Dynamic Routing Algorithms for Content-Oriented Elastic Optical Networks

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Agenda

- Introduction
- Elastic Optical Networks
- Problem Formulation
- Results
- Future Works

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- **Introduction**
- Elastic Optical Networks
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Computer Networks Group
Head: Prof. Krzysztof Walkowiak

- Optimization of computer networks
- Elastic optical networks (flex grid)
- Content oriented networks
- Network survivability
- Overlay and P2P networks

Computer Networks Group
Head: Prof. Krzysztof Walkowiak

- dr. Przemysław Ryba
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- Michał Kucharzak, Ph.D Student
- Michał Aibin, Ph.D Student

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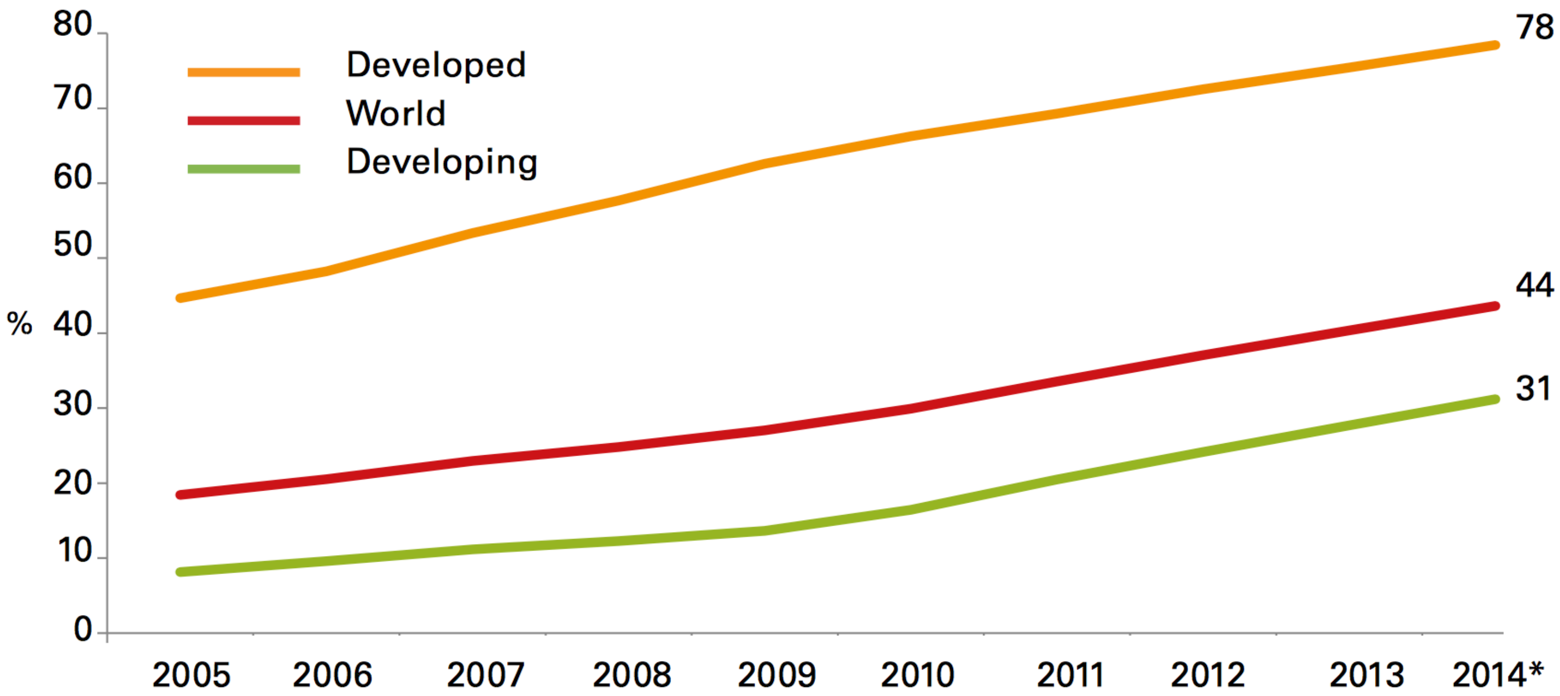
- Polish National Science Centre (NSC) Grant DEC-2012/07/B/ST7/01215 „Algorithms for optimization of routing and spectrum allocation in content oriented elastic optical networks”

Motivation

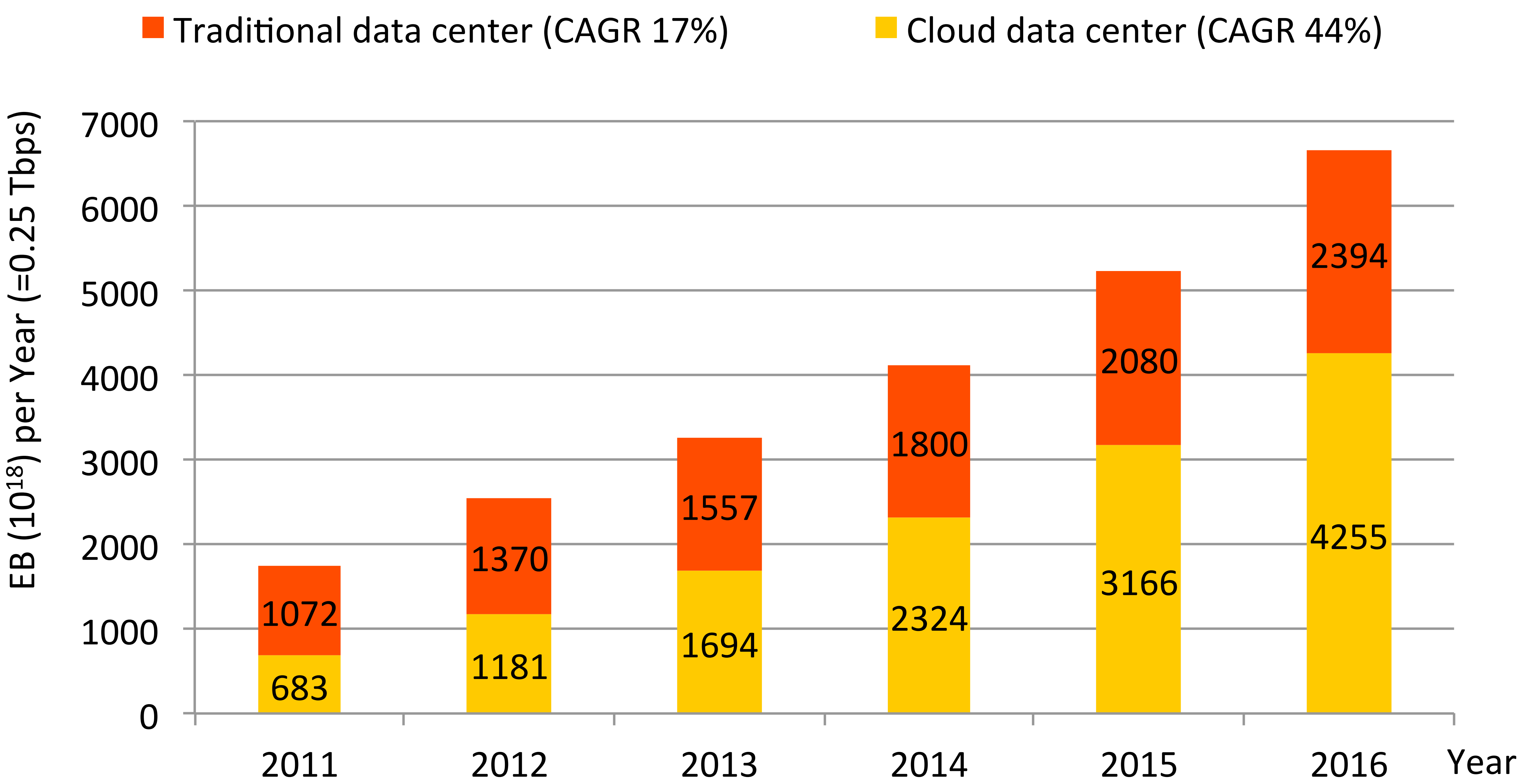
In 2014, over 3 billion people were using the Internet, which corresponds to 44% of the world's population.

The standards applied to computer networks are challenging. Networks have to accommodate the inflation of clients and be able to fulfill their demands.



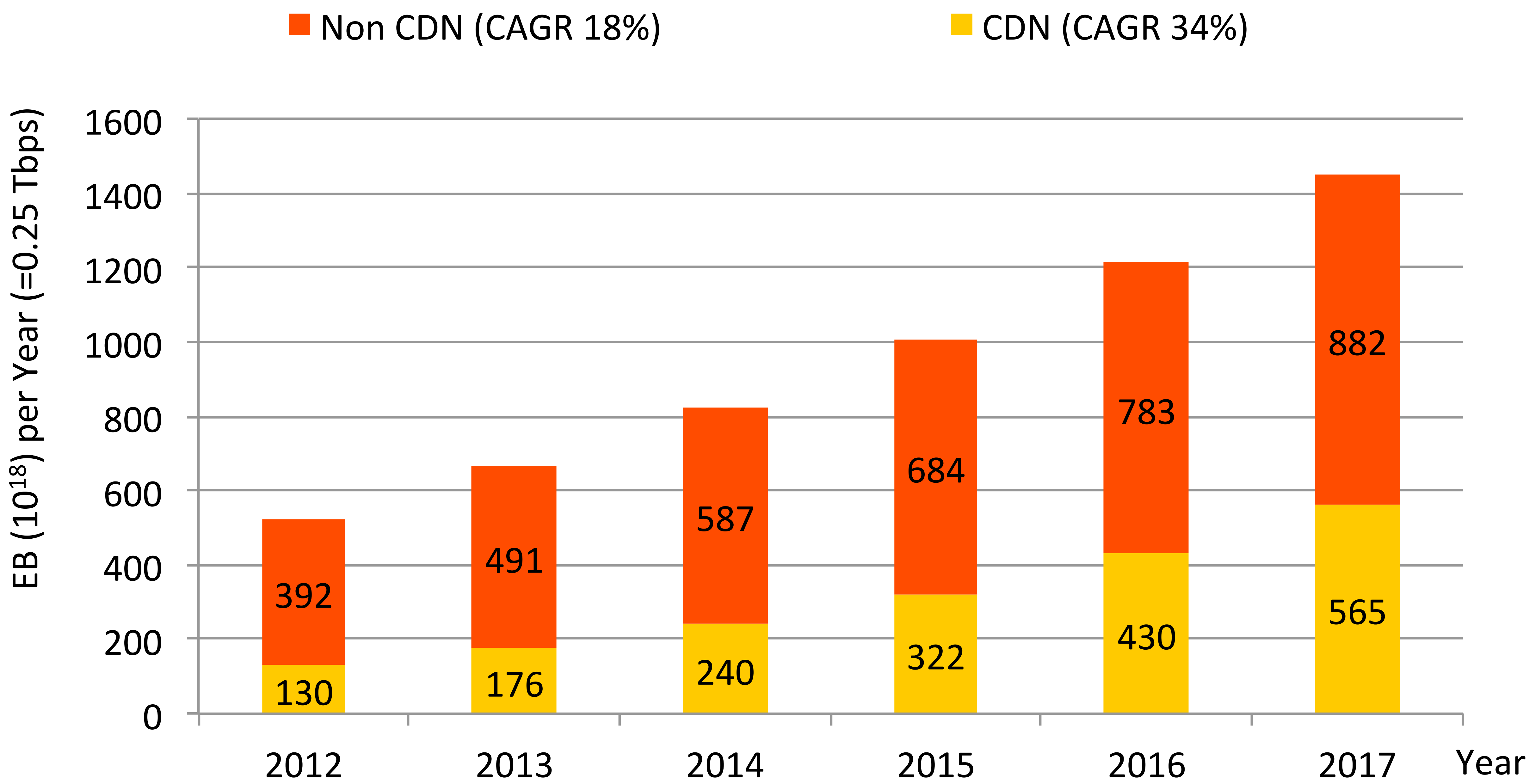
Note: * Estimate
Source: ITU World Telecommunication/ICT Indicators database

Motivation



Traditional data center (CAGR 17%)
Cloud data center (CAGR 44%)
EB (10^{18}) per Year (=0.25 Tbps)
7000
6000
5000
4000
3000
2000
1000
0
1072
683
1370
1181
1557
1694
1800
2324
2080
3166
2394
4255
2011
2012
2013
2014
2015
2016
Year

Motivation



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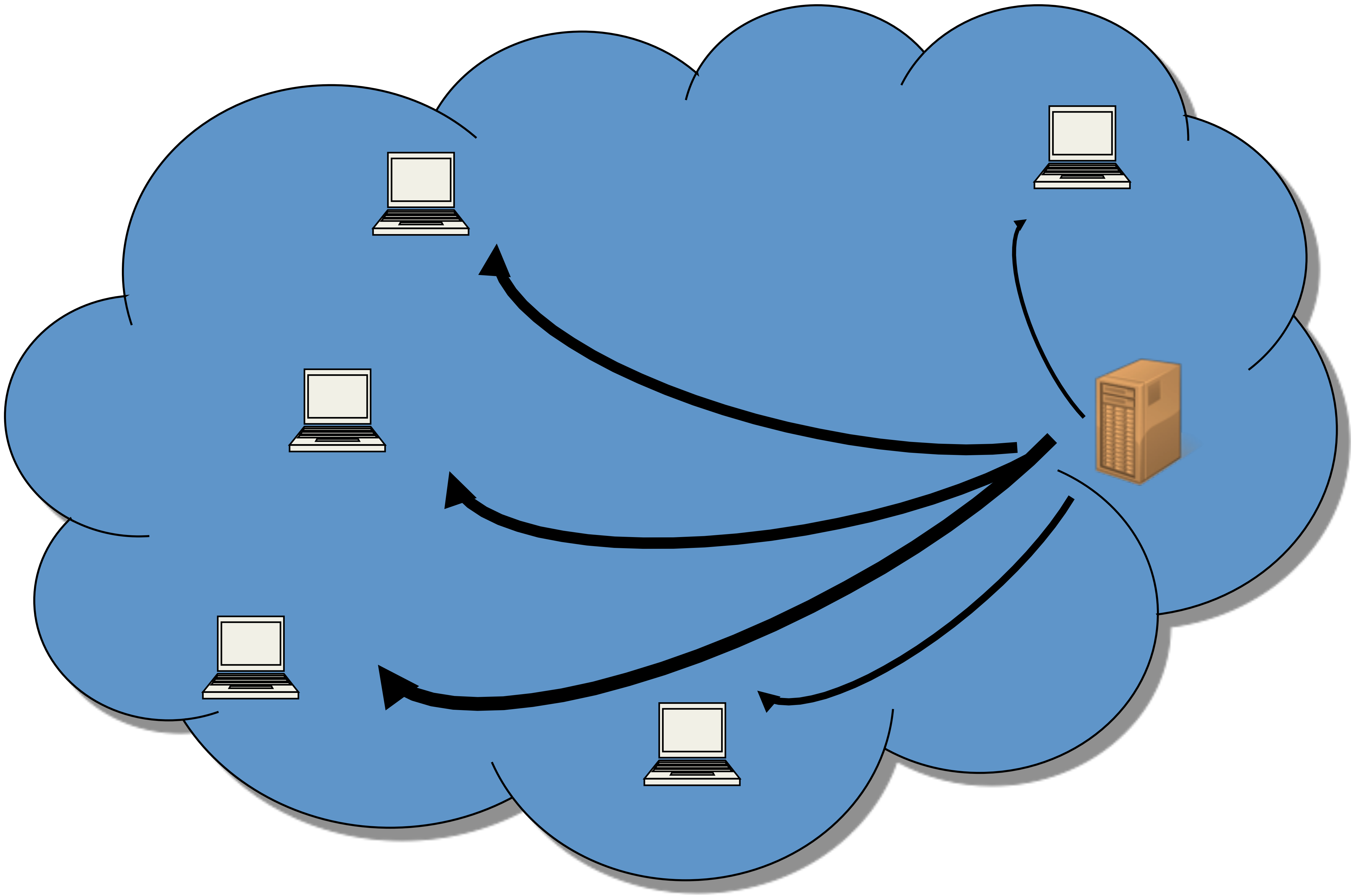
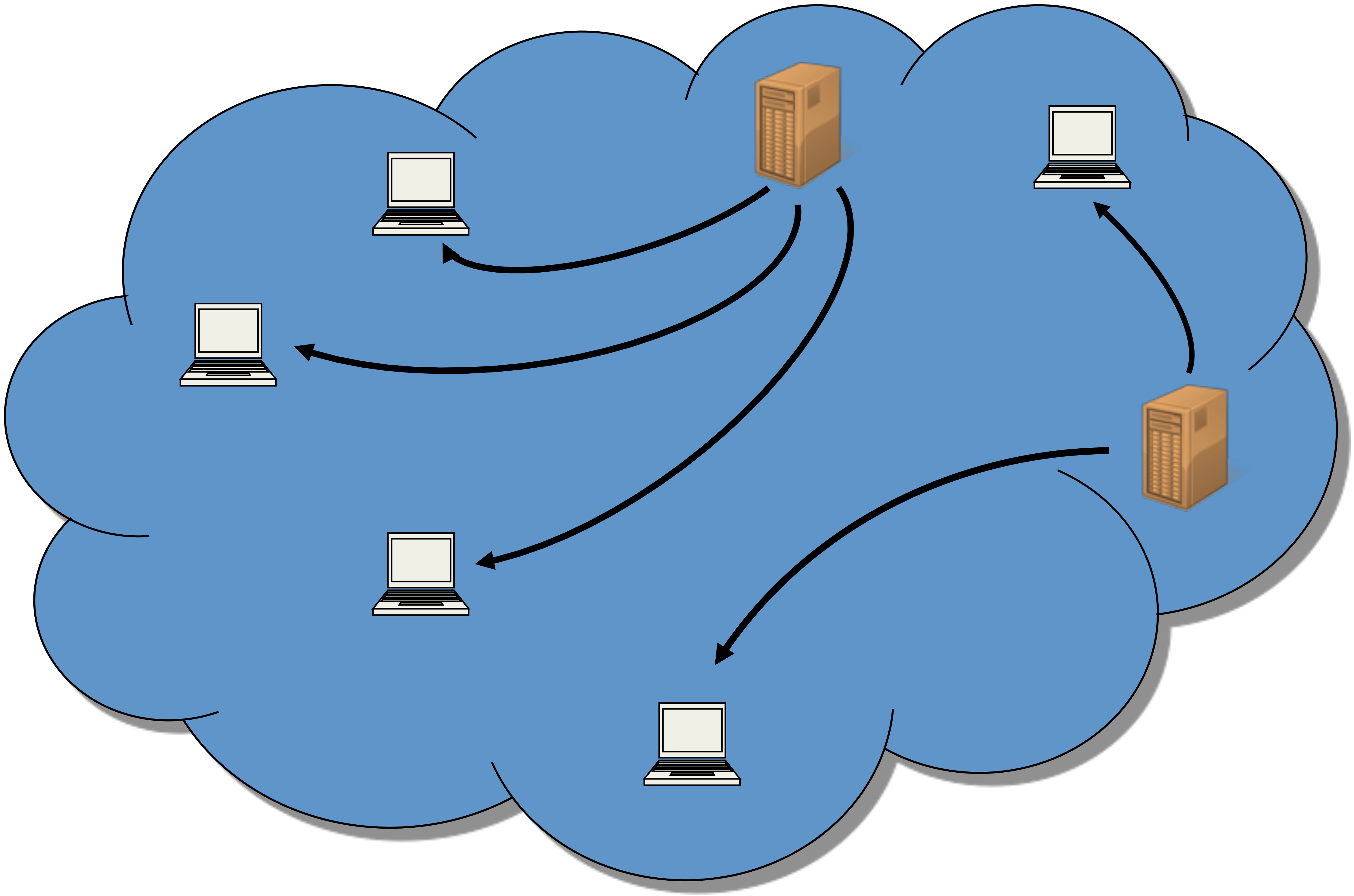


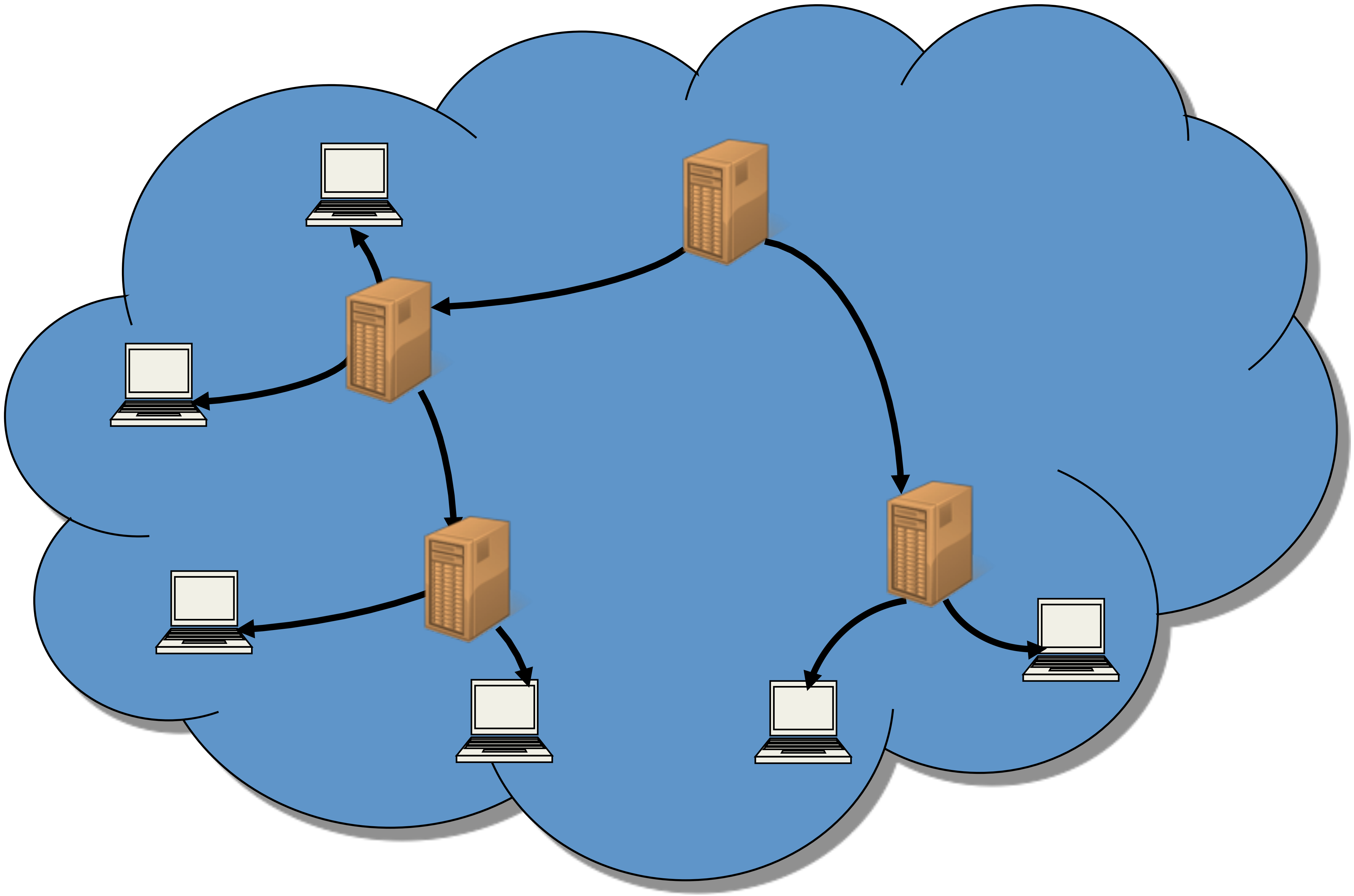
Unicast

One to one transmission



Anycast

One to one of many transmission



Content-Oriented

One to one of many transmission

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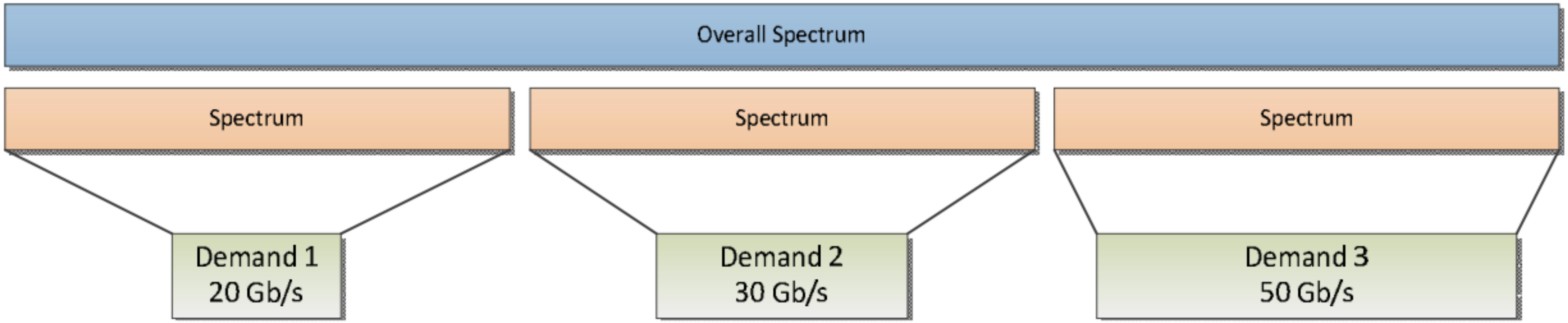
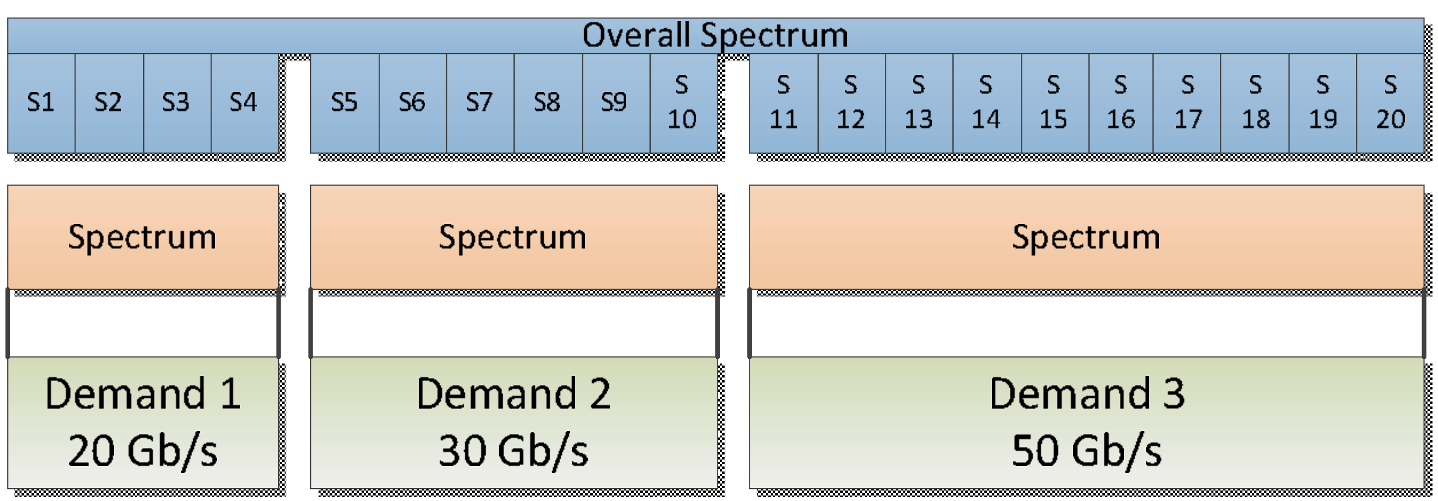
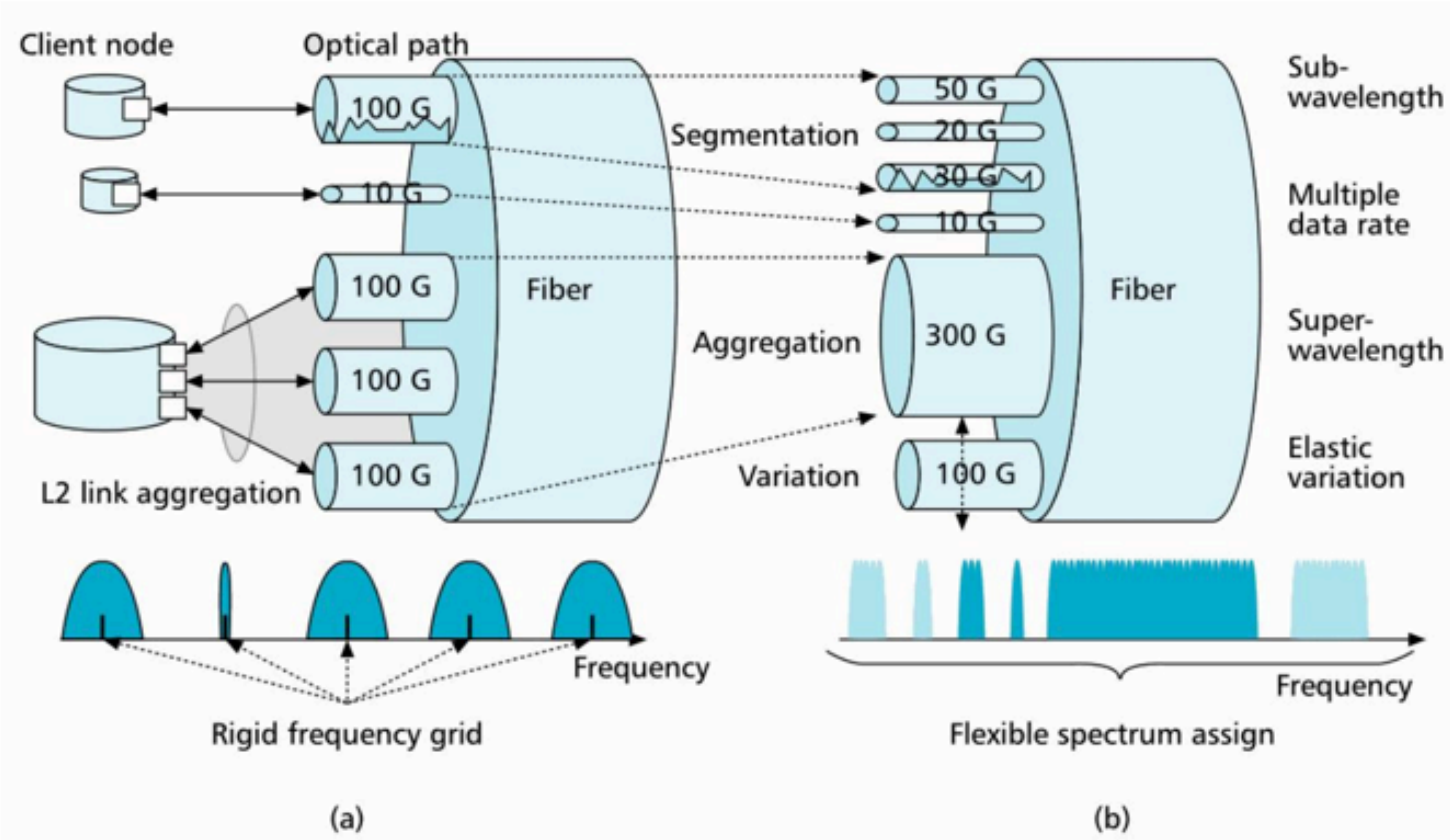
Optical networks - nowadays



Slice based optical networks - future





Elastic Optical Networks

Advantages

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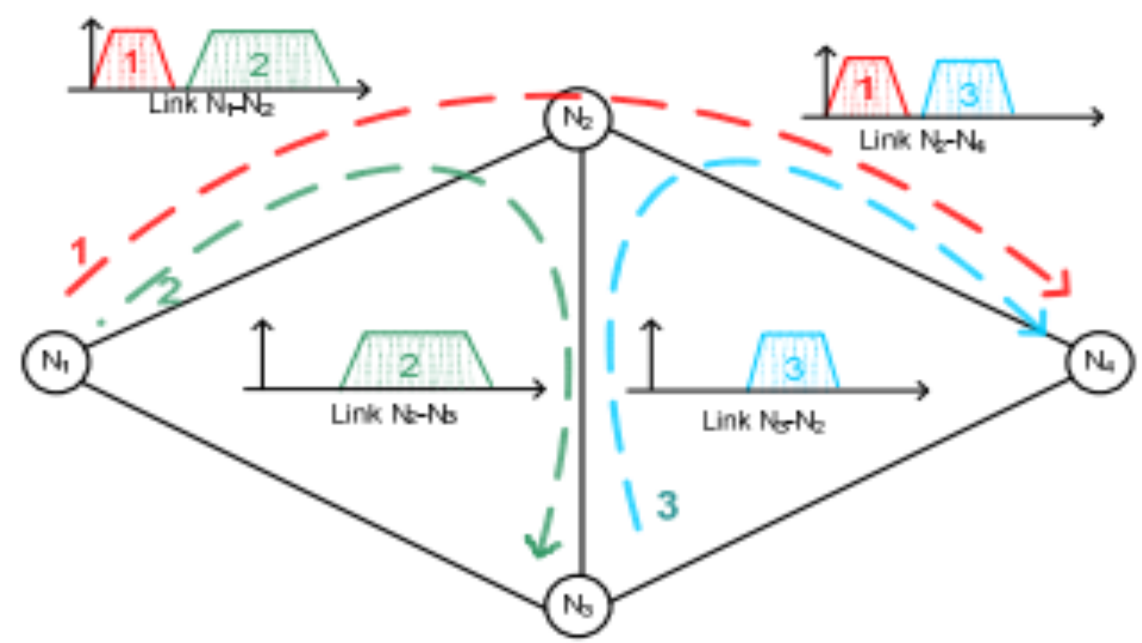
Dynamic RMSA Problem

RMSA - finding a routing path, a contiguous segment of spectrum subject to the constraint of no frequency overlapping in network links and modulation format



Constraints:

- spectrum continuity

- slices have to be next to each other (for example: 1-6, 3-10)

- slice can be used one time for one demand

- one regenerator can be used for one demand

- no grooming in regenerators

Regenerators in EONs

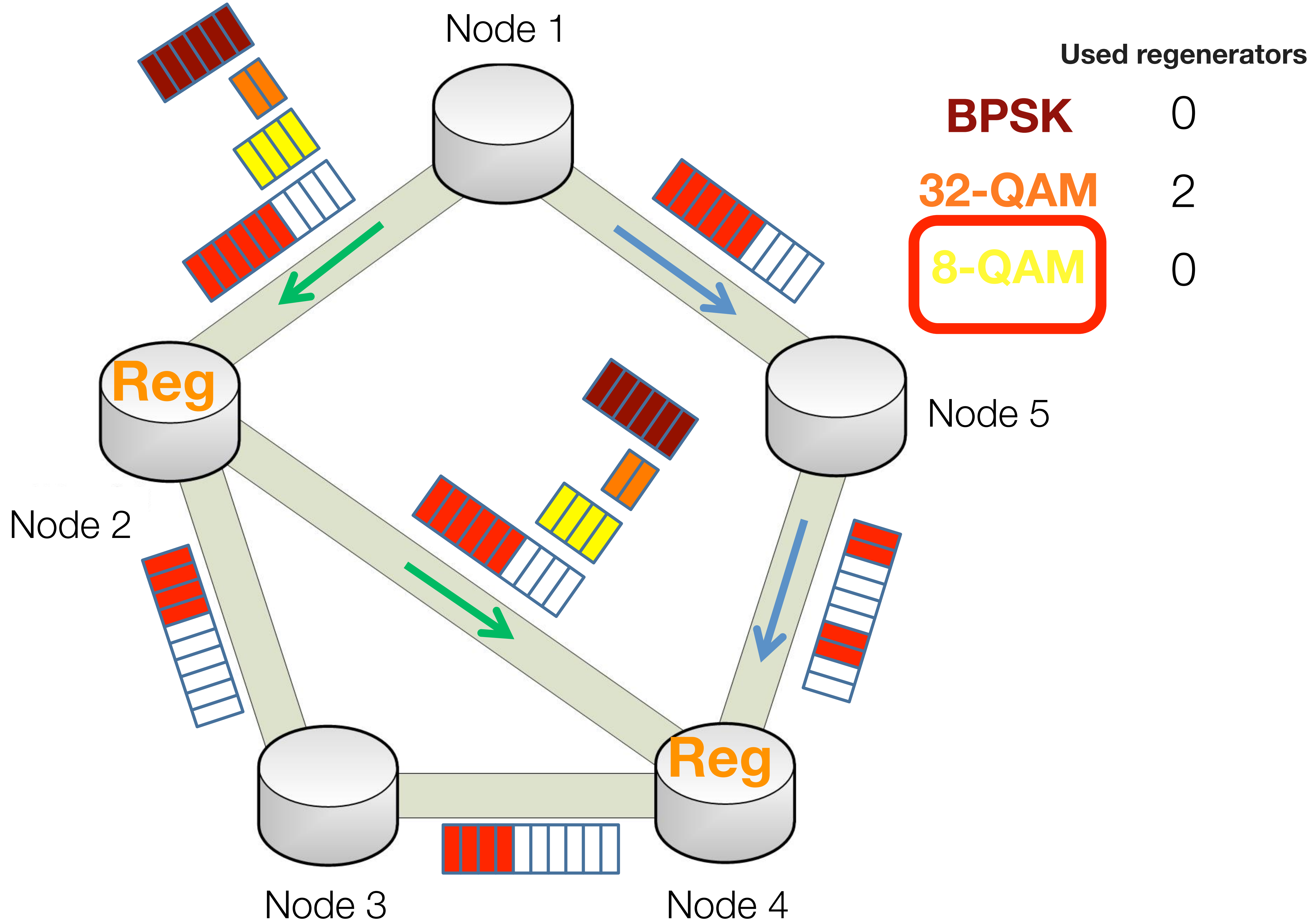
- Transmission model as in [C. Politi, et al., “Dynamic operation of flexi-grid OFDM-based networks”, in Proceedings of OFC, Los Angeles, CA, 2012, pp. 1-3.]

- The model estimates the transmission reach of an optical signal in a function of the selected modulation format and transported bit-rate

- Modulation formats: BPSK, QPSK, and m-QAM, where m belongs to {8, 16, 32, 64}

- Example for 400 Gb/s bit-rate

	64-QAM	32-QAM	16-QAM	8-QAM	QPSK	BPSK
SE [b/s/Hz]	6	5	4	3	2	1
# slices	8	10	10	14	18	34
Range [km]	359	569	779	989	1200	1912


Node 1
Node 2
Node 3
Node 4
Node 5
Reg
Reg
Used regenerators
BPSK 0
32-QAM 2
8-QAM 0

Adaptive **M**odulation and **R**egenerator **A**ware Algorithm (**AMRA**)

Algorithm 1. AMRA_ Unicast(s(d),t(d),c(d),k)

```
Update available spectrum on each link. Set b←INF, reg←INF, type←NULL
Calculate n candidate paths with LUM
for each p∈P(s(d),t(d),k) do
    Sum links lengths between nodes with regenerators on whole path
    Choose m available to allocate with best metric between nodes with regenerators
    if (m ∈ ∅) then return {NULL, INF, BBP_R}
    else combine link fragments (p_f) with the same modulation
    Include penalties for using regenerators
end for
Sort n candidate paths with new metrics
for each p_f ∈P(s(d),t(d),k) do
    (b_mf,reg_mf)←FF(p_f ,nn_f)
    nn = ∑nn_f (c(d),p_f ,m_f)
    b_m = ∑b_mf,, reg_m = ∑reg_mf
    if (b_m!=INF) and ((reg_m<reg) or (reg_m==0))
        then reg←reg_m, p←p_m,b←b_m
    end if
end for
if b<INF then return {p, b, NULL}  //established
else return {NULL, INF, BBP_S}  //blocked
```

Link **U**tilization **M**etric - **LUM**

{0-9% Utilization of Link -> LUM = 1,
10-19% -> 2
20-29% -> 3
...
90-99% -> 10
100% -> ∞}

Adaptive Penalties

Link Usage	BPSK	QPSK	8-QAM	16-QAM	32-QAM	64-QAM
<20%	0	1	2	3	4	5
21-40%	1	0	1	2	3	4
41-60%	2	2	0	1	2	3
61-75%	3	3	3	0	1	2
76-90%	4	4	4	4	0	1
>90%	5	5	5	5	5	0

Example situation

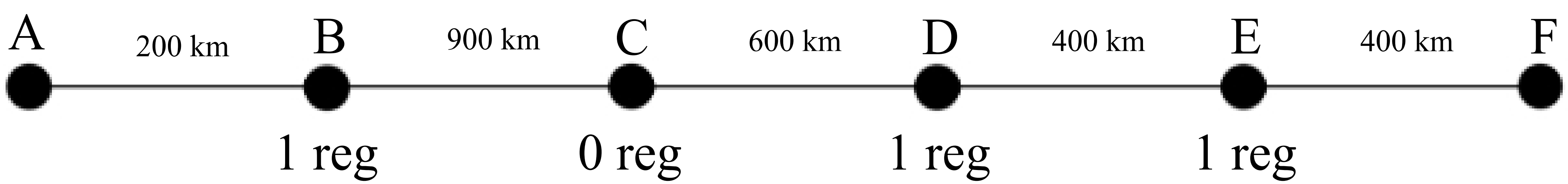


Fig. 1. Initial state.

Example situation

Fig. 2. Network after combining links between nodes with regenerators.

Example situation

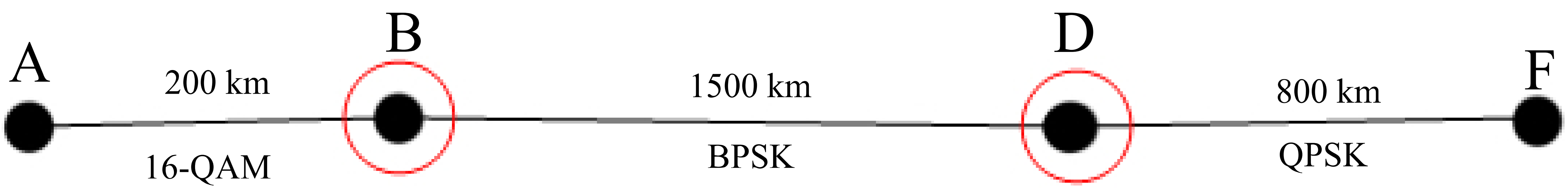


Fig 3. Final state of the network.

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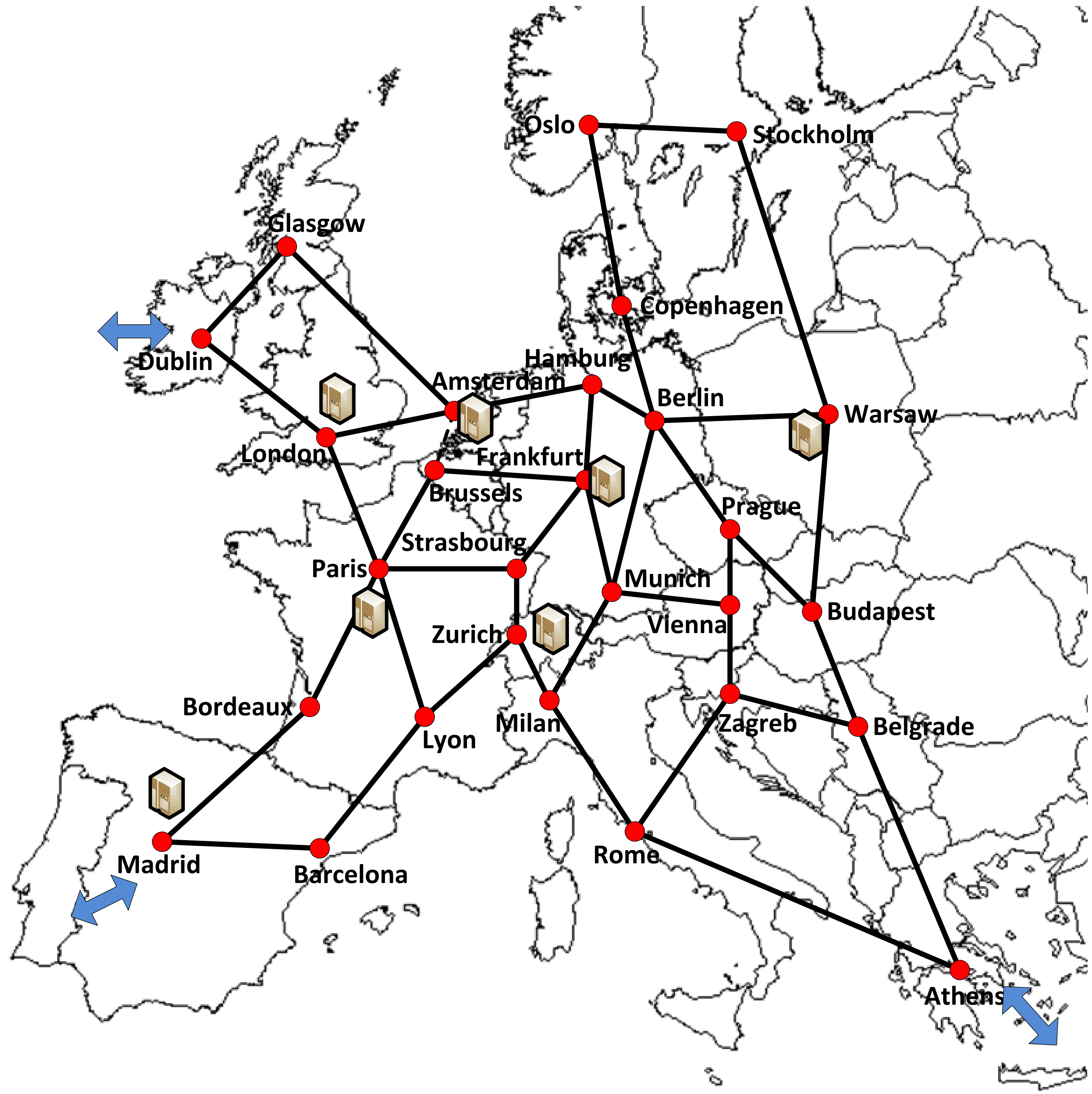

Euro 28 network

28 nodes, 7 Data Centers

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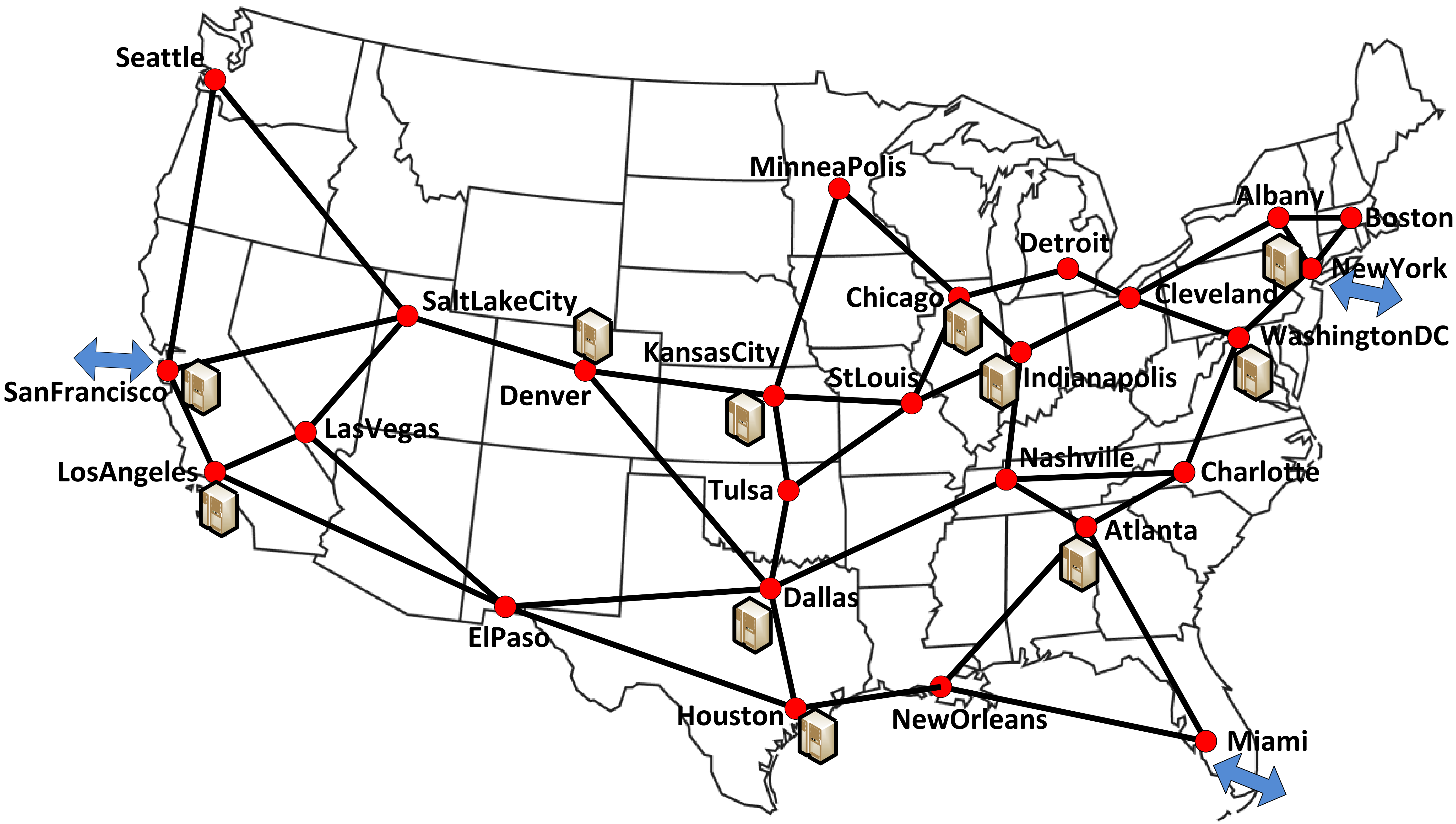
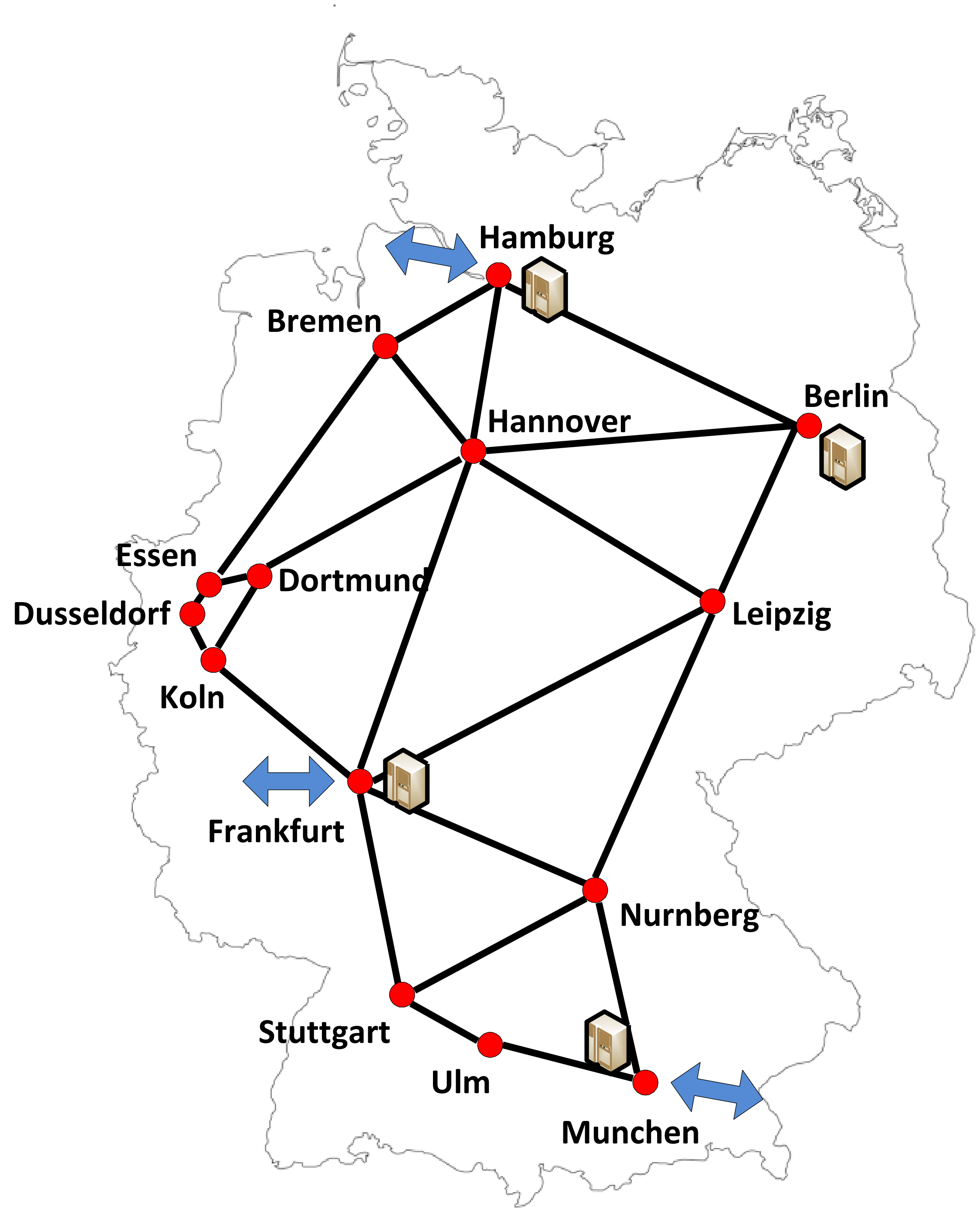


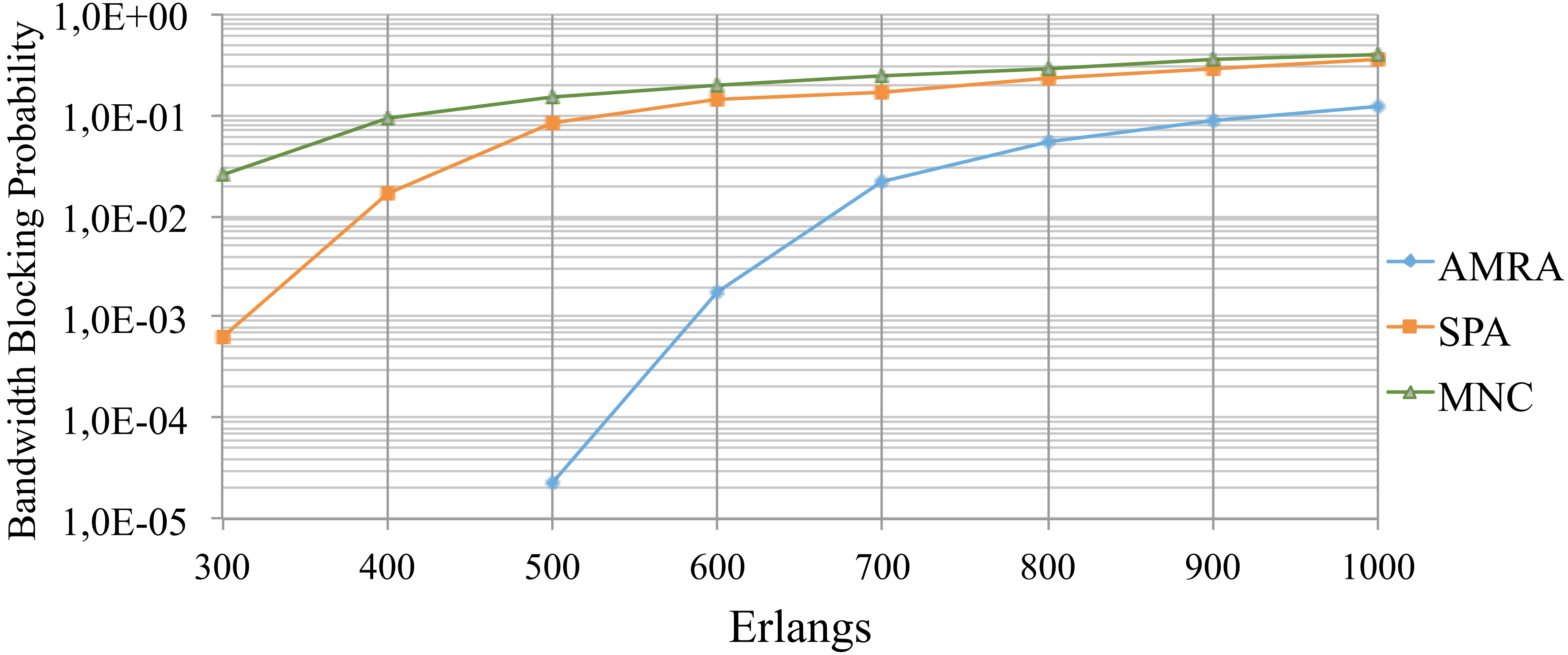
US 26 network

26 nodes, 10 Data Centers



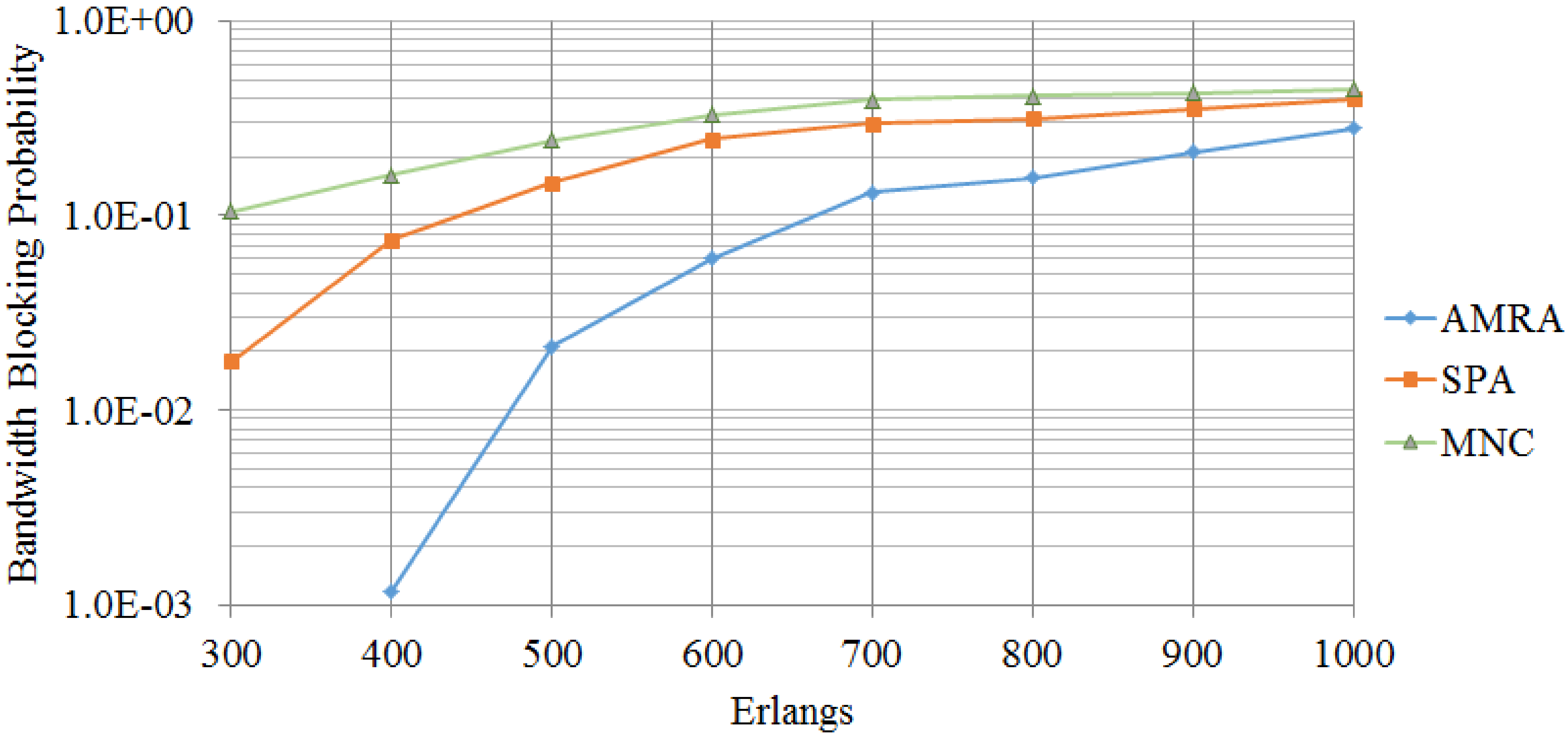
DT 14 network

14 nodes, 4 Data Centers



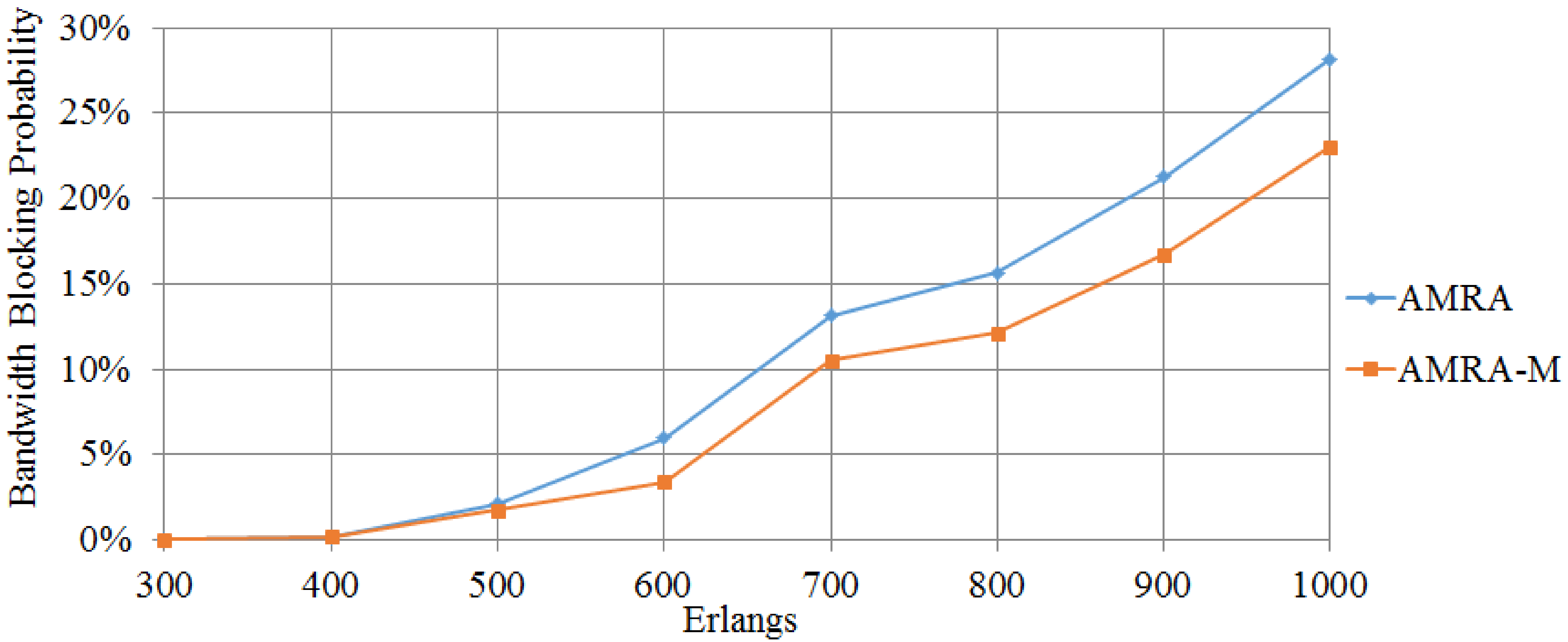
Bandwidth Blocking Probability

Euro28 Network



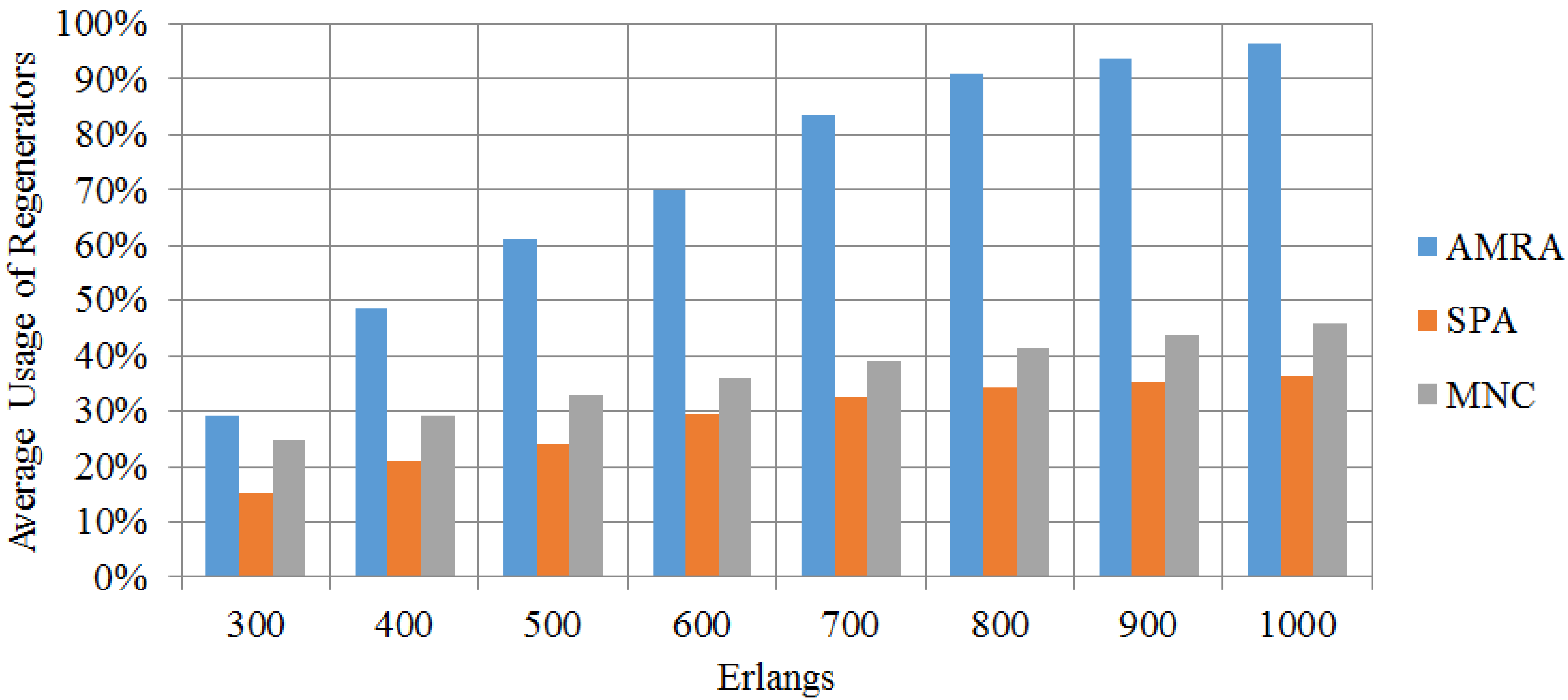
Bandwidth Blocking Probability

US26 network



Comparison of AMRA algorithms with and without modulation format change in the nodes

US26 network



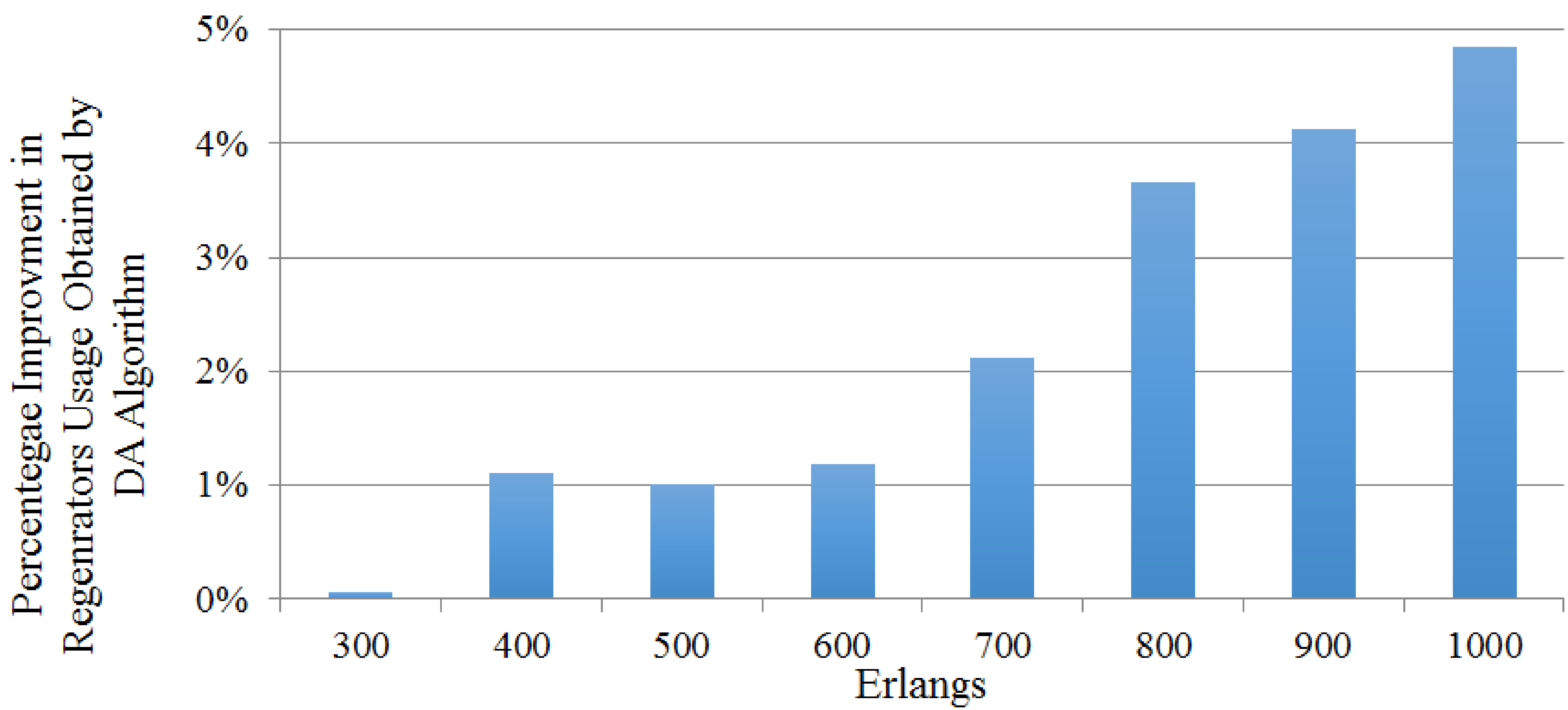
Average Usage of Regenerators

US26 network

Regenerator Placement Problem

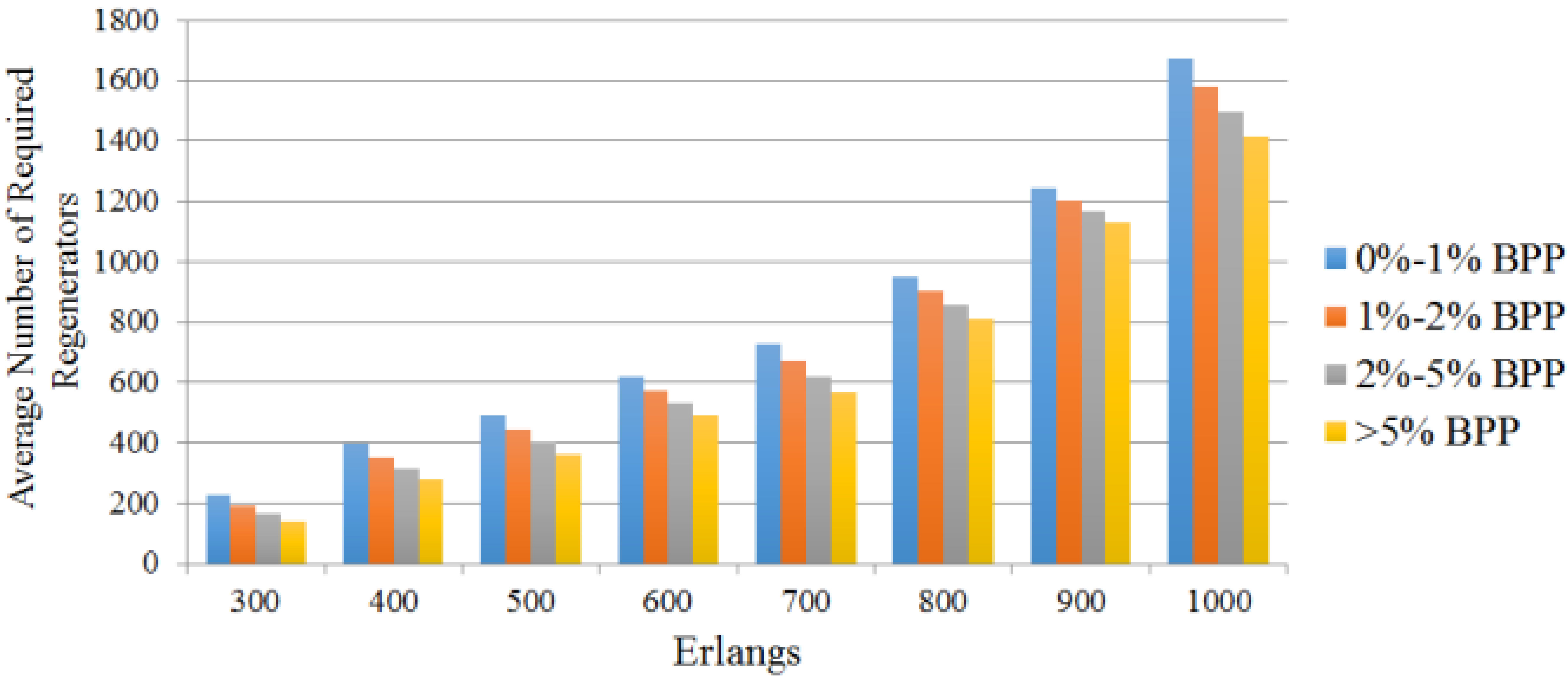
Algorithm 2. DA Regenerator Localization Algorithm

Set $x = \sum L$, $x_V = \sum l_V$, $nregs$ = number of regenerators to use
for each $v \in V$ **do**
    $\lfloor nregs_v \rfloor = nregs \times (x_V \div x)$
end for



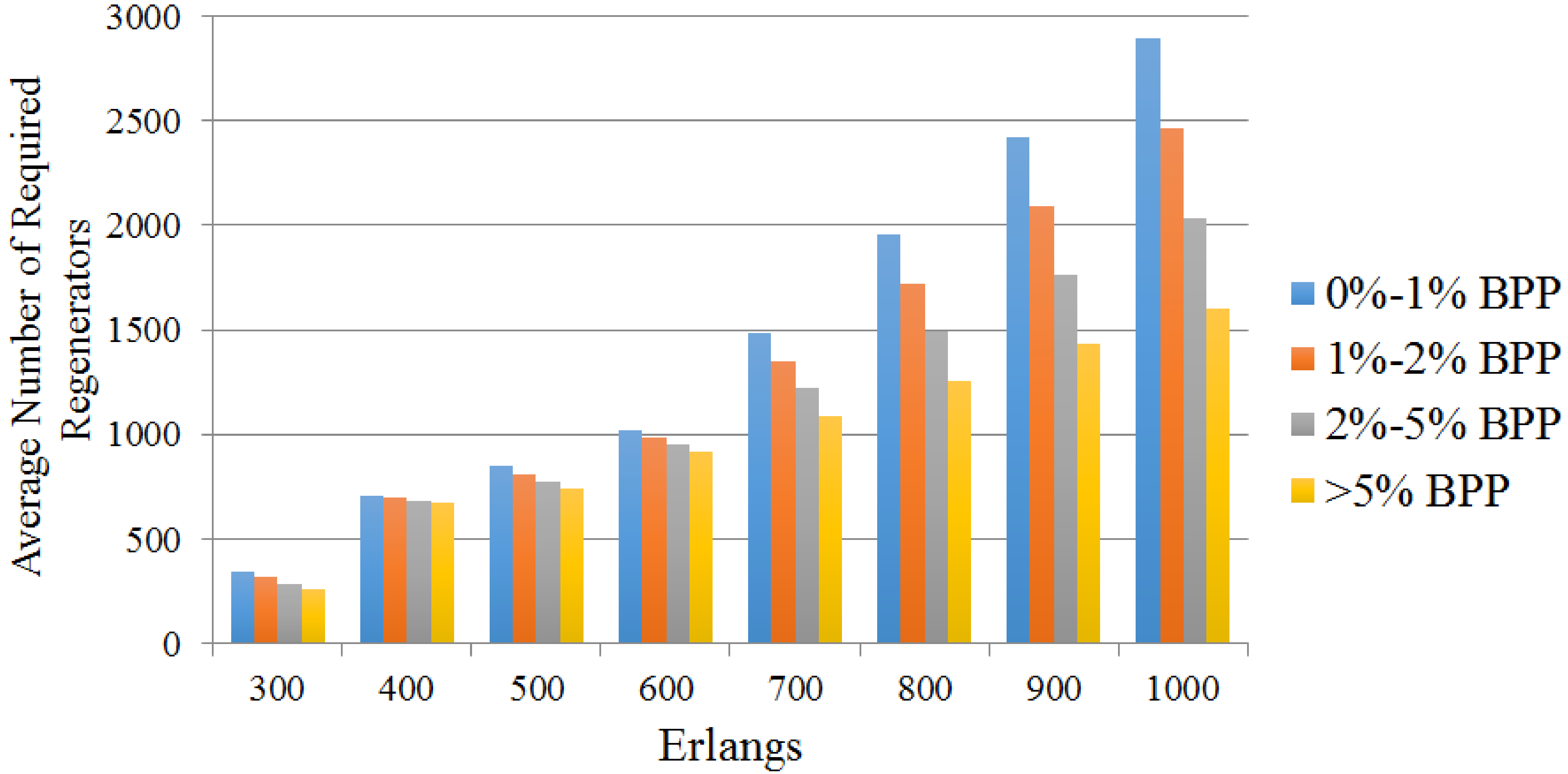
Gain in regenerators usage obtained by DA algorithm

US26 network



Average number of required regenerators

Euro28 network



Average number of required regenerators

US26 network

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Future works

- Algorithms for calculating the best regenerators' location
- More sophisticated algorithms for dynamic routing
- Multicast traffic
- Network simulator with availability to choose particular modulations, networks and traffic
- Network orchestration using SDN controllers

Thank You For Your Attention

Any questions?

Michał Aibin