Quality of Service Provision in Dynamic WDM Optical Networks with Wavelength Continuity Constraints

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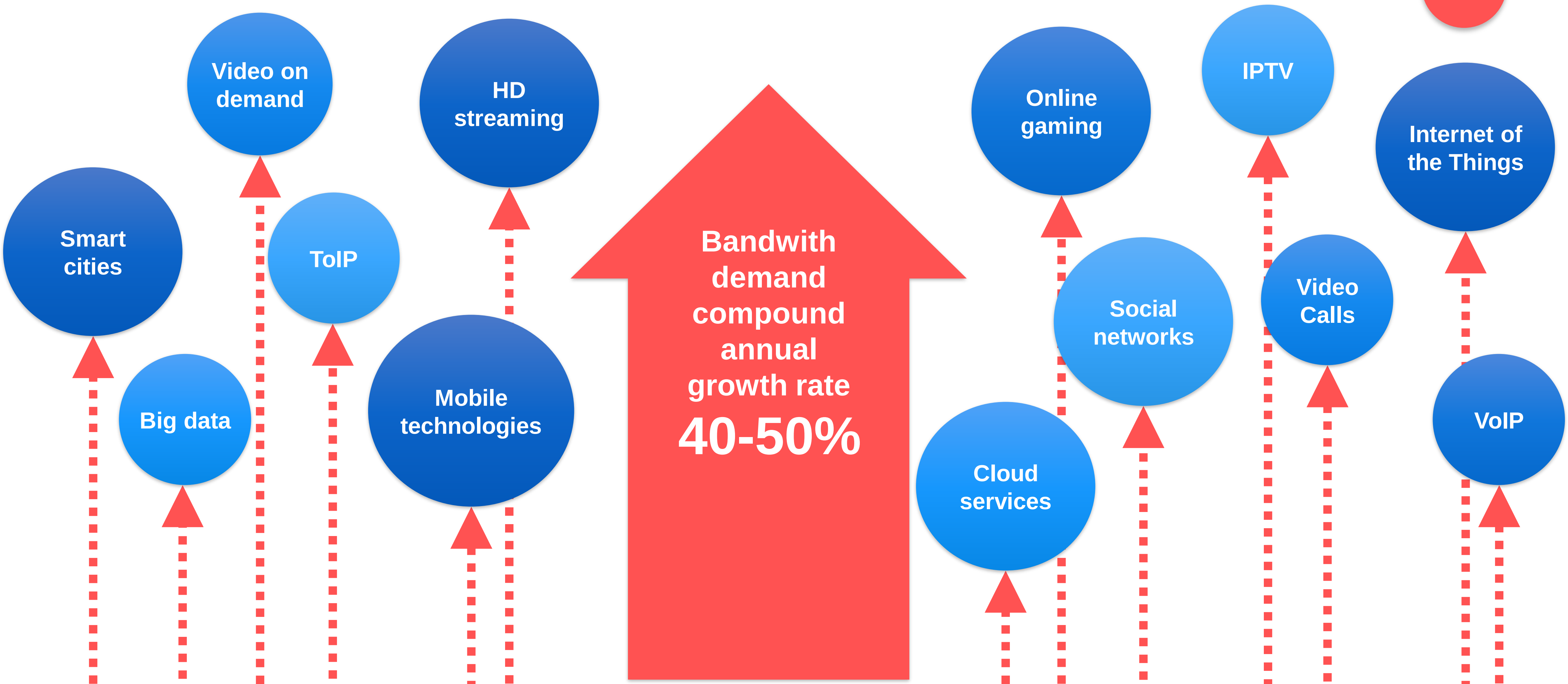
Bandwidth Demand



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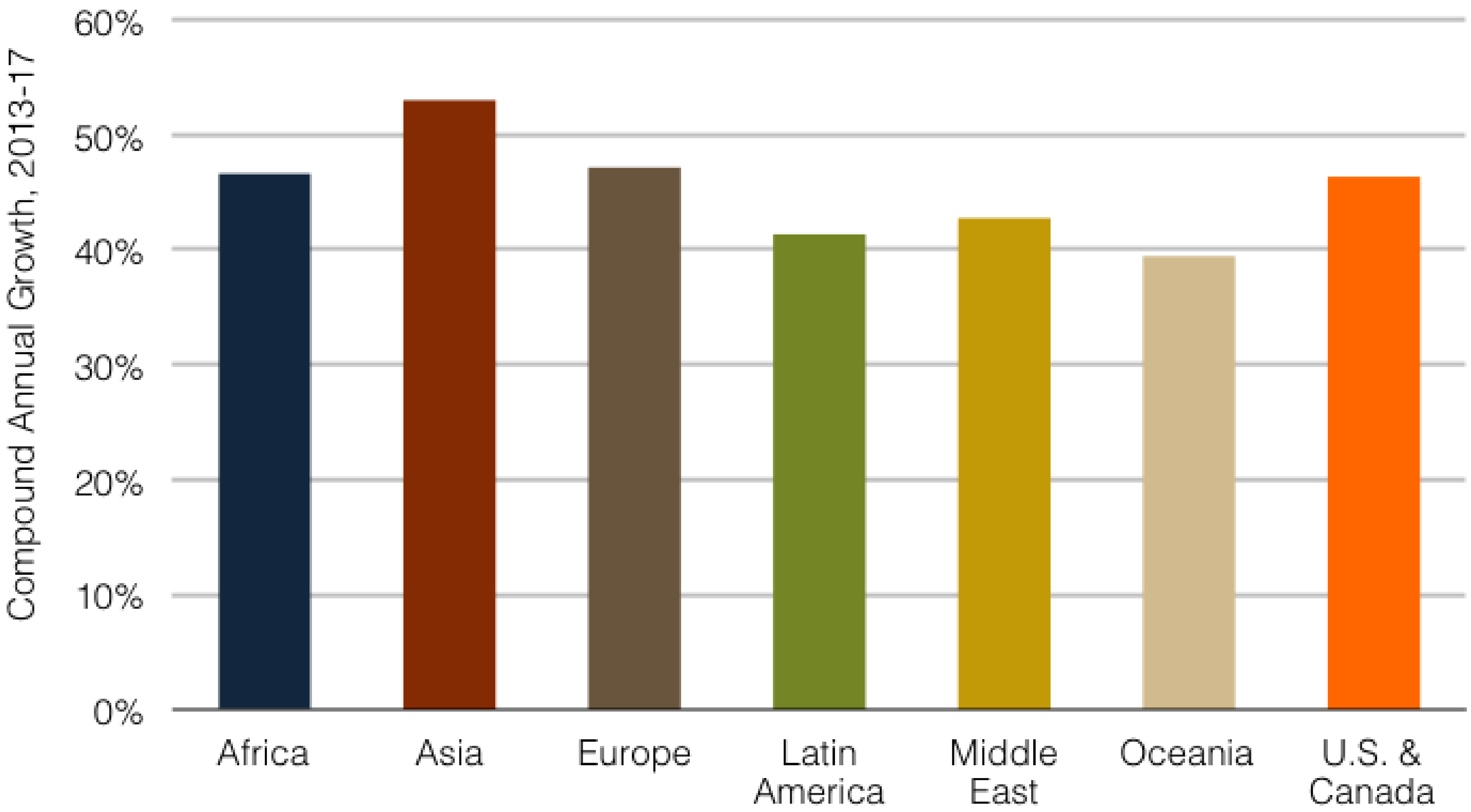

* https://www.telegeography.com/

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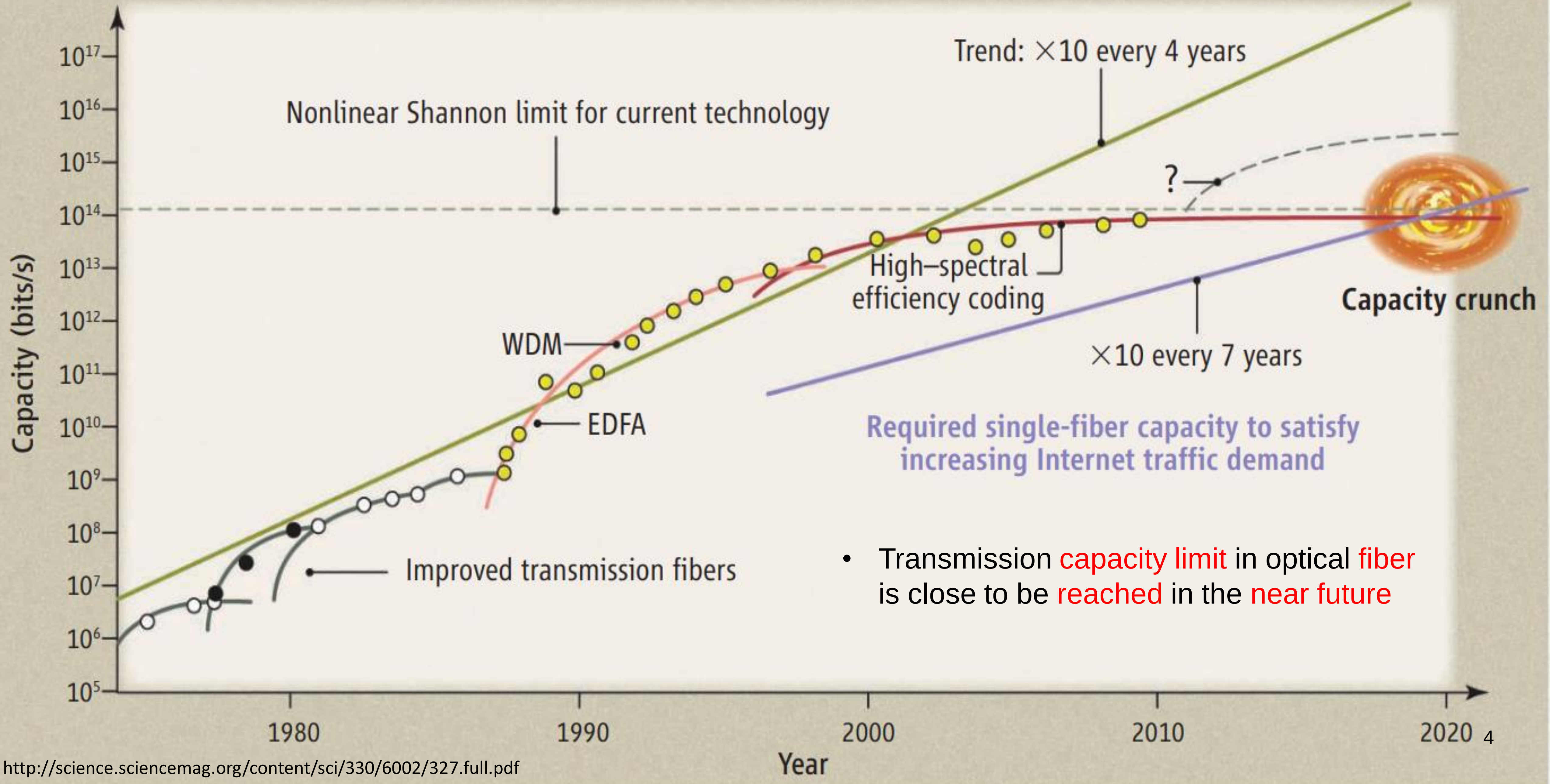
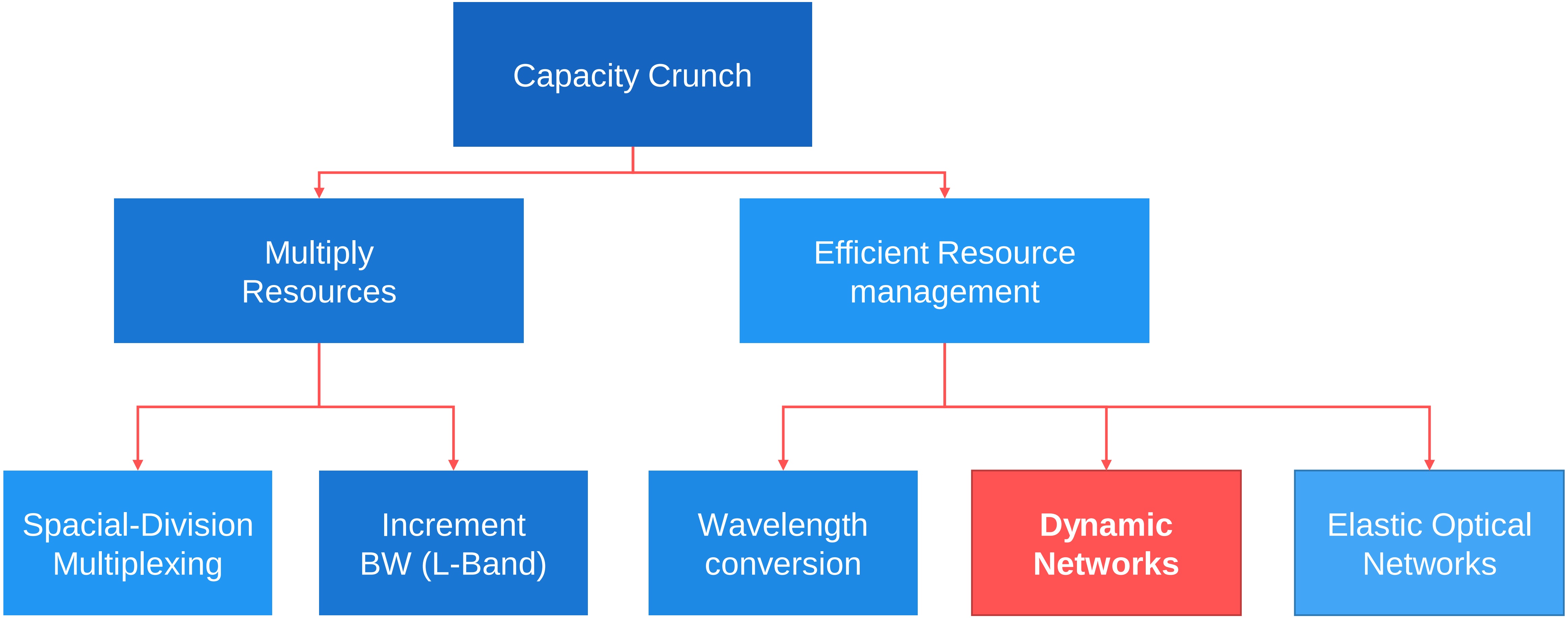


- Transmission capacity limit in optical fiber is close to be reached in the near future

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

Capacity Crunch Solutions



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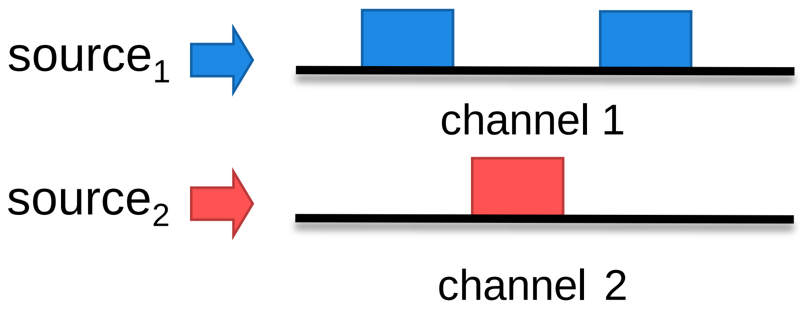
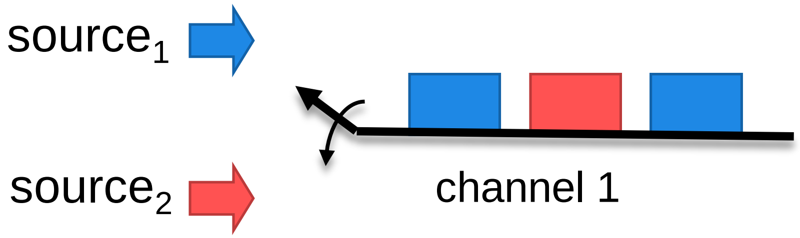
Resource Allocation

Static operation



- Easy to manage
- Resources usage inefficient

Dynamic operation



- Efficient use of resources
- Possible lack of resources (blocking probability)

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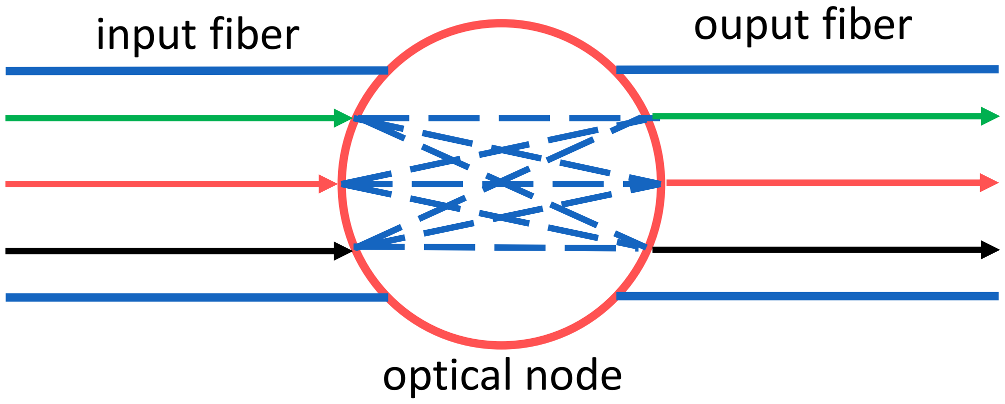
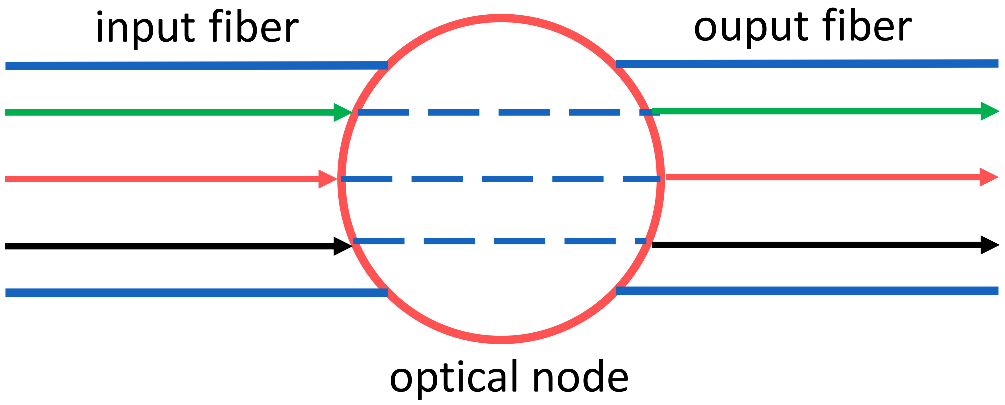
(No) Wavelength Conversion

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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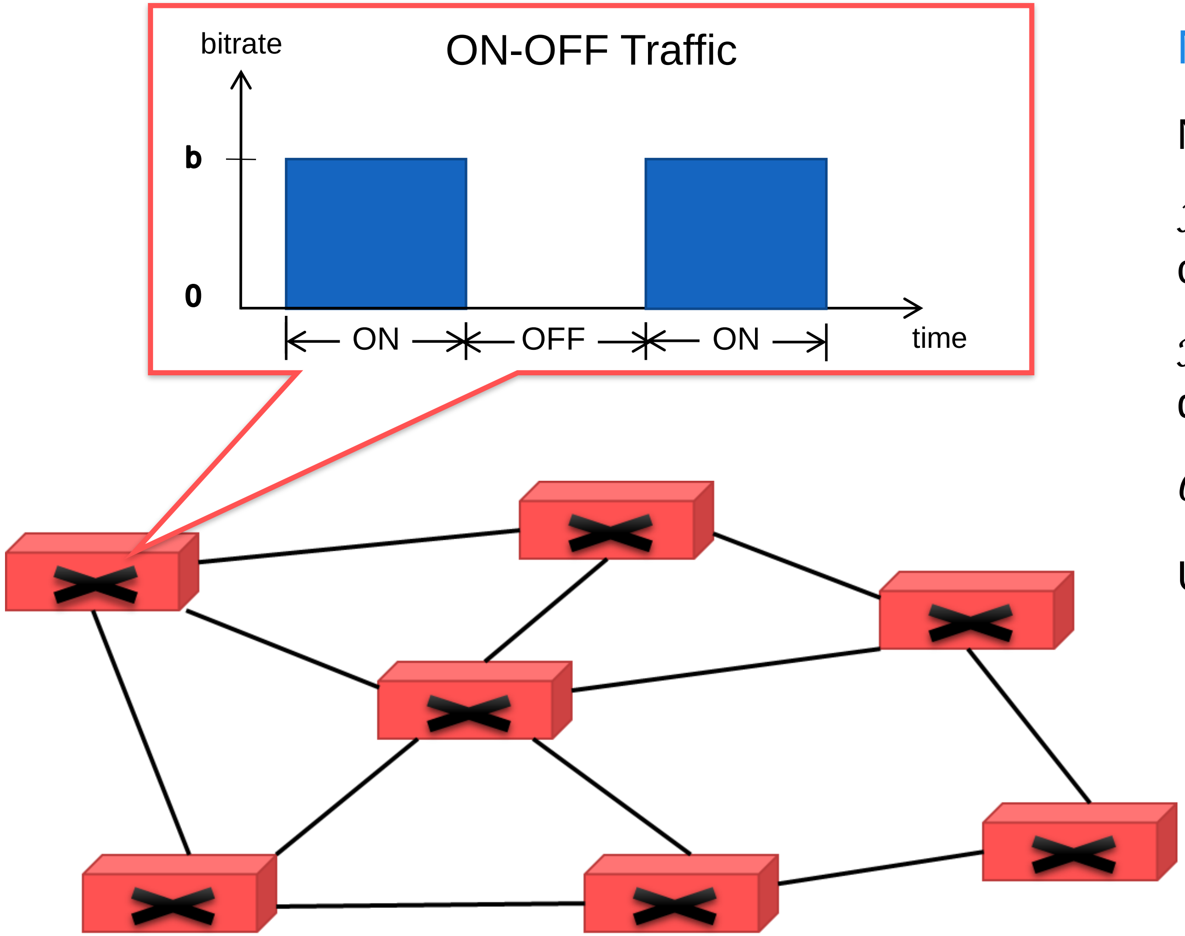
Network and Traffic Model



Network model

Network $\mathcal{G} = (\mathcal{N}, \mathcal{L})$

$\mathcal{X}$: Set of users c, i.e. source-destination pair of nodes with communications between them.

$\mathcal{R}$: Set of routes r_c that enable communications among the different users.

C_ℓ: Link ℓ capacity, measure as number of FSUs.

User c mean traffic load,

$$\varrho_c = \frac{t_{ON_c}}{t_{ON_c} + t_{OFF_c}}$$

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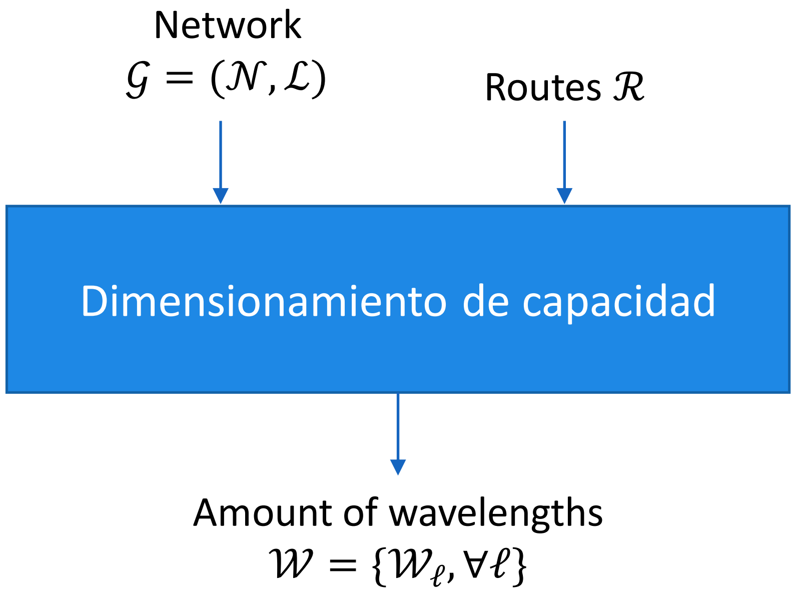
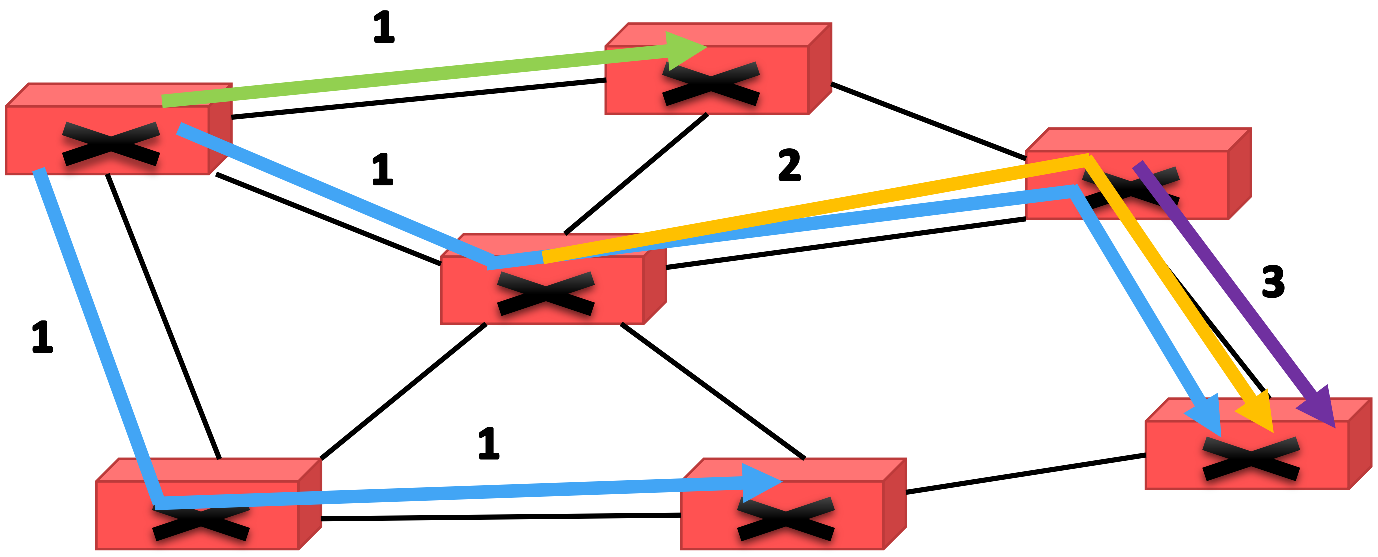
Dimensioning Problem

*Dimensioning a network is to computed the mínimum resource capacity allowing to fulfill the Service Level Agreement (SLA) constraints





* Penttinen A., Chapter 10 – Network Planning and Dimensioning, Lecture Notes: S-38.145 – Introduction to Teletraffic Theory, Helsinki University of Technology, Fall 1999.

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Wavelength Dimensioning

Wavelength Dimensioning

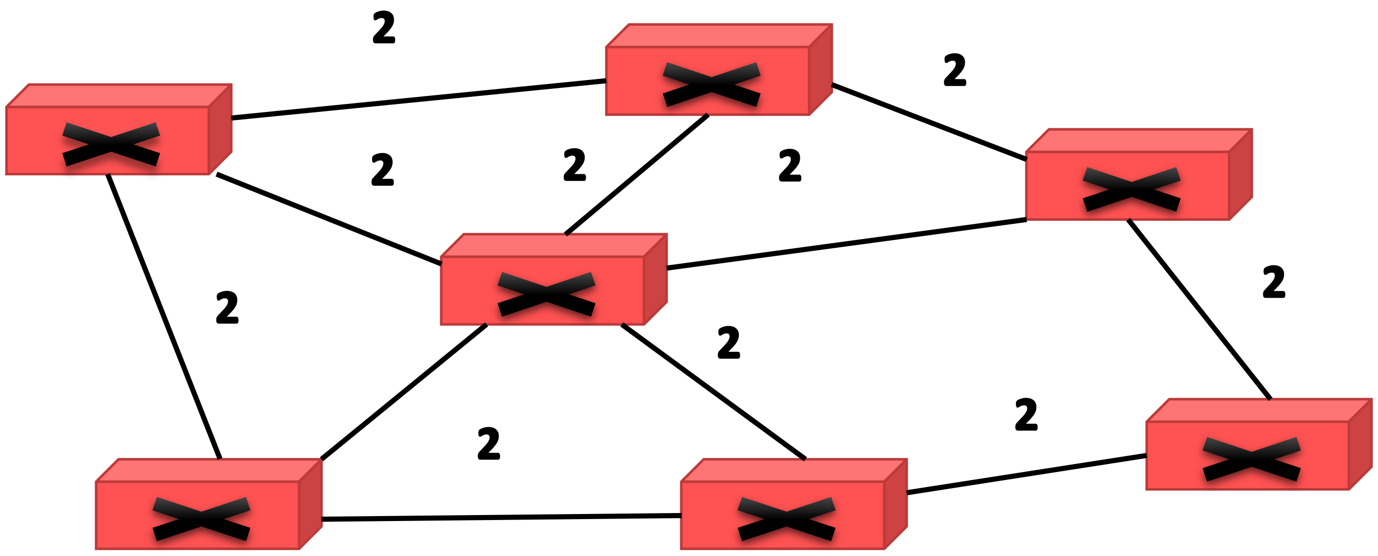
To define how many wavelengths are needed on the network links.

AP — Approximations

They give theoretical lower limits or bounds.

UD — Statistical Methods

They calculate the WD considering the QoS proposed (typically the same amount to all links, **Uniform Dimensioning**)



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Wavelength Dimensioning

UD

Statistical Methods

They calculate the WD considering the QoS proposed (typically the same amount to all links, **Uniform Dimensioning**)

… but

FIRST QUESTION

¿Must the capacity of the network links be the same?

No technical reason for this decision

Worst-case scenario

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Wavelength Dimensioning

UD

Statistical Methods

They calculate the WD considering the QoS proposed (typically the same amount to all links, **Uniform Dimensioning**)

… but

SECOND QUESTION

Once the dimensioning strategy is decided, ¿how to manage the wavelengths on each link?

All user can use all the wavelengths, despite their QoS constraints

The Offered QoS to some users are much stricter than required (SLA)

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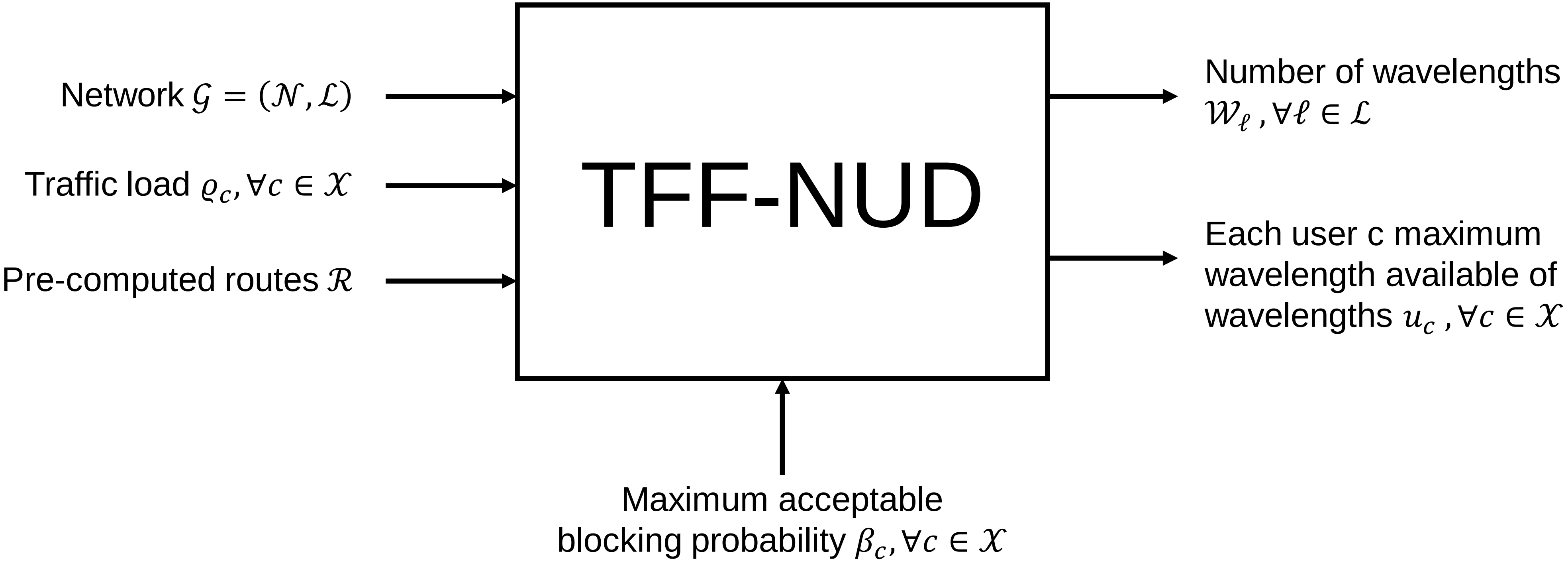
Wavelength Dimensioning method diagram



Tight First-Fit – Non Uniform Dimensioning

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Wavelength Dimensioning method

- The wavelengths are numbered sequentially (i.e. 1,2,...,$\mathcal{W}_\ell$).
- The routes $\mathcal{R}$ are fixed, pre-computed by any method available on the literature
- The method uses a First-Fit wavelength assignment approach, and during the method's execution, it will be modified by the Tight QoS policy.
- $\mathcal{Q} = \{ c \mid c \in \mathcal{X}\}$, set of users with their QoS constraint satisfied (maximum acceptable blocking probability) during the iterative procedure.
- $\mathcal{U} = \{ u_c \mid c \in \mathcal{X}\}$, set containing the maximum available wavelength to each user c.

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TFF-NUD Method

STEP 1

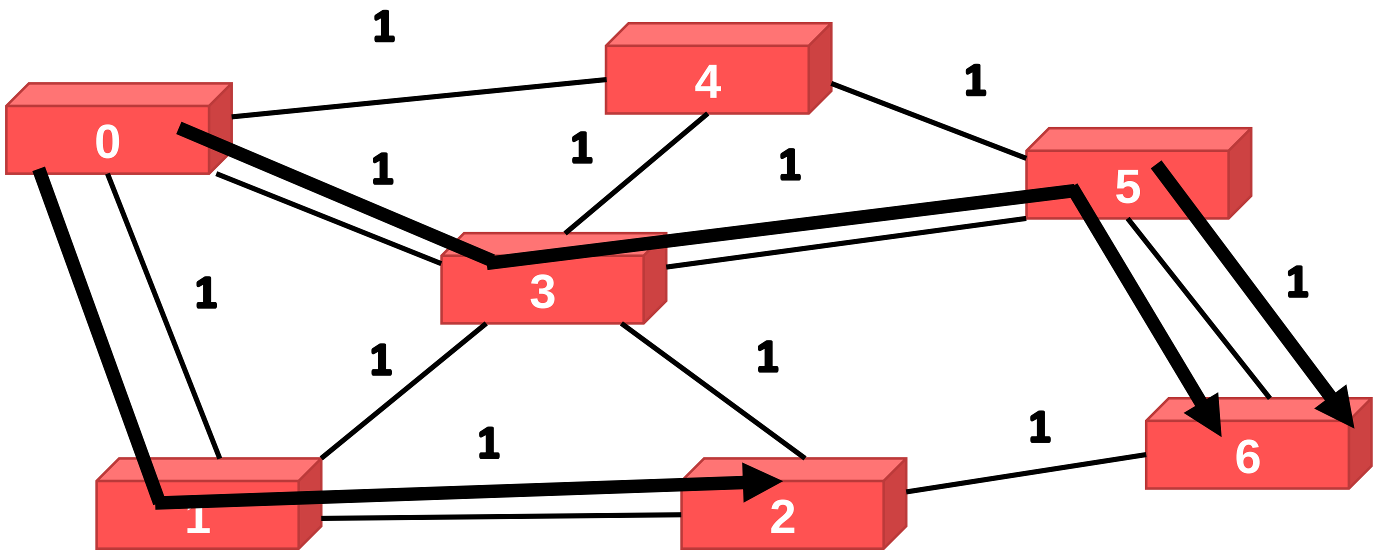
Inputs: $\mathcal{G}, \mathcal{X}, \mathcal{R}$ and β_c

$\mathcal{Q} = \{\} = \phi$

$\mathcal{U} = \{\} = \phi$

$\mathcal{W}_\ell = 1, \forall \ell \in \mathcal{L}$

$\beta_{(0,6)} = 10^{-3}$ $\beta_{(0,2)} = 10^{-1}$ $\beta_{(5,6)} = 10^{-1}$



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TFF-NUD Method

STEP 2

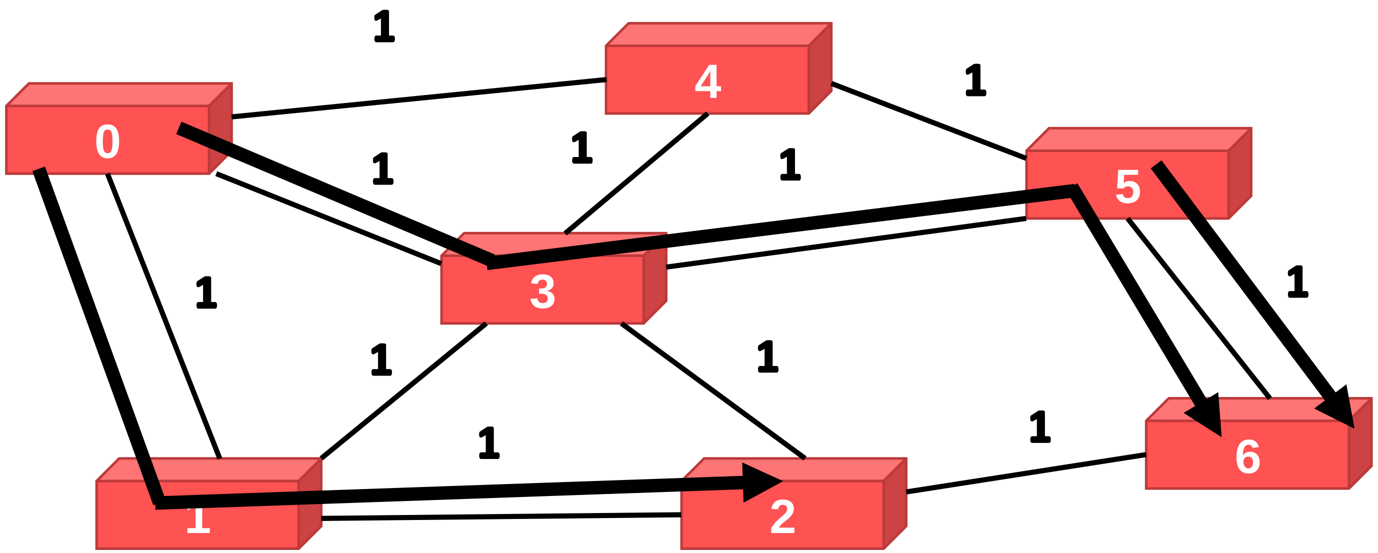
Inputs: $\mathcal{G}, \mathcal{X}, \mathcal{R}$ and β_c

$$\mathcal{Q} = \{\} = \phi$$

$$\mathcal{U} = \{\} = \phi$$

$\beta_{(0,6)} = 10^{-3}$ $\beta_{(0,2)} = 10^{-1}$ $\beta_{(5,6)} = 10^{-1}$

$BP_{(0,6)} = 0{,}09$ $BP_{(0,2)} = 0{,}09$ $BP_{(5,6)} = 0{,}09$



user's blocking evaluation

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TFF-NUD Method

STEP 2

Inputs: $\mathcal{G}, \mathcal{X}, \mathcal{R}$ and β_c

$\mathcal{Q} = \{\} = \phi$

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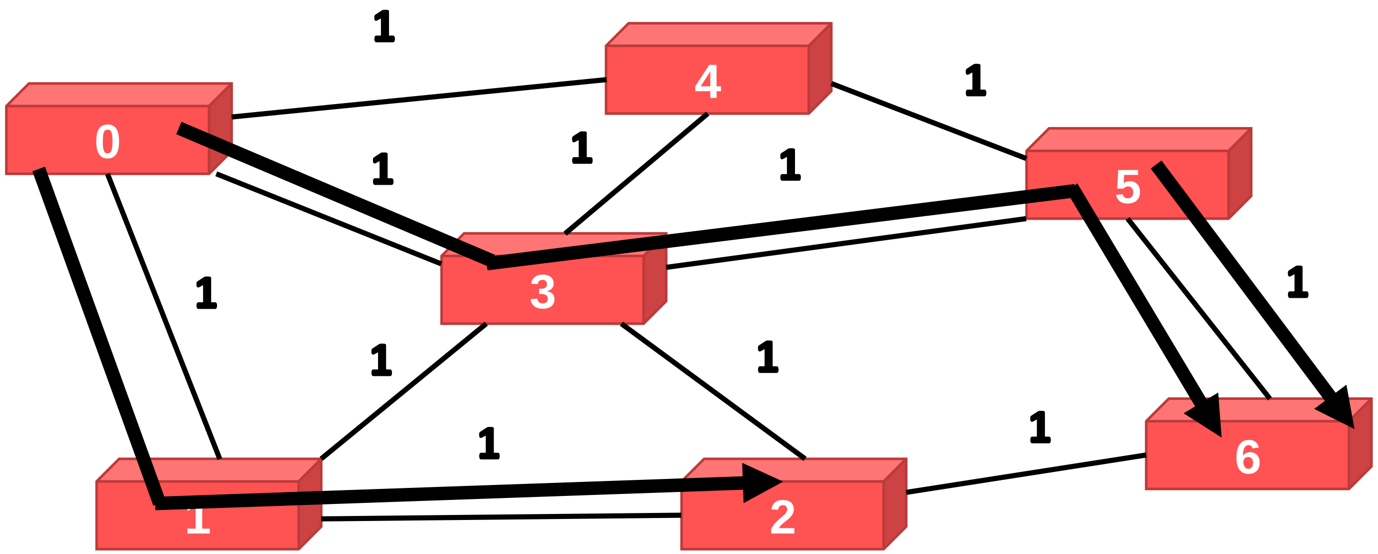

user's blocking evaluation → $BP_c \leq \beta_c$

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TFF-NUD Method

STEP 2

Inputs: $\mathcal{G}, \mathcal{X}, \mathcal{R}$ and β_c

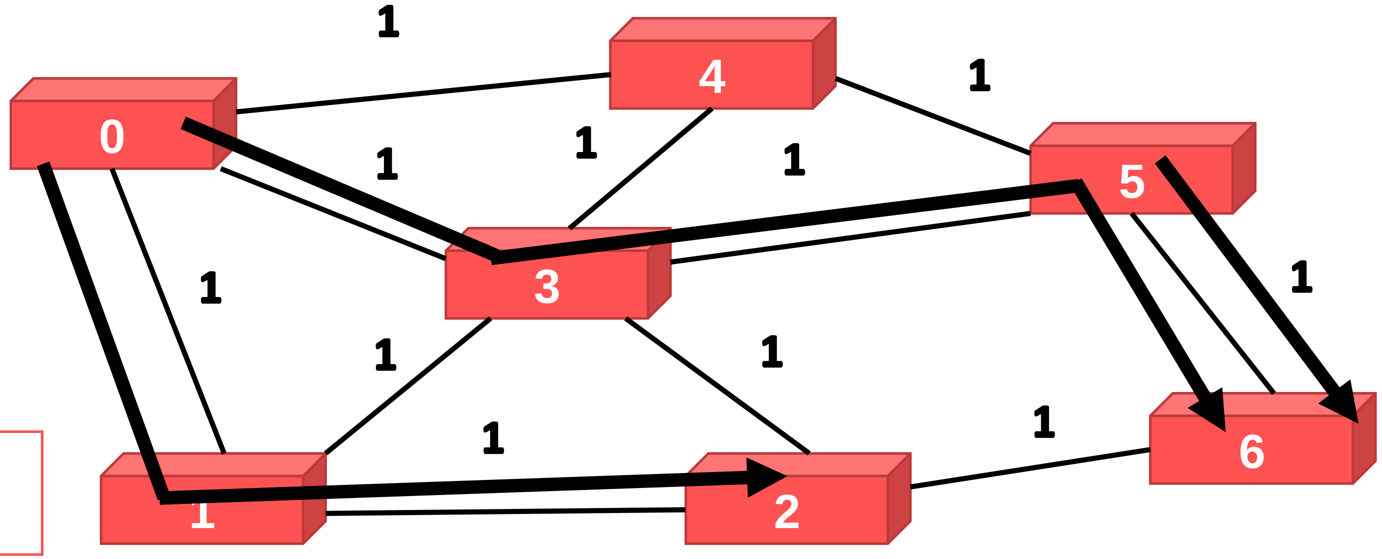
$$\mathcal{Q} = \{(0,2),(5,6)\}$$

$$\mathcal{U} = \{1,1\}$$

Wavelength Grouping

$$\beta_{(0,6)} = 10^{-3}$$

$$BP_{(0,6)} = 0{,}09$$



user's blocking evaluation → $BP_c \leq \beta_c$

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TFF-NUD Method

STEP 3

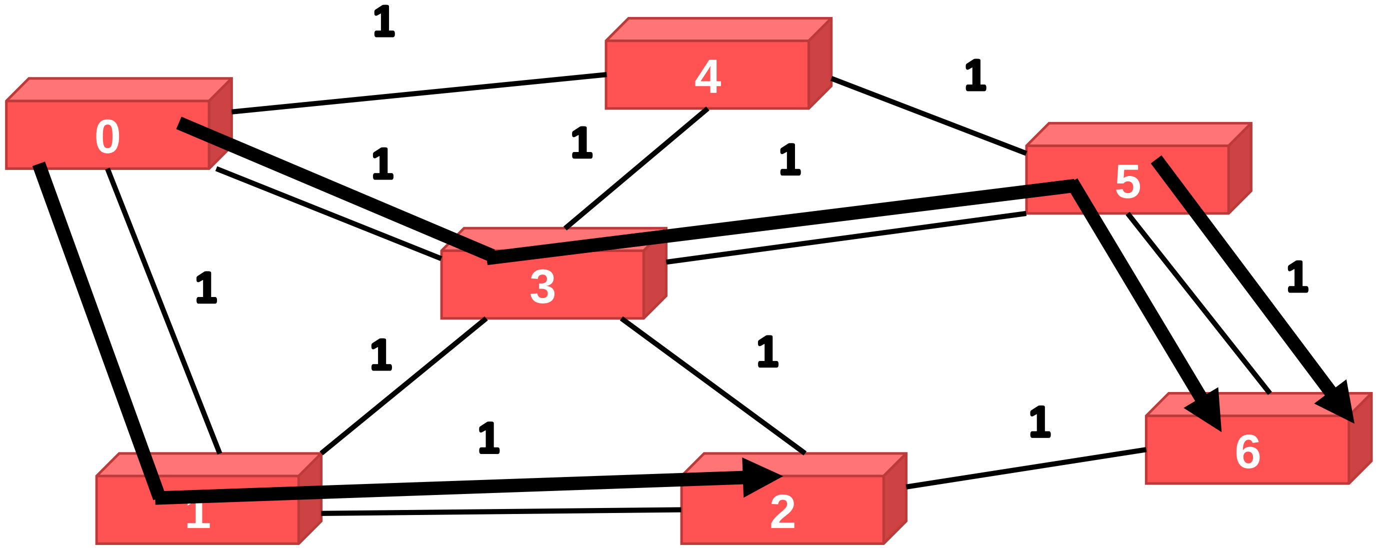
Inputs: $\mathcal{G}, \mathcal{X}, \mathcal{R}$ and β_c

$$\mathcal{Q} = \{(0,2), (5,6)\}$$

$$\mathcal{U} = \{1,1\}$$

$$\beta_{(0,6)} = 10^{-3}$$

$$BP_{(0,6)} = 0{,}09$$



¿every user c using link ℓ, for all $\forall \ell \in \mathcal{L}$, has satisfied its QoS constraints?

TFF-NUD Method

STEP 3

Inputs: $\mathcal{G}, \mathcal{X}, \mathcal{R}$ and β_c

$$\mathcal{Q} = \{(0,2),(5,6)\}$$

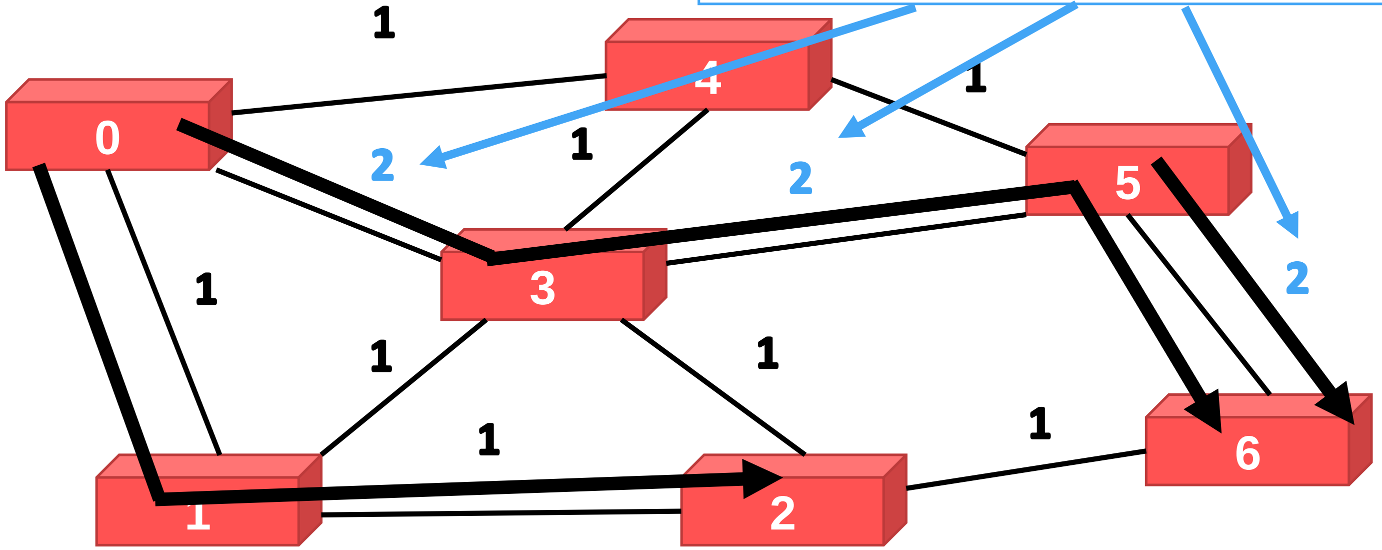
$$\mathcal{U} = \{1,1\}$$

$$\mathcal{W}_\ell = \mathcal{W}_\ell + 1$$

$$\beta_{(0,6)} = 10^{-3}$$

$$BP_{(0,6)} = 0{,}09$$

Non-Uniform Dimensioning



¿every user c using link ℓ, for all $\forall \ell \in \mathcal{L}$, has satisfied its QoS constraints?

TFF-NUD Method

ITERATIVE STEP 2 AND 3

Inputs: $\mathcal{G}, \mathcal{X}, \mathcal{R}$ and β_c

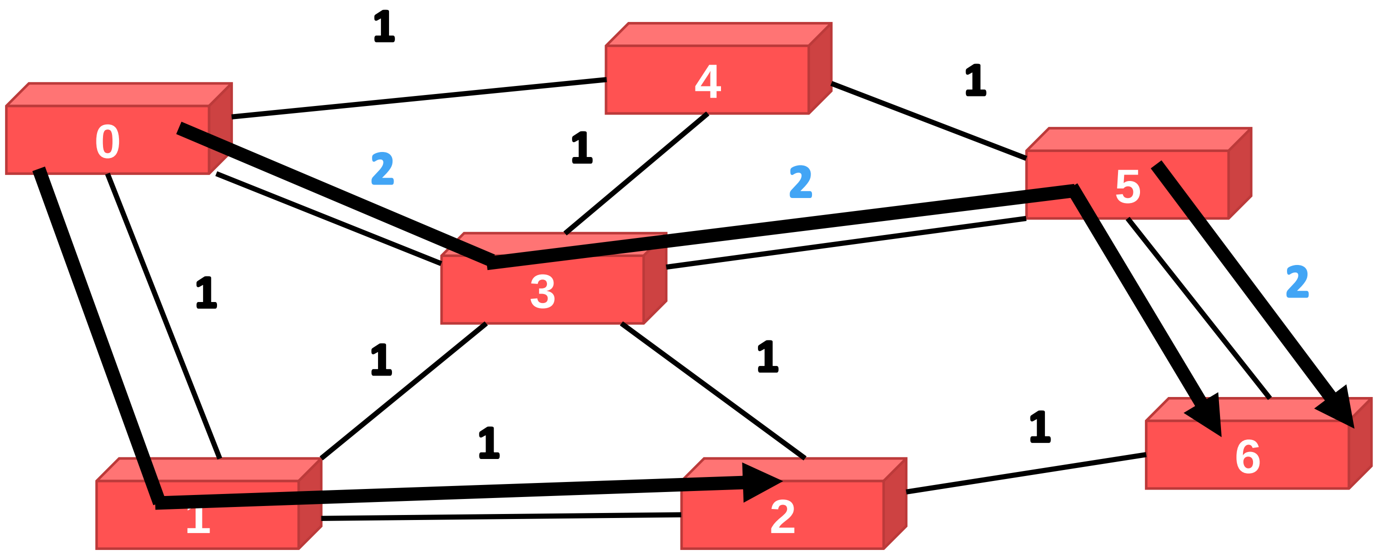
$$\mathcal{Q} = \{(0,2),(5,6)\}$$

$$\mathcal{U} = \{1,1\}$$

$$\mathcal{W}_\ell = \mathcal{W}_\ell + 1$$

$$\beta_{(0,6)} = 10^{-3}$$

$$BP_{(0,6)} = 0{,}09$$



Iterate step 2 and 3, until $\mathcal{Q} = \mathcal{X}$

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TFF-NUD Method

ITERATIVE STEP 2 AND 3

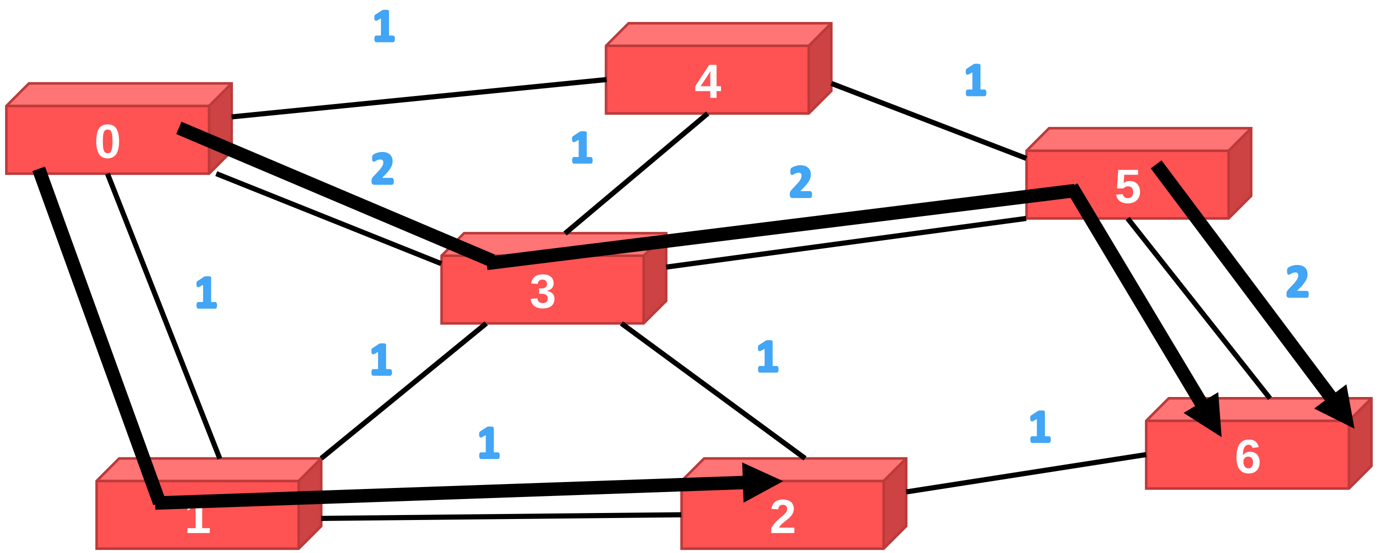
Inputs: $\mathcal{G}, \mathcal{X}, \mathcal{R}$ and β_c

$$\mathcal{Q} = \{(0,2),(5,6),(0,6)\}$$

$$\mathcal{U} = \{1,1,2\}$$

$$\beta_{(0,6)} = 10^{-3}$$

$$BP_{(0,6)} = 0{,}0009$$

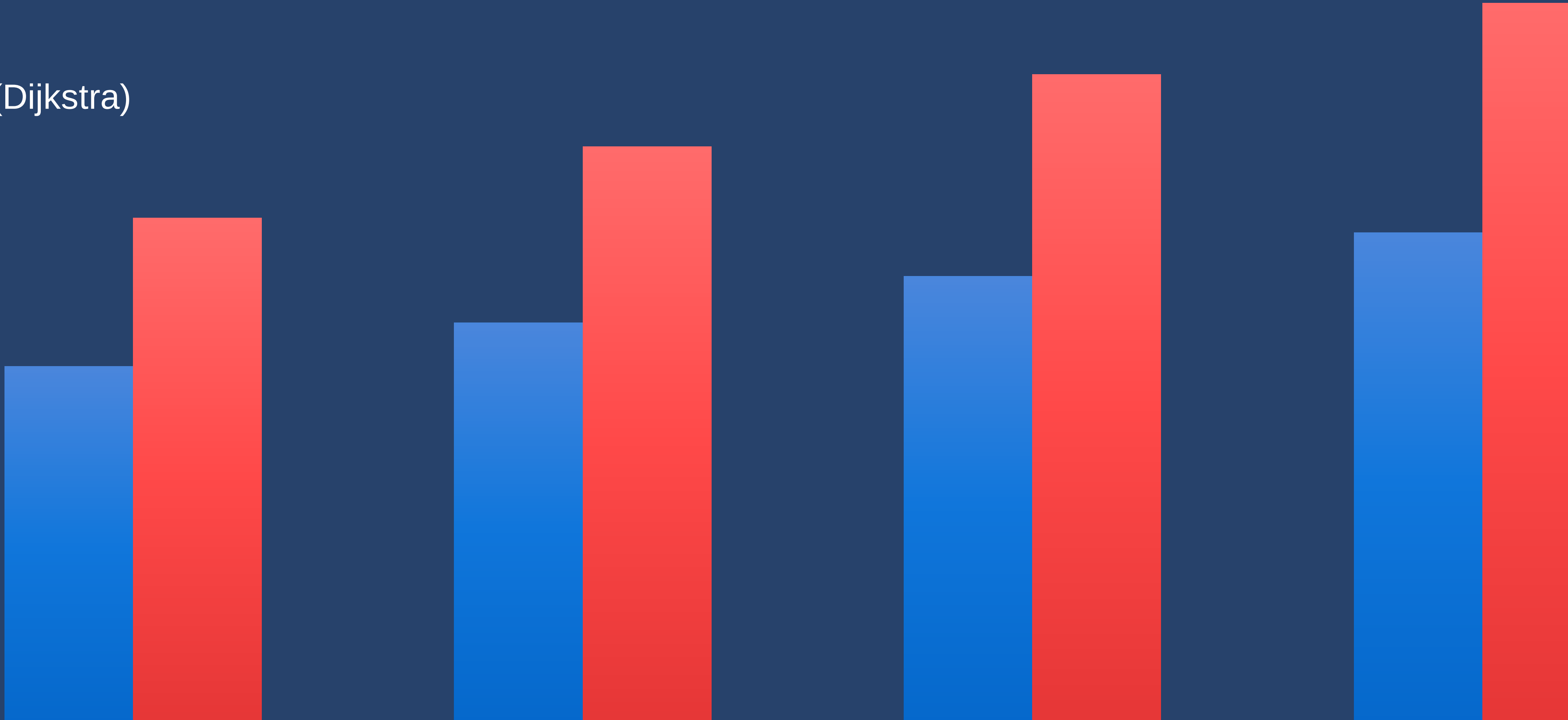


Iterate step 2 and 3, until $\mathcal{Q} = \mathcal{X}$

Numerical Examples

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

- Several different Real Mesh Topologies
- Compared to First-Fit WA and Uniform WD (FF-UD).
- Same fixed routes (Dijkstra)
- We measured the overall network capacity $\mathcal{C}_{net}$ as the sum of all wavelengths in the network



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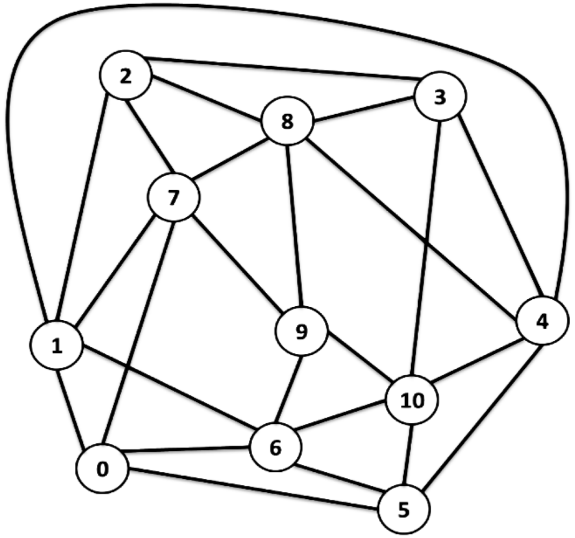
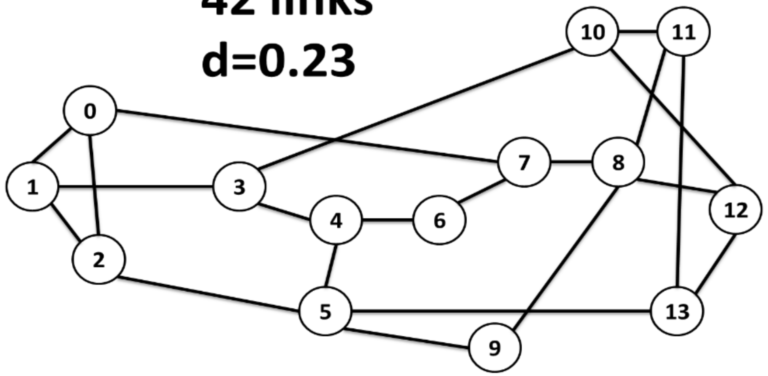
Real Network Topologies

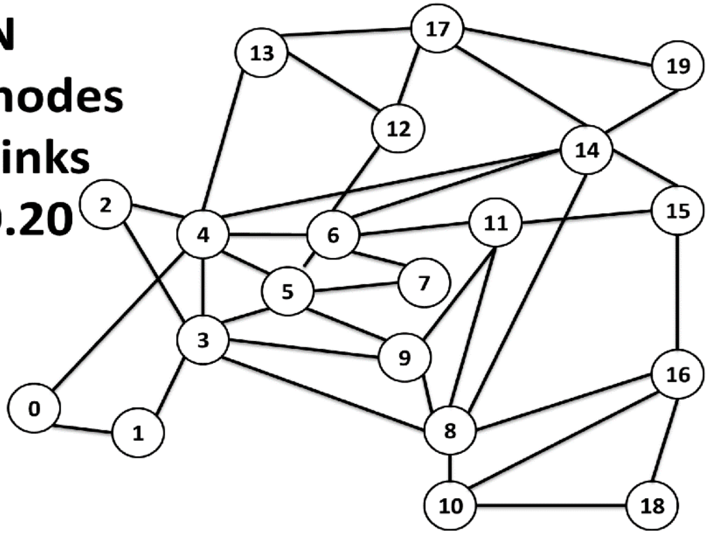
Eurocore
11 nodes
50 links
d=0.45



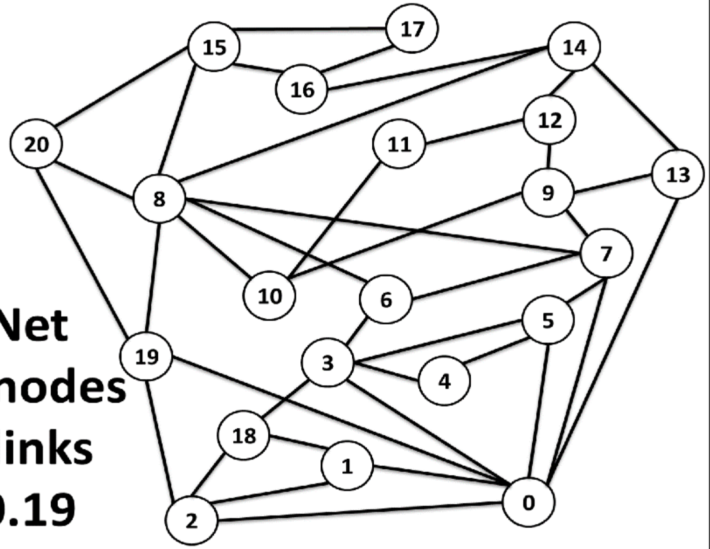
NSFNet
14 nodes
42 links
d=0.23



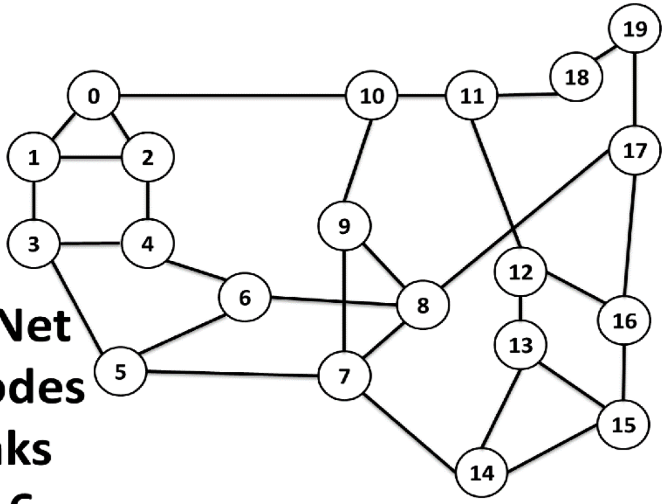
EON
20 nodes
78 links
d=0.20



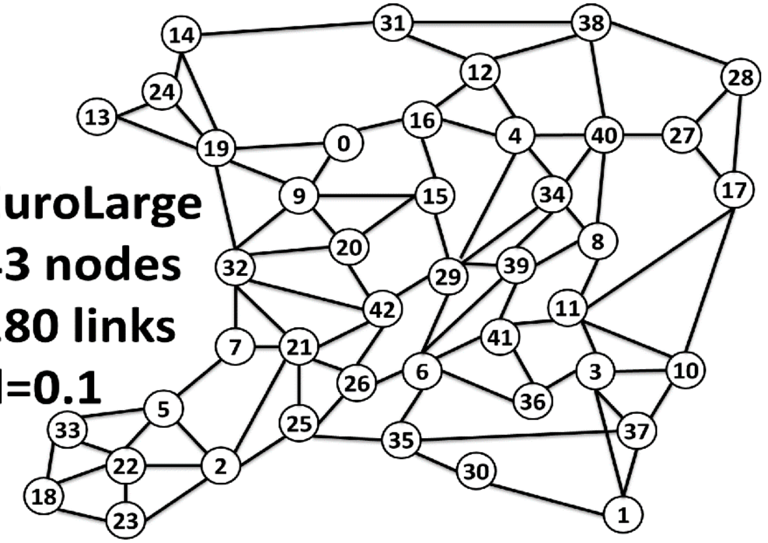
UKNet
21 nodes
78 links
d=0.19



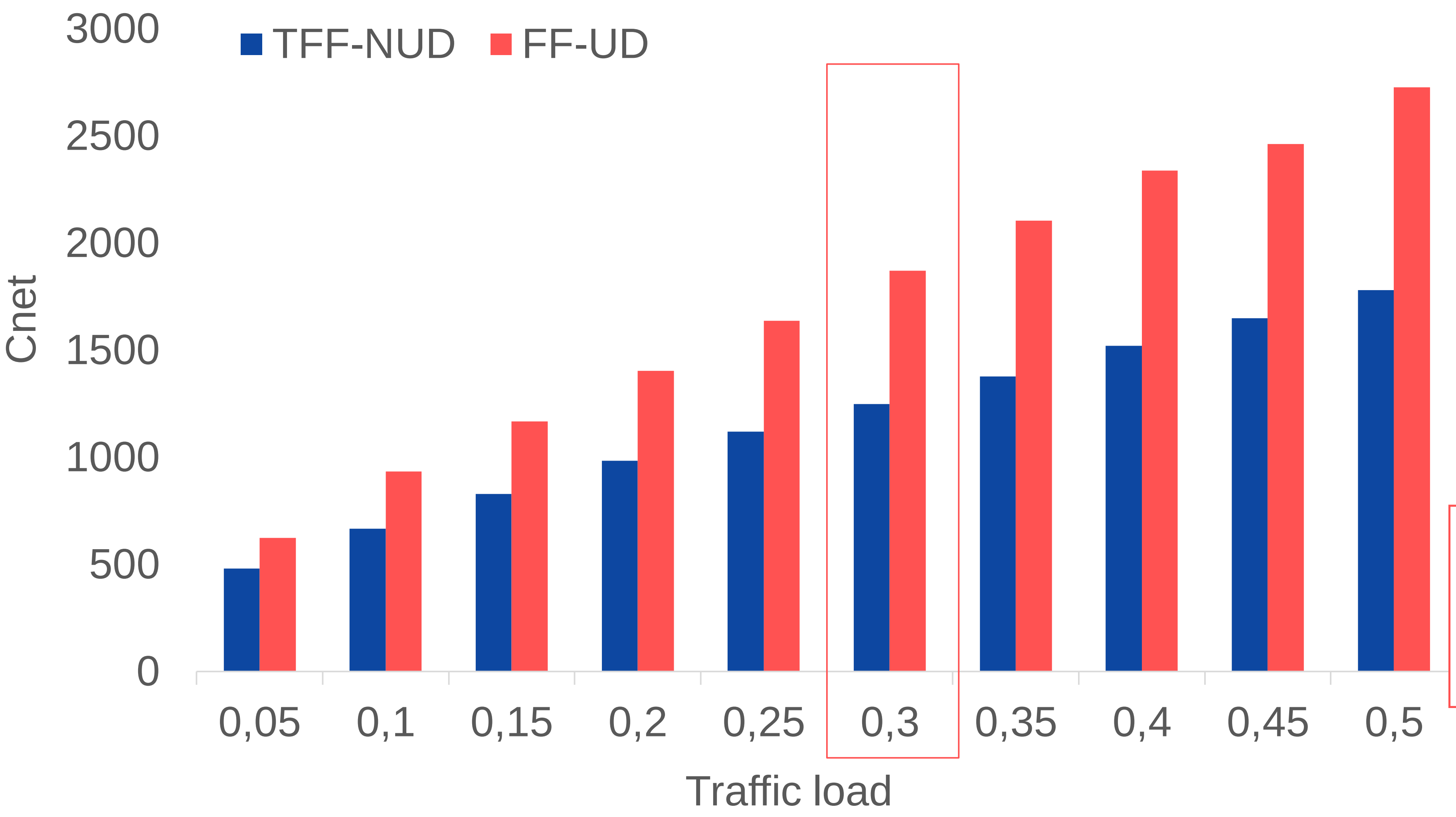
ArpaNet
20 nodes
62 links
d=0.16



EuroLarge
43 nodes
180 links
d=0.1



Numerical Examples



The total number of wavelengths $\mathcal{C}_{net}$ obtained with TFF-NUD and with FF-UD on EON, for different users traffic loads with an homogeneous maximum acceptable blocking probability $\beta_c = 10^{-3}$.

On average, TFF-NUD obtains a 30% less wavelengths than FF-UD, on a standard traffic load equal to 0,3.

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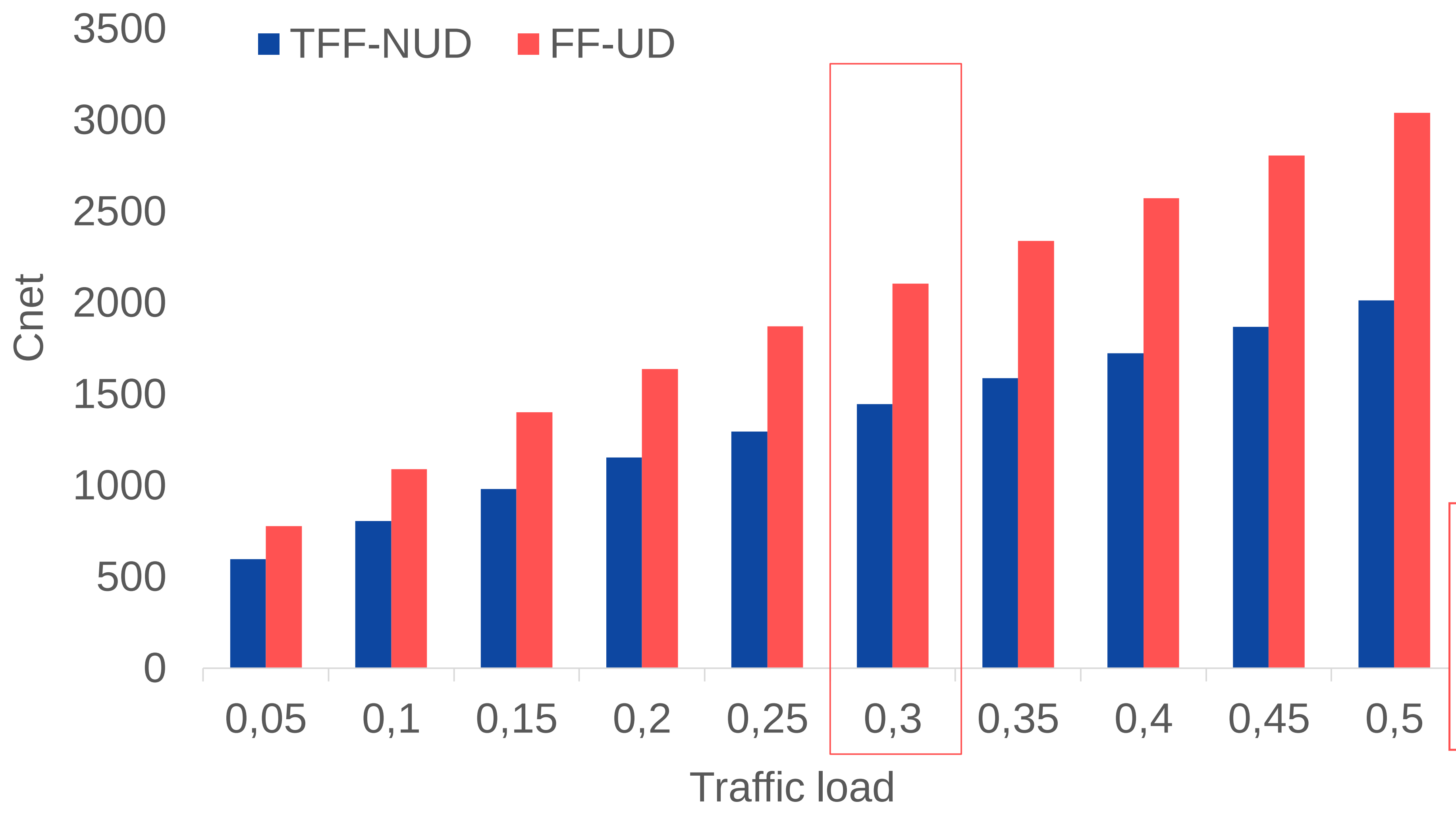
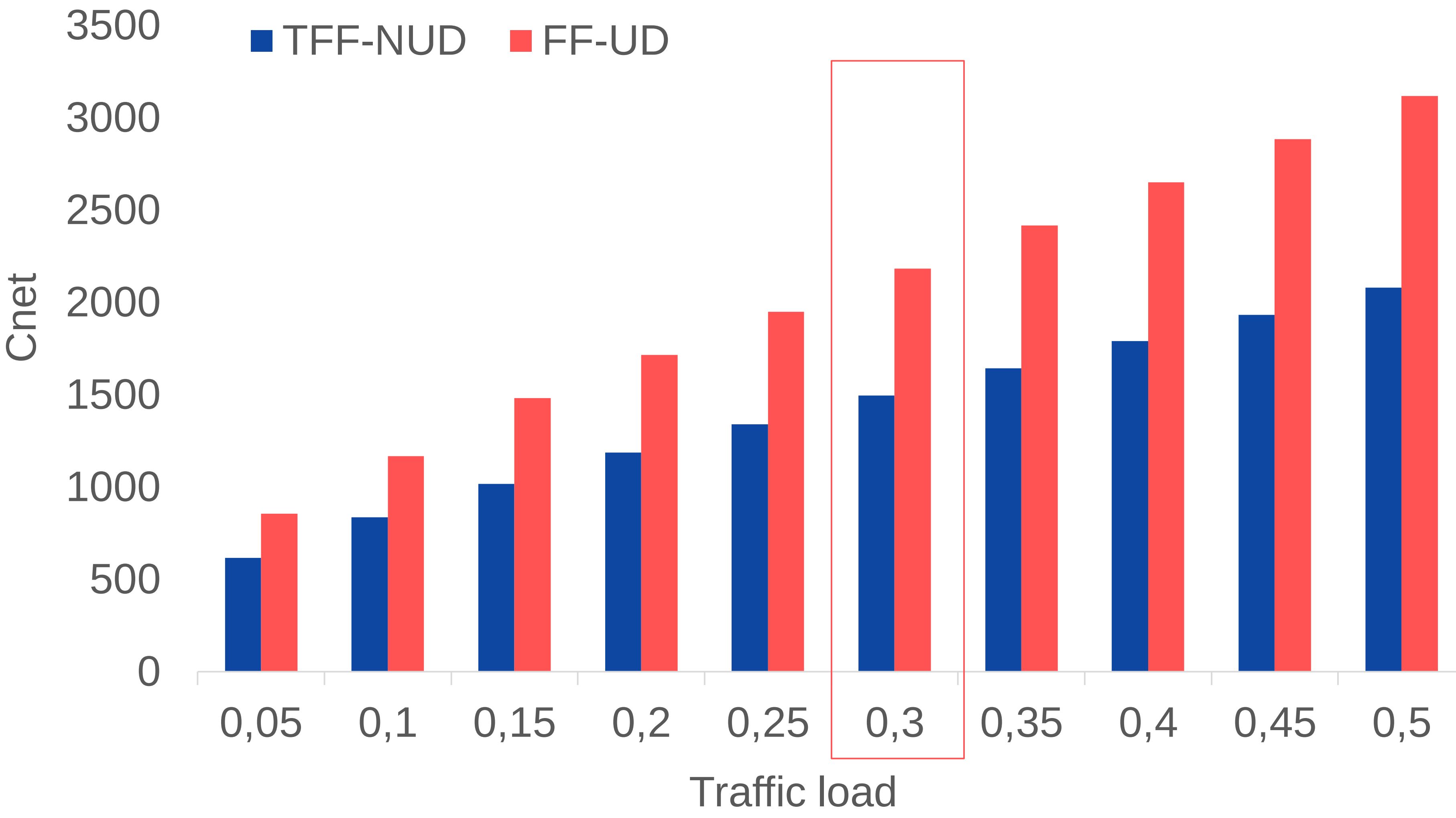
Numerical Examples



The total number of wavelengths C_{net} obtained with TFF-NUD and with FF-UD on EON, for different connection traffic loads. The values of β_c are chosen between 10^{-6} and 10^{-3} in an arbitrary form.

On average, TFF-NUD obtains a 28% less wavelengths than FF-UD, on a standard traffic load equal to 0,3.

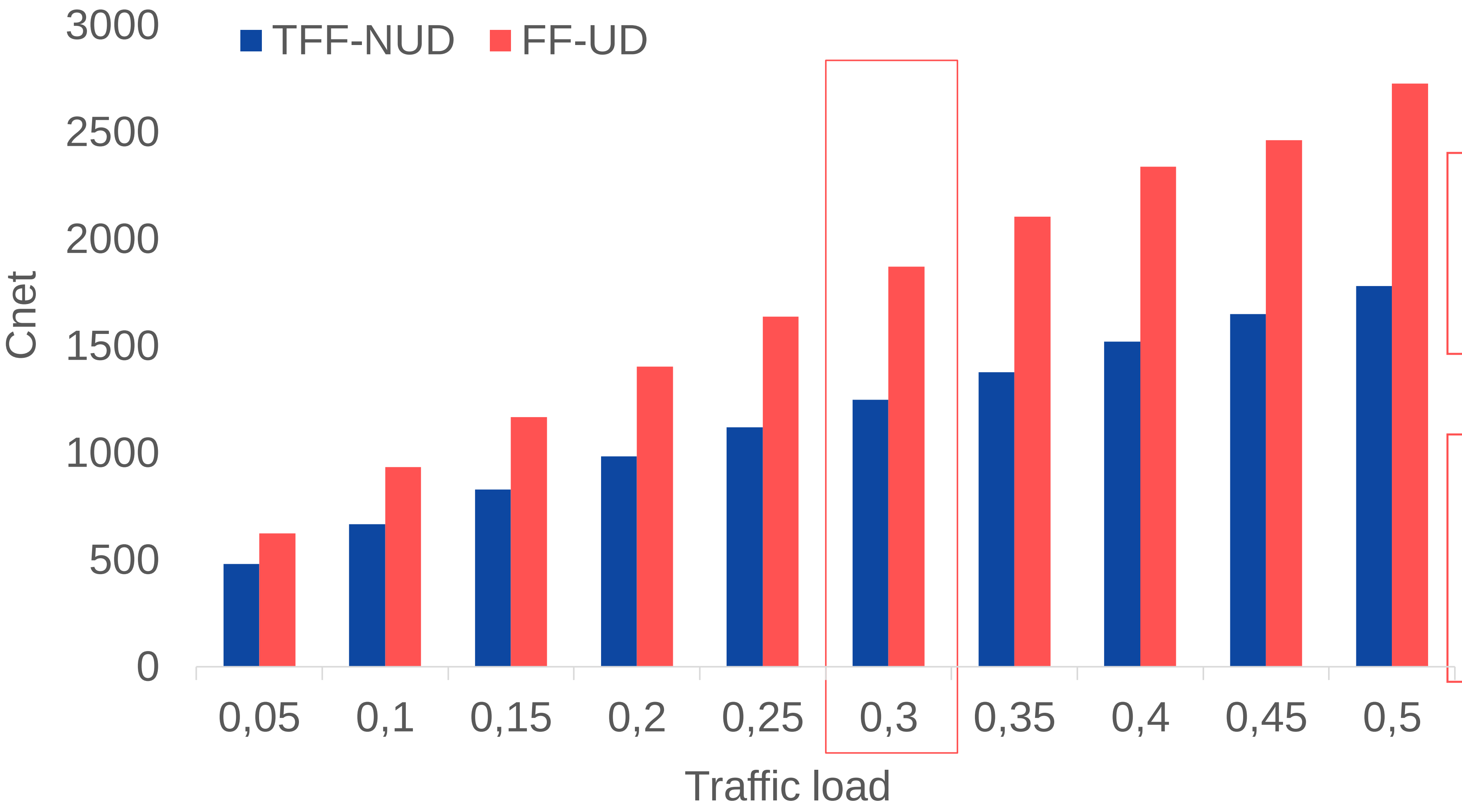
Numerical Examples



The total number of wavelengths C_{net} obtained with TFF-NUD and with FF-UD on EON, for different connection traffic loads. The values of β_c are chosen between 10^{-3} and 10^{-6} in an ascending order proportional to the routes length.

On average, TFF-NUD obtains a 30% less wavelengths than FF-UD, on a standard traffic load equal to 0,3.

Numerical Examples



On average, the non-uniformity on the wavelength dimensioning provides an 80% of the savings

On the other side, the "tightness" on the QoS provision contributes with the remaining 20% of the savings achieved.

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Contributions of the paper

Assessing the impact of different strategies of wavelength dimensioning

Planning the network considering wavelength grouping on a wavelength continuity constraints context

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Questions?

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