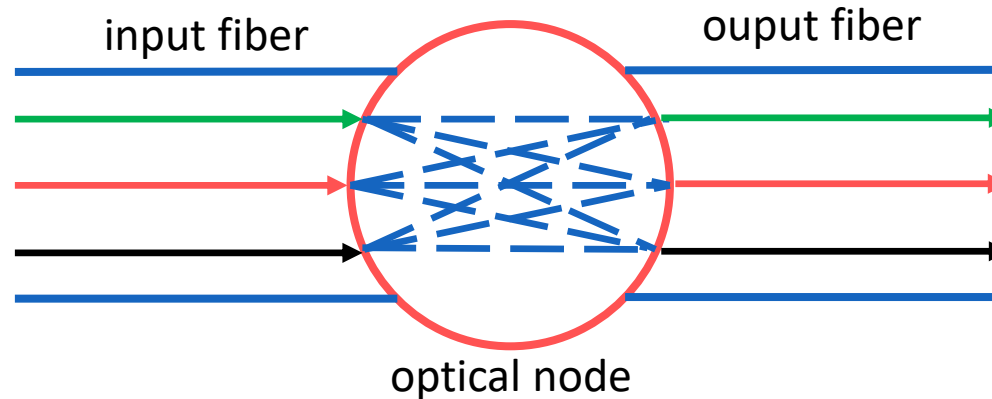
RSA

EXAMPLES

9



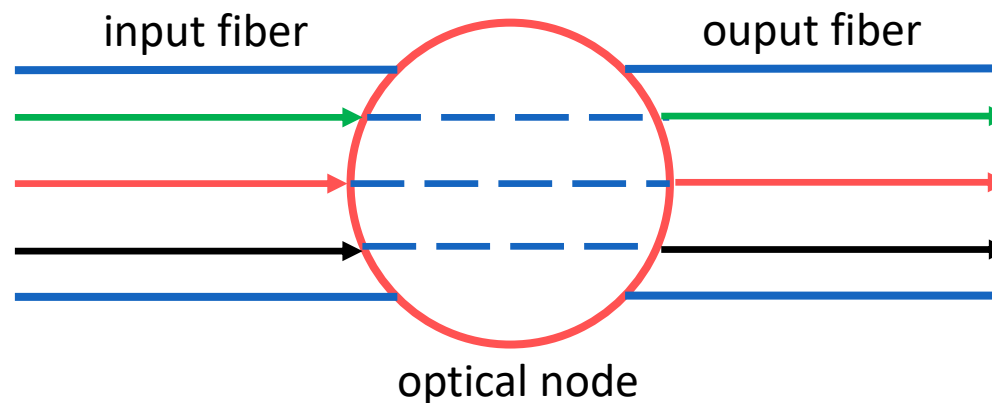
Wavelength
Conversion



- Optical nodes are capable of optically changing 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

Routing and Spectrum Allocation

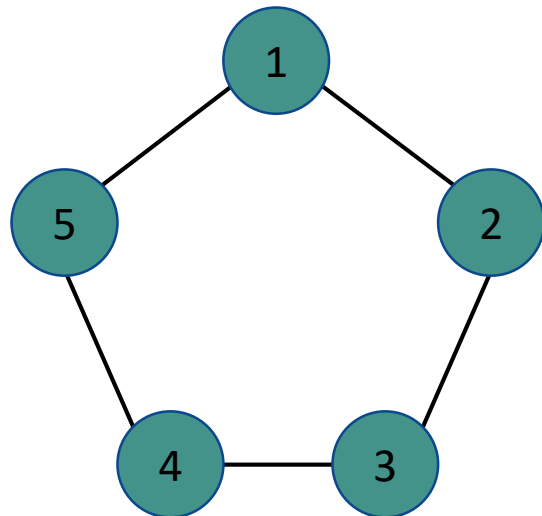
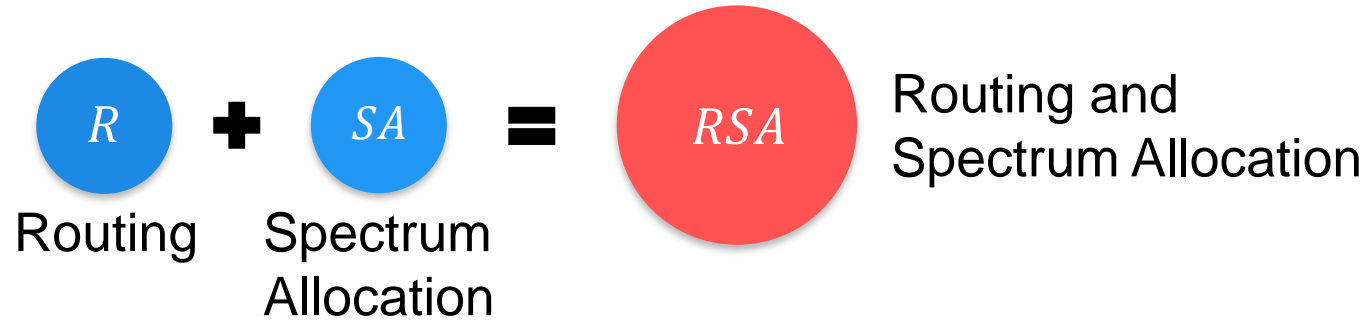
INTRODUCTION

NETWORK AND TRAFFIC

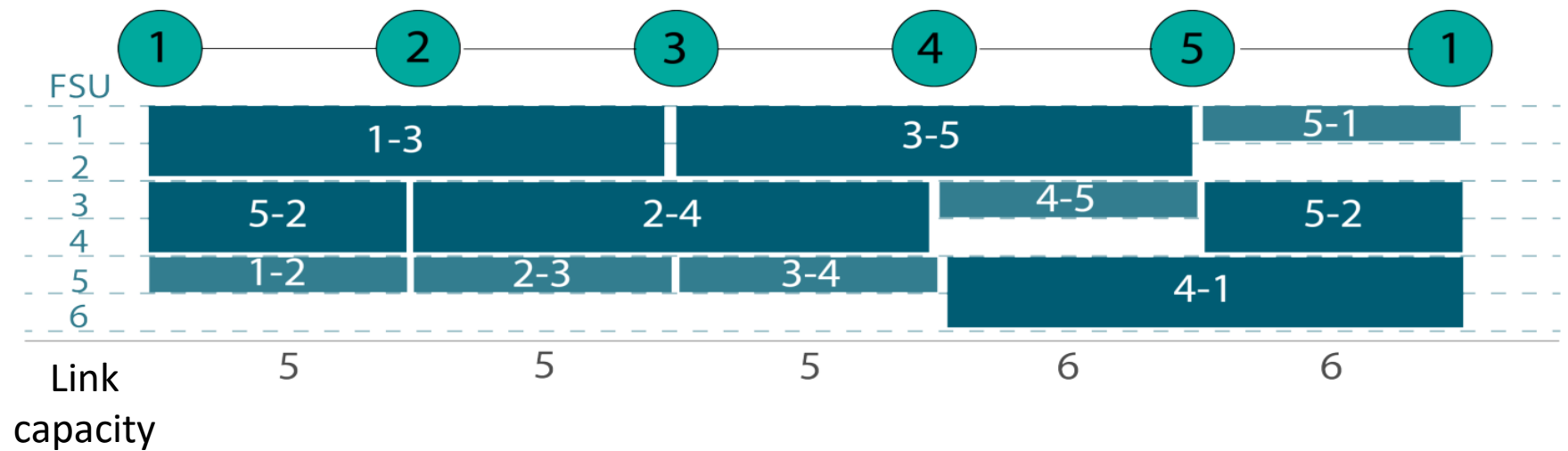
RSA

EXAMPLES

10



Clockwise



Routing and Spectrum Allocation

INTRODUCTION

NETWORK AND TRAFFIC

RSA

EXAMPLES

11

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

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

Routing and Spectrum Allocation

INTRODUCTION

NETWORK AND TRAFFIC

RSA

EXAMPLES

12

A standard heuristic solution is to solve the problem in stages



Routing

Shortest Path
Balancing
K-Shortest Path

Spectrum
Allocation

First-Fit
Best-Fit
Random-Fit

Routing and Spectrum Allocation

INTRODUCTION

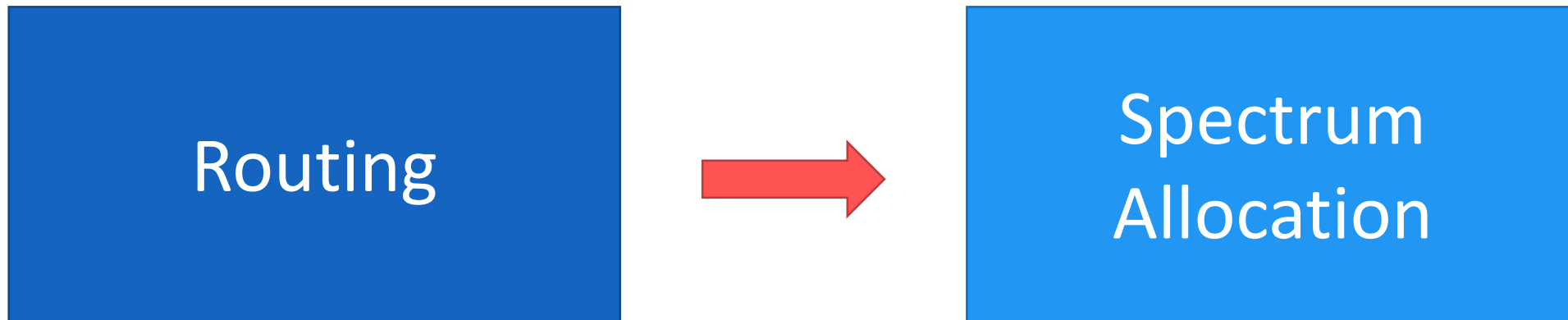
NETWORK AND TRAFFIC

RSA

EXAMPLES

13

A standard heuristic solution is to solve the problem in stages



QUESTION

¿Is the order important?

Routing and Spectrum Allocation

INTRODUCTION

NETWORK AND TRAFFIC

RSA

EXAMPLES

14

A standard heuristic solution is to solve the problem in stages

Routing

Shortest Path
Balancing
K-Shortest Path

Spectrum
Allocation

First-Fit with:

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

Routing and Spectrum Allocation

INTRODUCTION

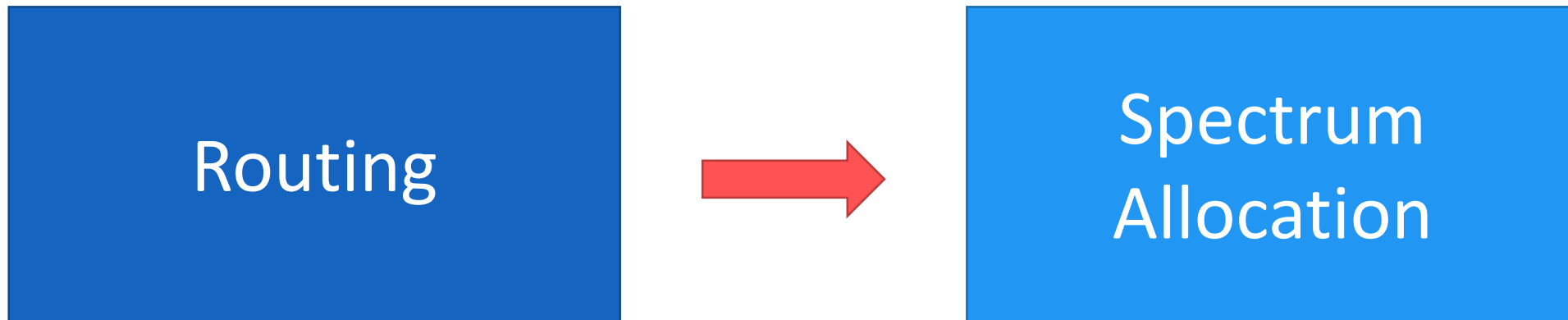
NETWORK AND TRAFFIC

RSA

EXAMPLES

15

A standard heuristic solution is to solve the problem in stages



QUESTION
¿Is this enough?

Routing and Spectrum Allocation

INTRODUCTION

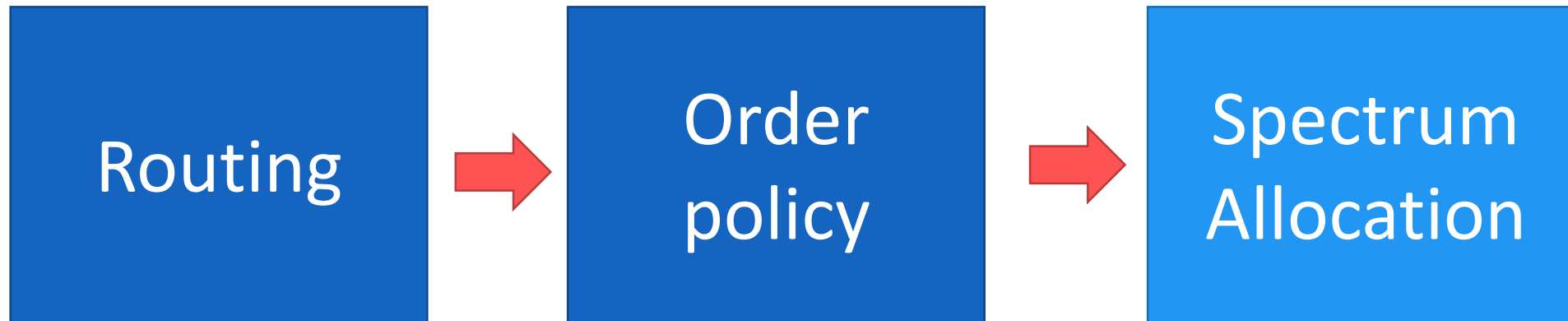
NETWORK AND TRAFFIC

RSA

EXAMPLES

16

A standard heuristic solution is to solve the problem in stages



Spiral Strategy

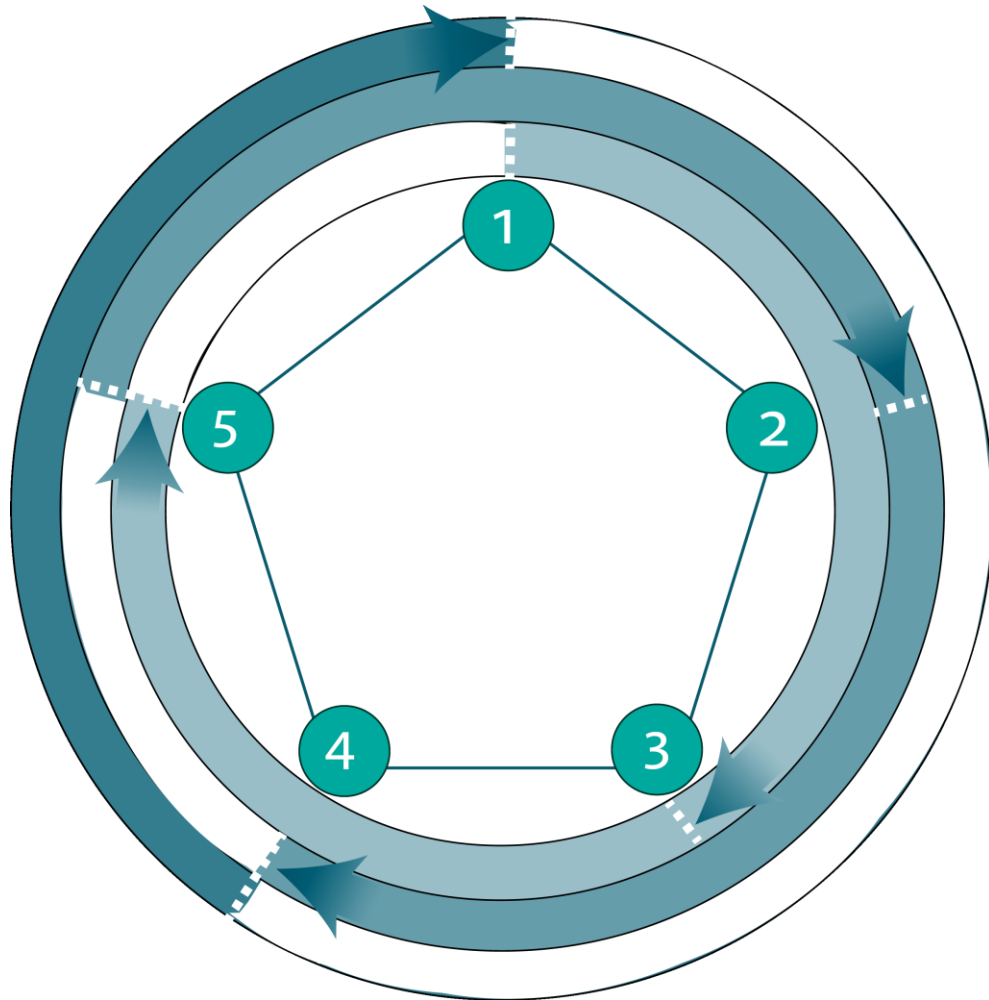
INTRODUCTION

NETWORK AND TRAFFIC

RSA

EXAMPLES

17



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.

Routing and Spectrum Allocation diagram

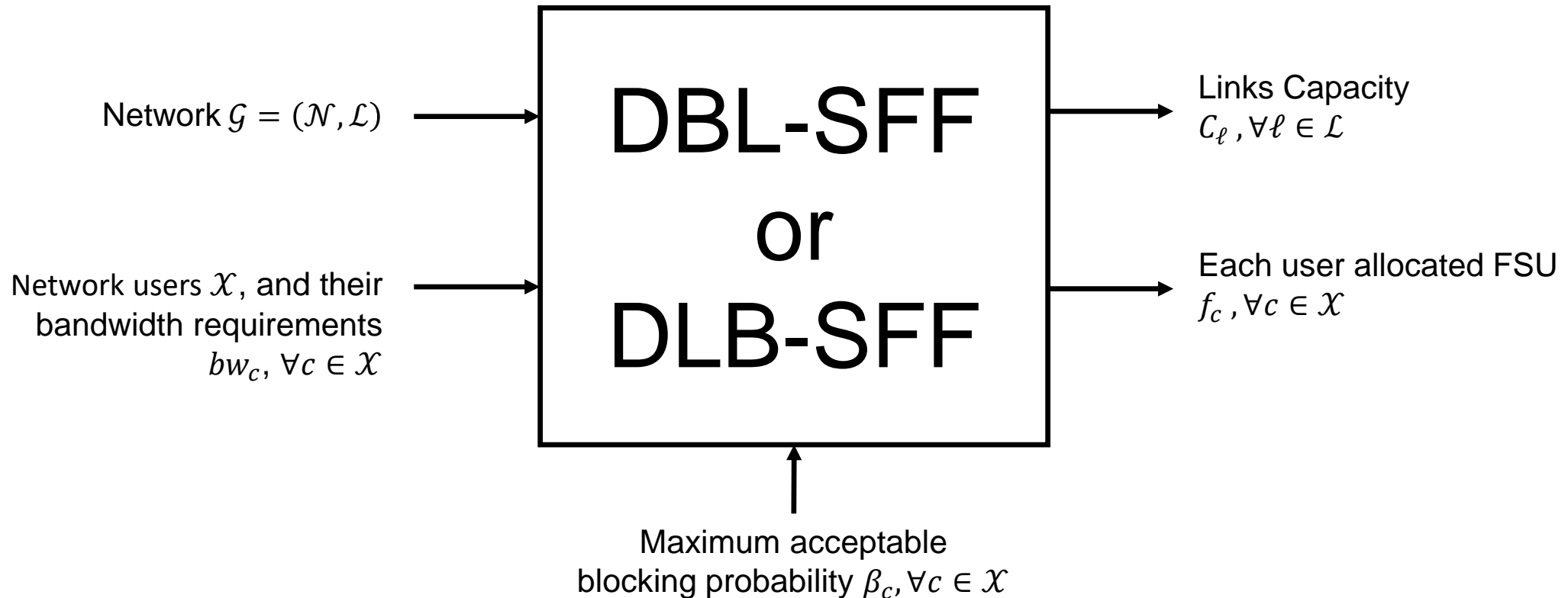
INTRODUCTION

NETWORK AND TRAFFIC

RSA

EXAMPLES

18



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

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

Routing and Spectrum Allocation

INTRODUCTION

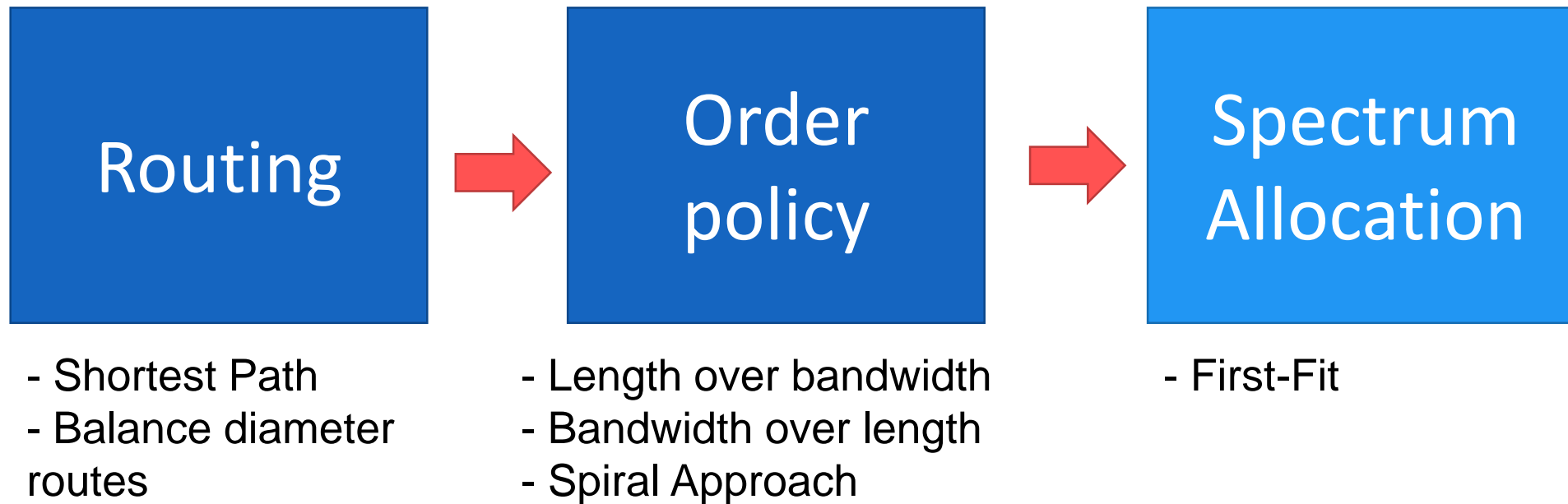
NETWORK AND TRAFFIC

RSA

EXAMPLES

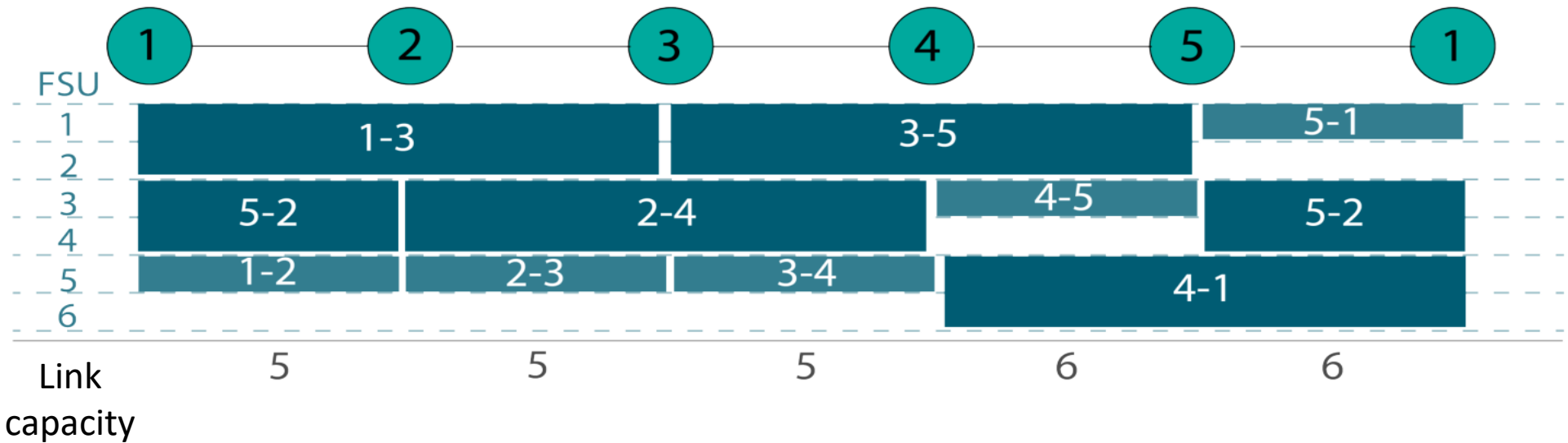
19

A standard heuristic solution is to solve the problem in stages

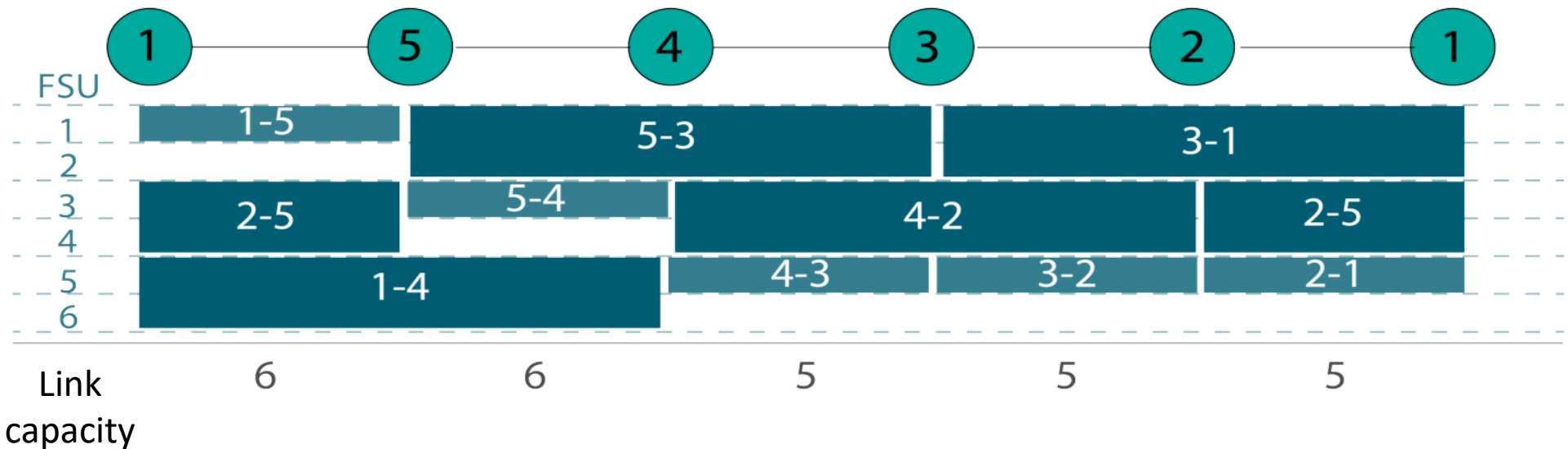


Example

Clockwise



Anti-clockwise



Numerical Examples

- ✓ Several sizes ring topologies
- ✓ Compared to First-Fit
- ✓ We measured the overall network capacity C_{net} as the sum of FSUs in all network links

$$C_{net} = \sum_{\forall \ell \in \mathcal{L}} FSU_{\ell}$$

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

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

Numerical Examples

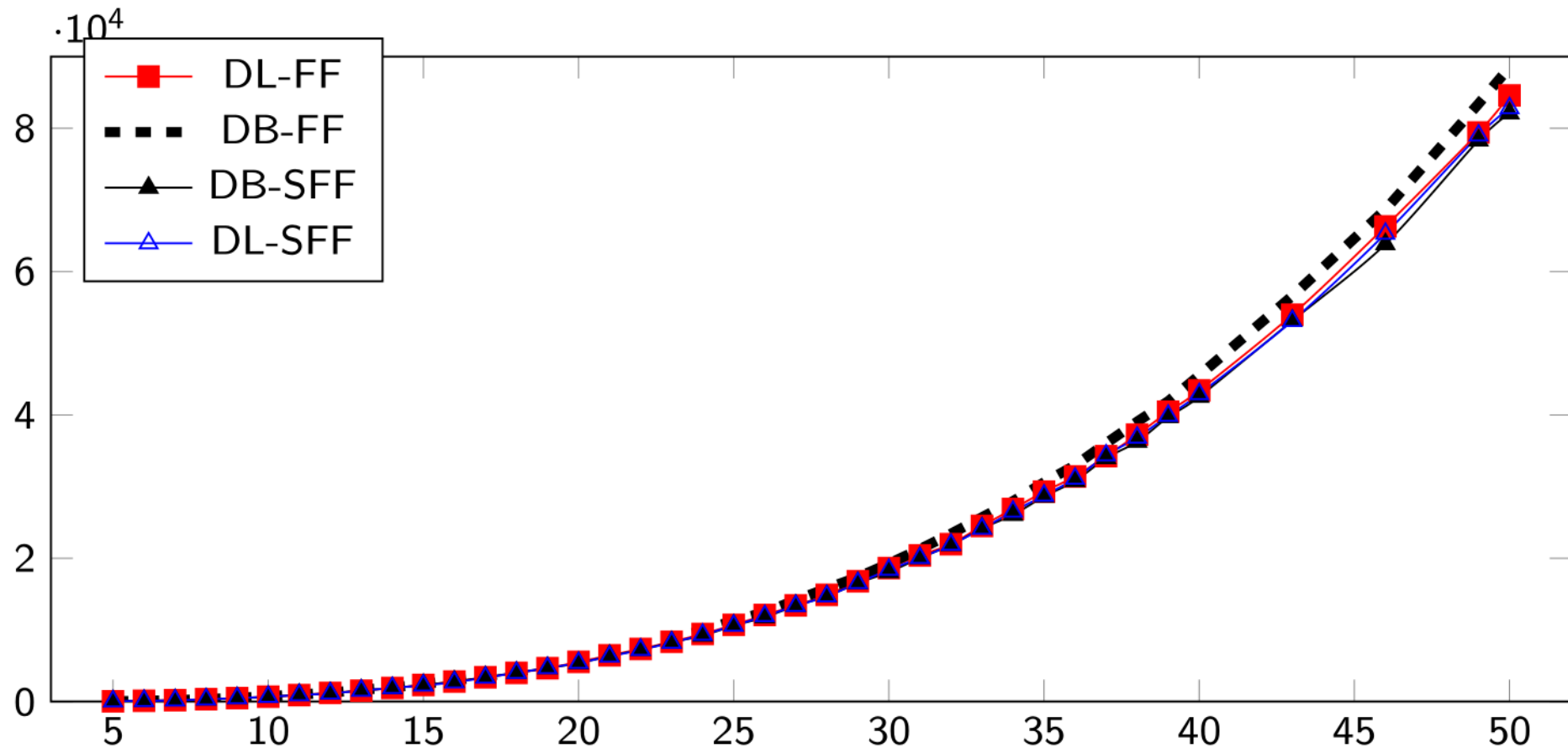
INTRODUCTION

NETWORK AND TRAFFIC

RSA

EXAMPLES

24



Network total capacity by amount of ring nodes

Numerical Examples

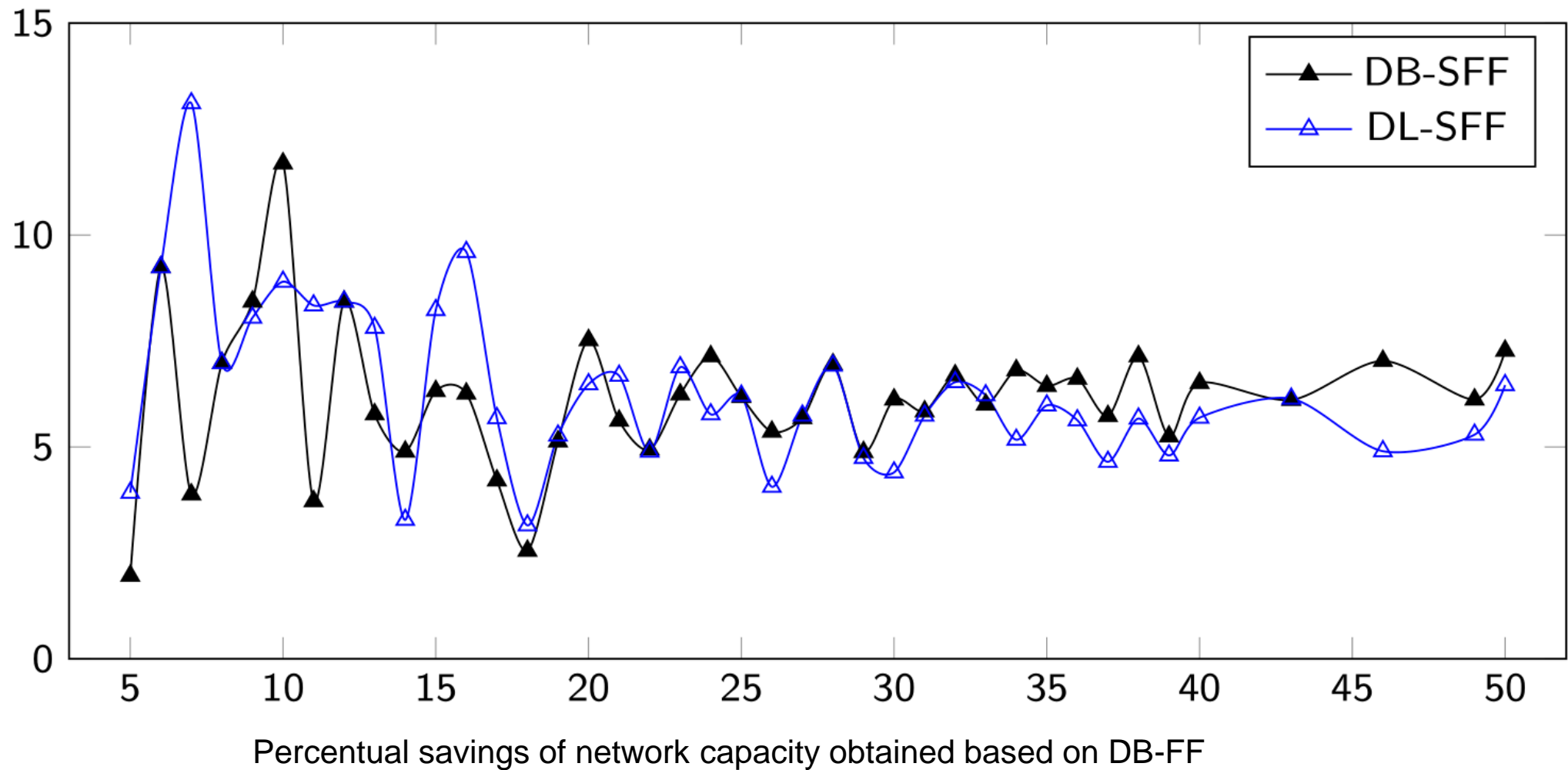
INTRODUCTION

NETWORK AND TRAFFIC

RSA

EXAMPLES

25



Numerical Examples

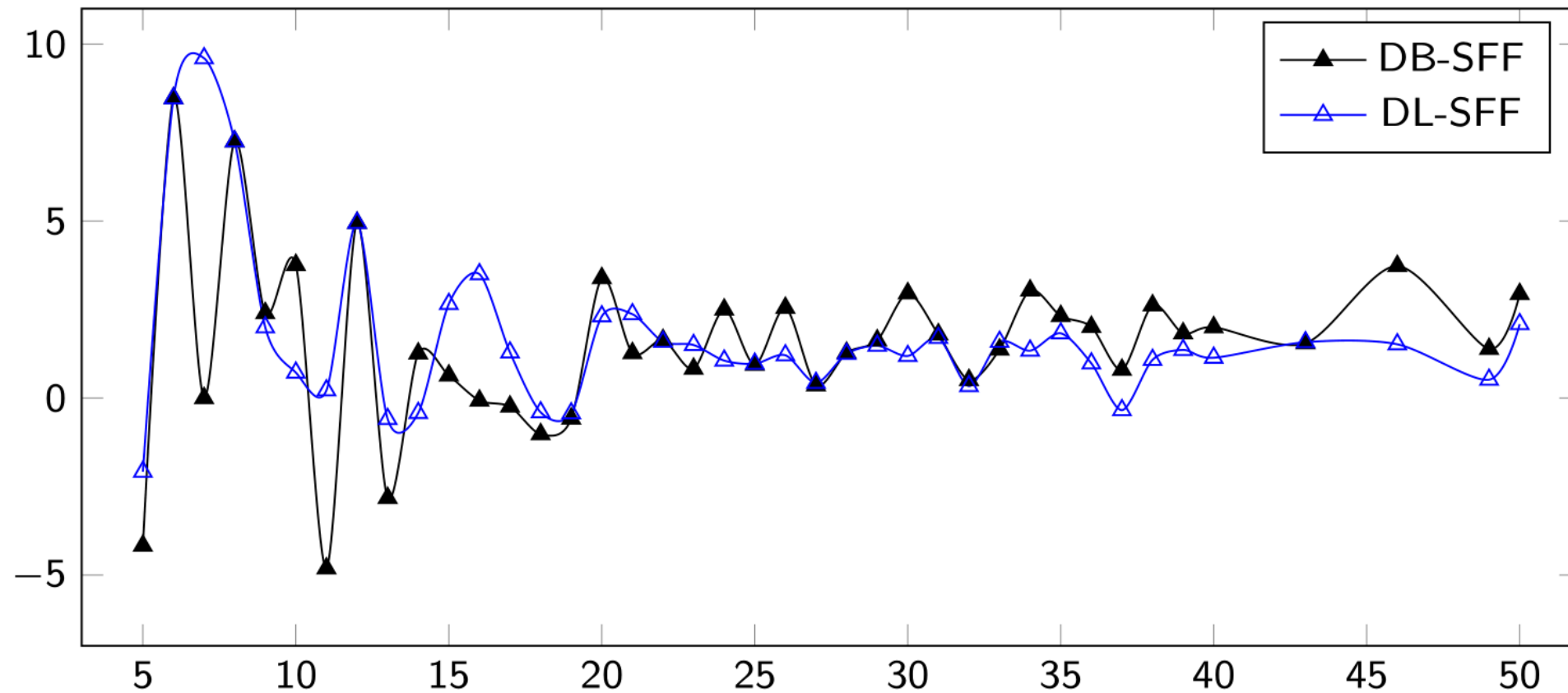
INTRODUCTION

NETWORK AND TRAFFIC

RSA

EXAMPLES

26



Percentual savings of network capacity obtained based on DL-FF

Numerical Examples

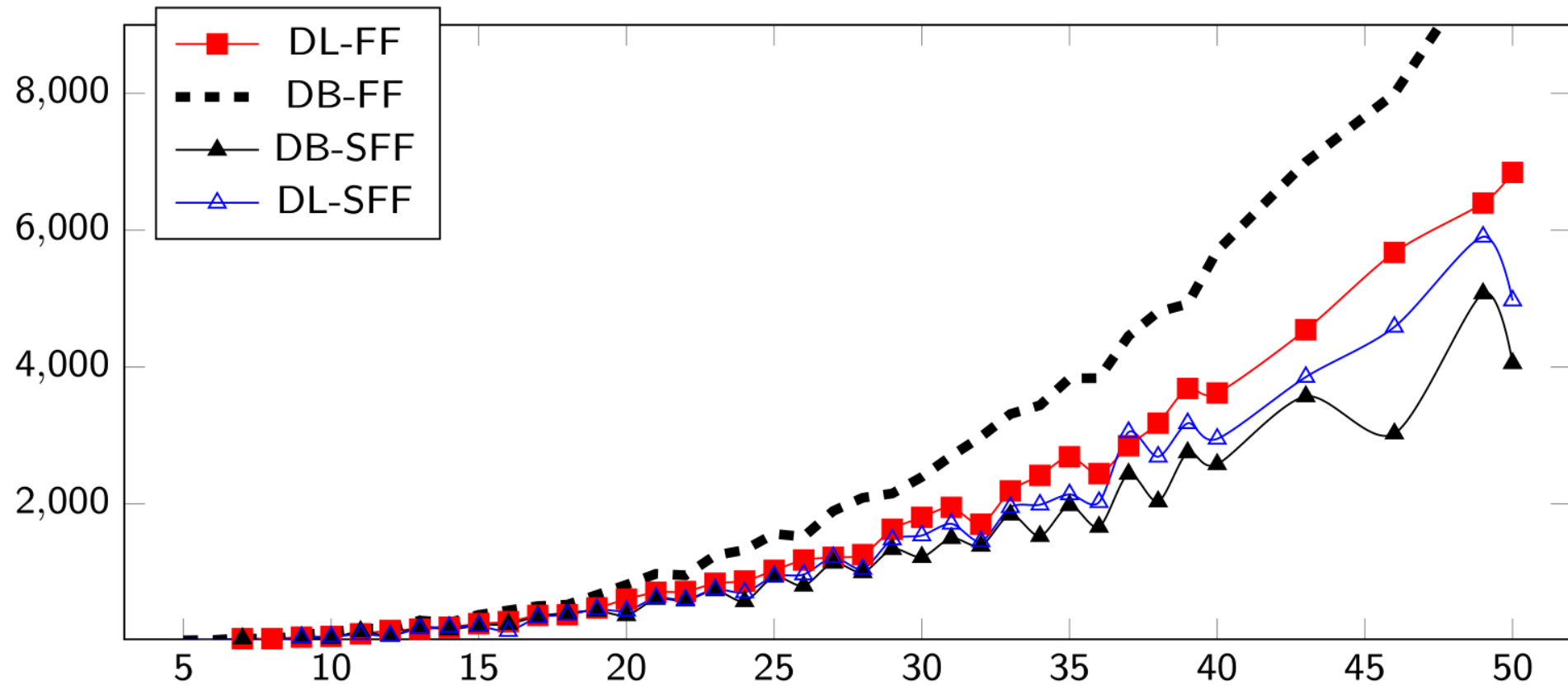
INTRODUCTION

NETWORK AND TRAFFIC

RSA

EXAMPLES

27



Amount of FSU fragmented 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.



UNIVERSIDAD TECNICA
FEDERICO SANTA MARIA

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

Questions?

July 29 – 31, 2019
Prague, Czech Republic

SIMULTECH 2019

9th International Conference on Simulation and Modeling

30-07/10-08-2019
Methodologies, Technologies and Applications