Chair of Communication Networks
TUM School of Computation, Information and Technology
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Cost-efficient Multi-period Optical Network Planning

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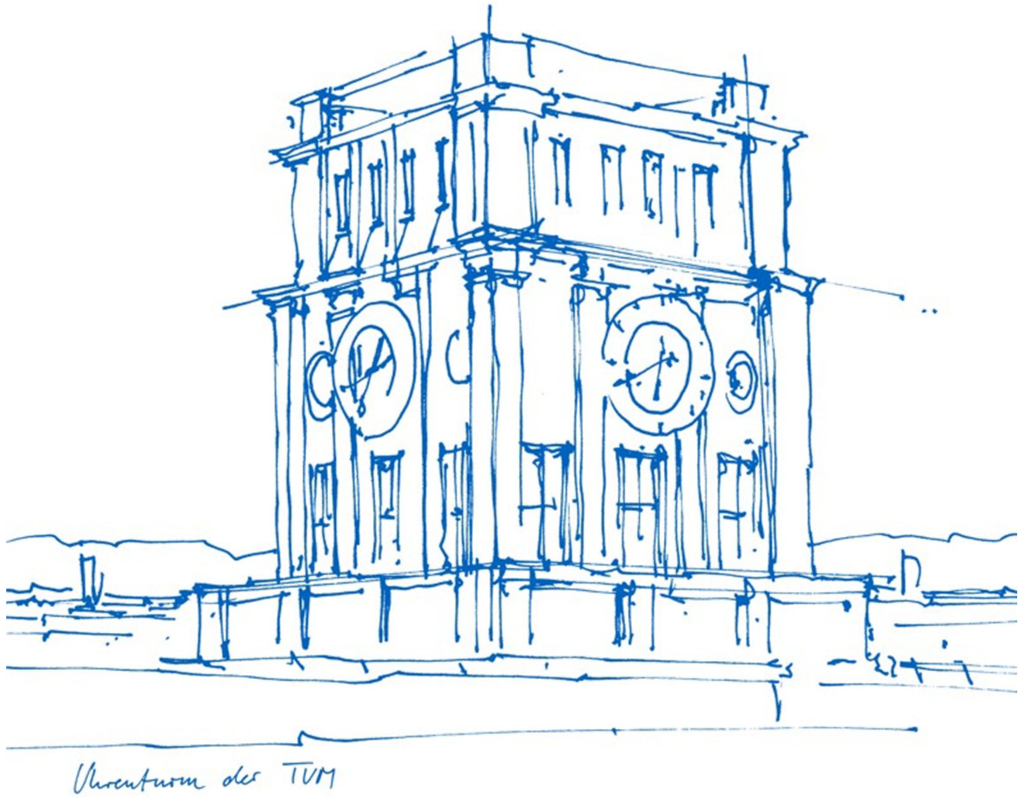
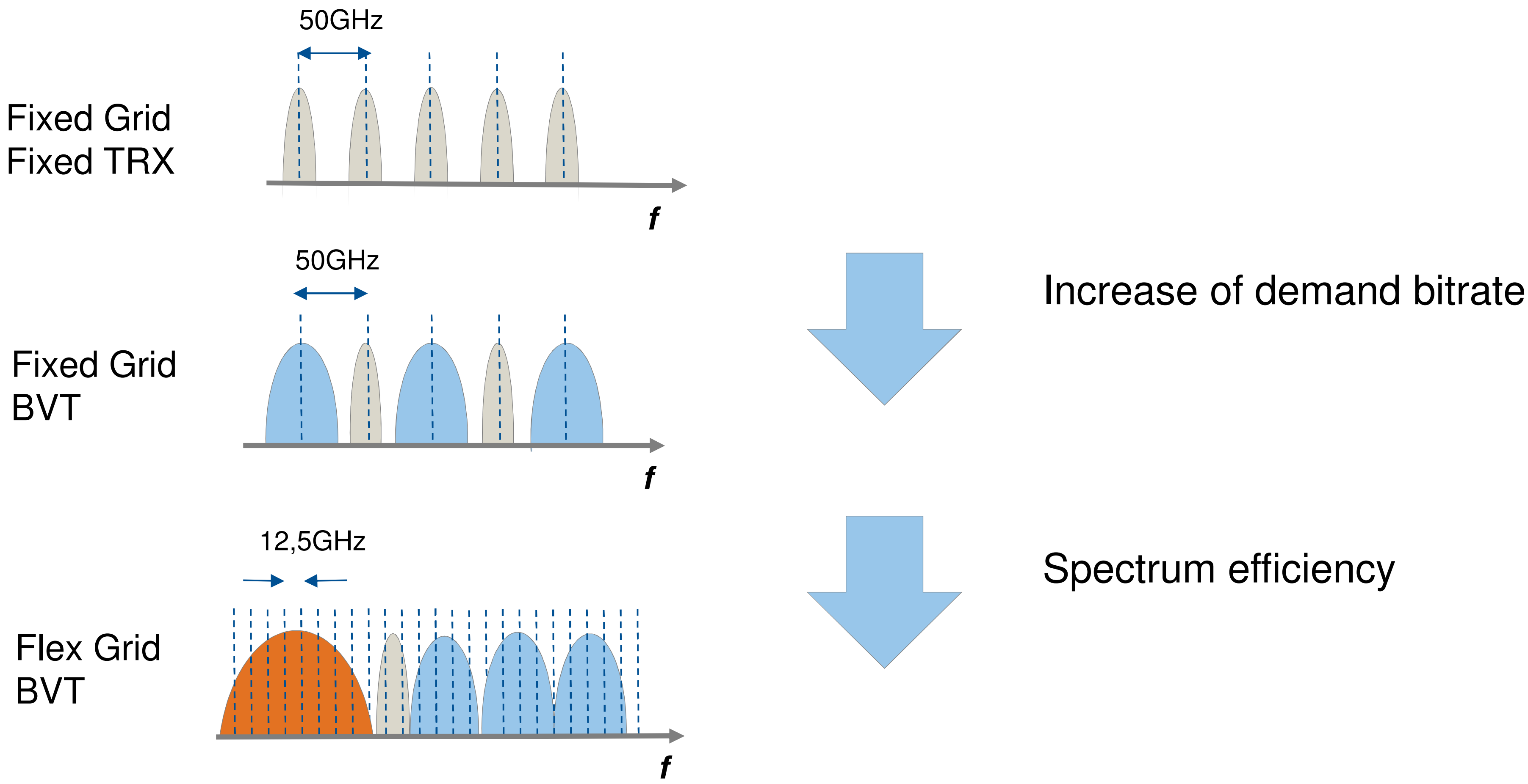


Optical technology evolution



Use of BVT (Bandwidth Variable Transponders)→

Support different configurations (bitrate, modulation, fec)→

min OSNR, required frequency slots (FS)

Issues faced by operators

Will my network cope with expected&inexpected traffic increase?

Can the network cope with all demands/reduce blocked/partially breached demands?

How will my traffic increase?

How can the spectrum utilization efficiency be increased?

How can the investments be reduced?

Comparison of different multi-period RCSA solutions

RCSA: Routing, Configuration and Spectrum Assignment

Routing, Configuration and Spectrum Assignment (RCSA) Problem

Input

- Network
- Demands
- Configs.

RCSA

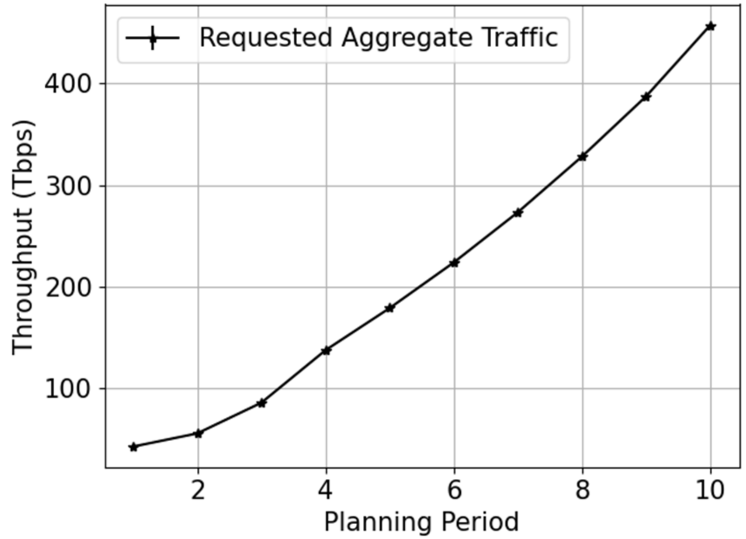
Find for each demand, the set of lighpaths (path, configuration, spectrum) such that

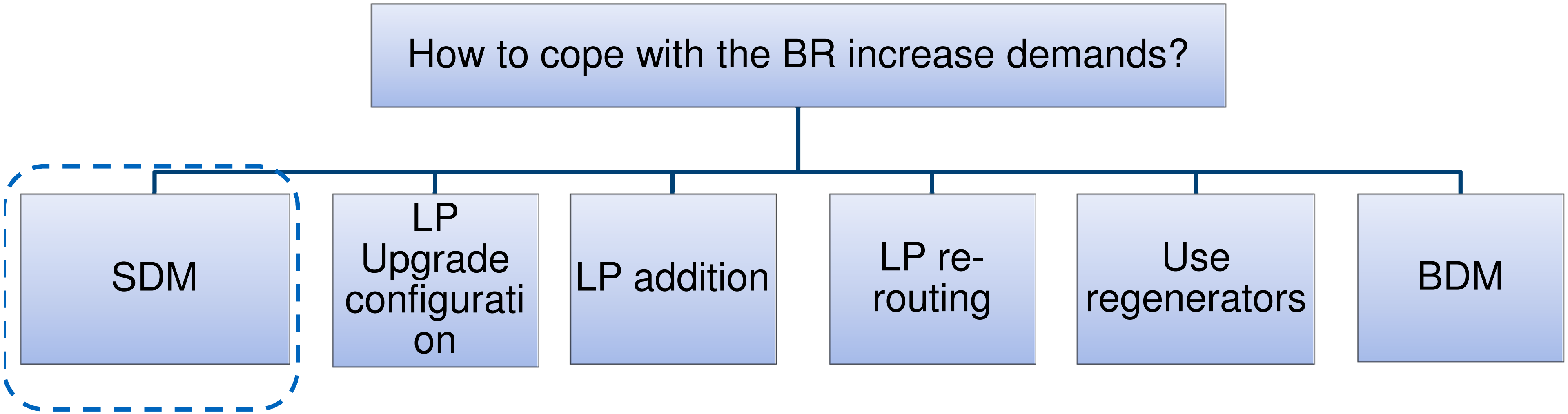
- Min number of BVTs
- minOSNR is guaranteed
- BR of demand is offered
- Spectrum continuity constraint
- Spectrum contiguity constraint

Performance

- Network throughput
- Under-provisioning
- Configurations
- Cost & power

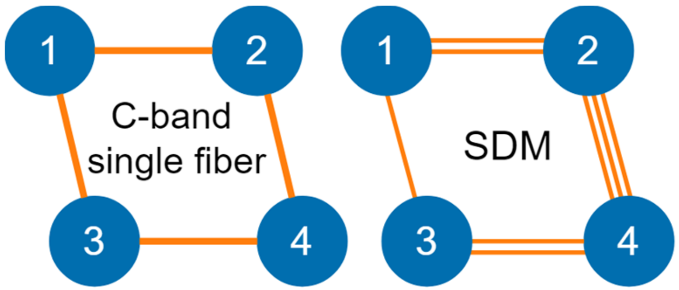
Multi-period RCSA problem



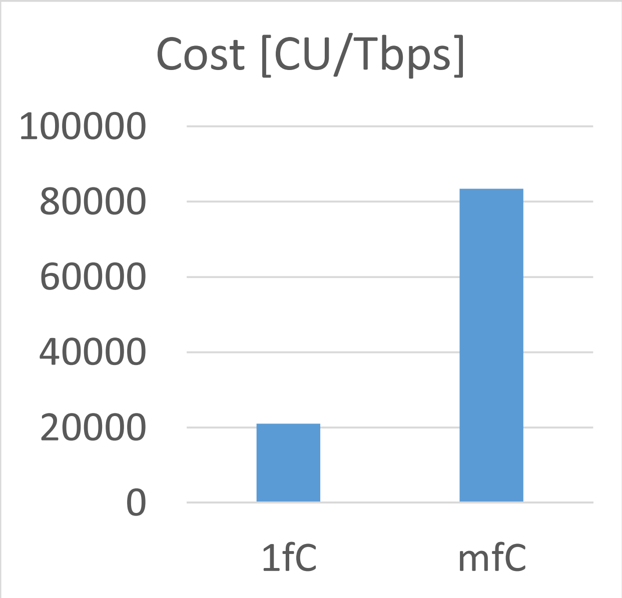


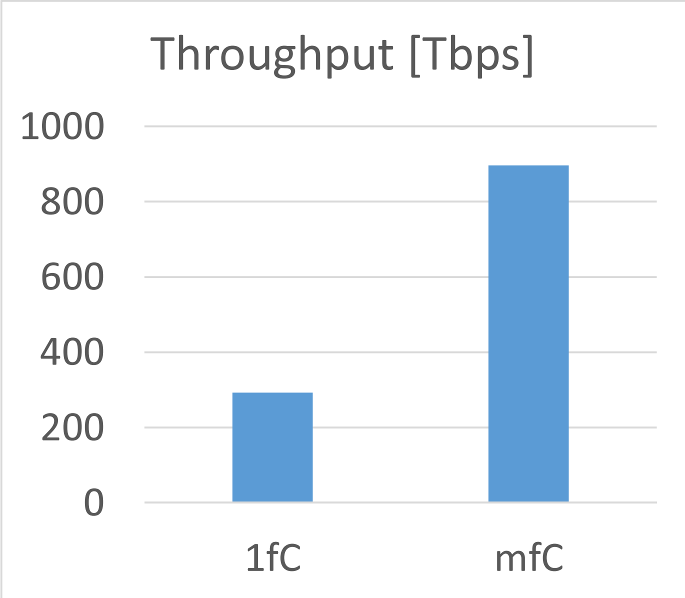
Impact of Space Division Multiplexing (SDM)

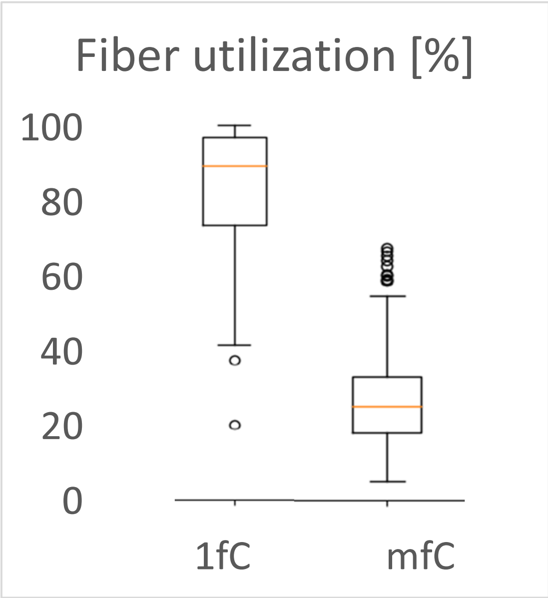
Lighting fibers up as required to cope with all demands



Nobel_EU

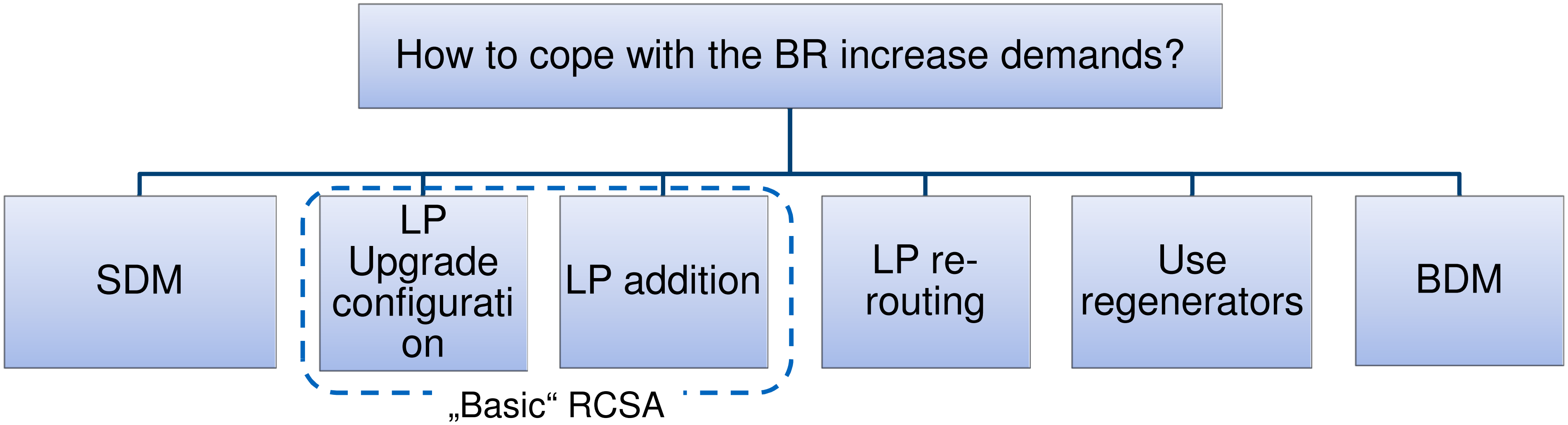




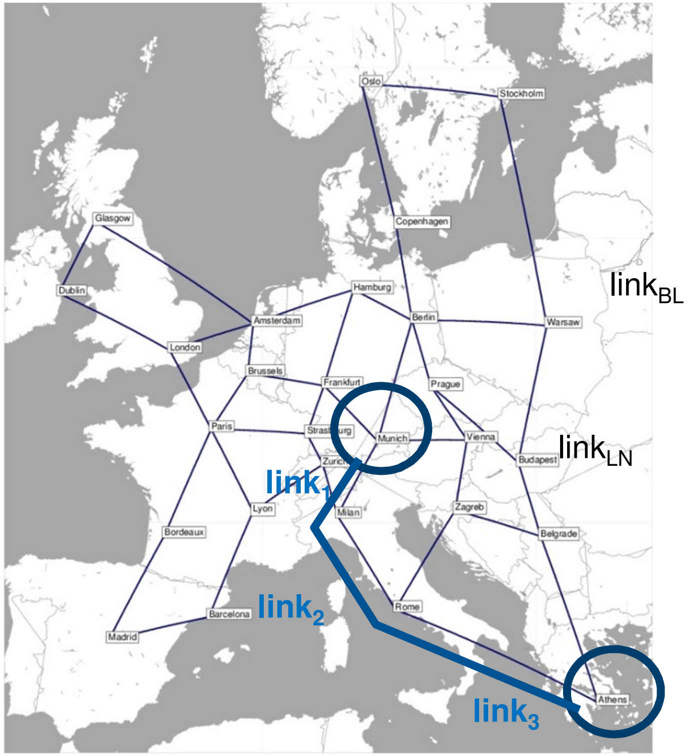


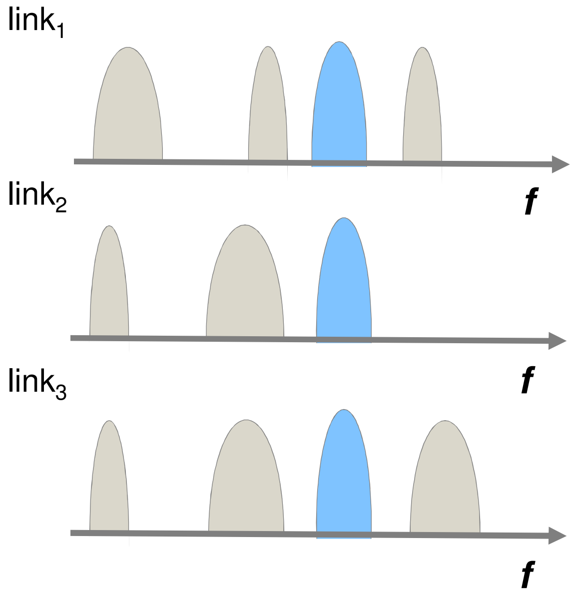
An option to cope with all demands if cost was not an issue

Multi-period RCSA problem



Basic RCSA



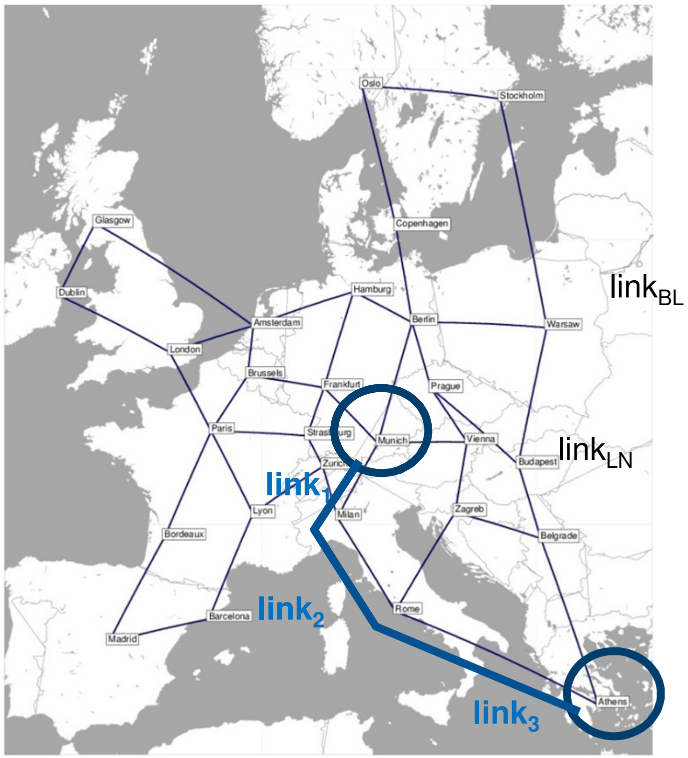


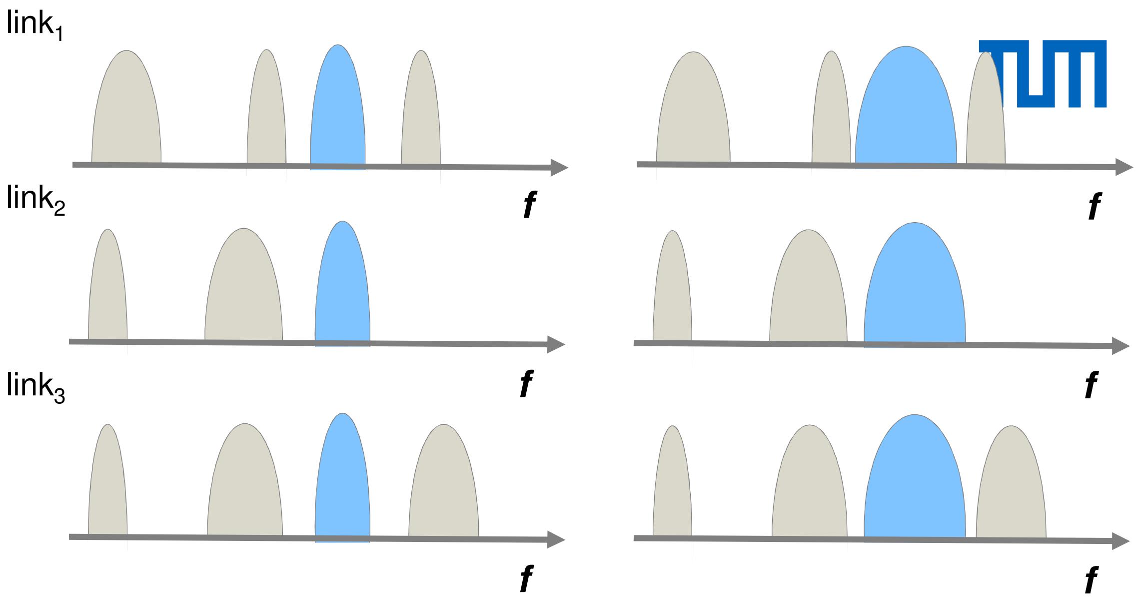
d_3=(München, Athens, 100Gbps) @2022

d_3=(München, Athens, 200Gbps) @2023

Which are the options?

LP Upgrade





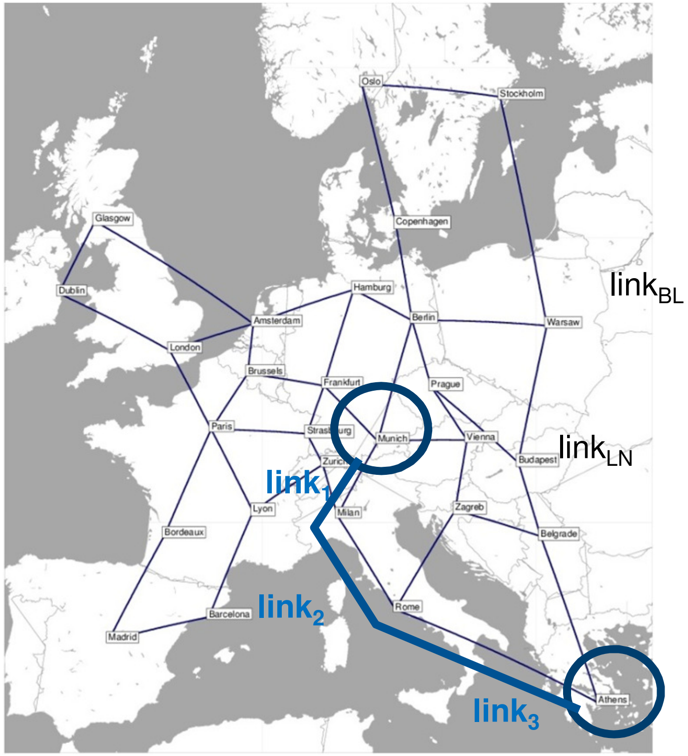
d_3=(München, Athens, 100Gbps) @2022

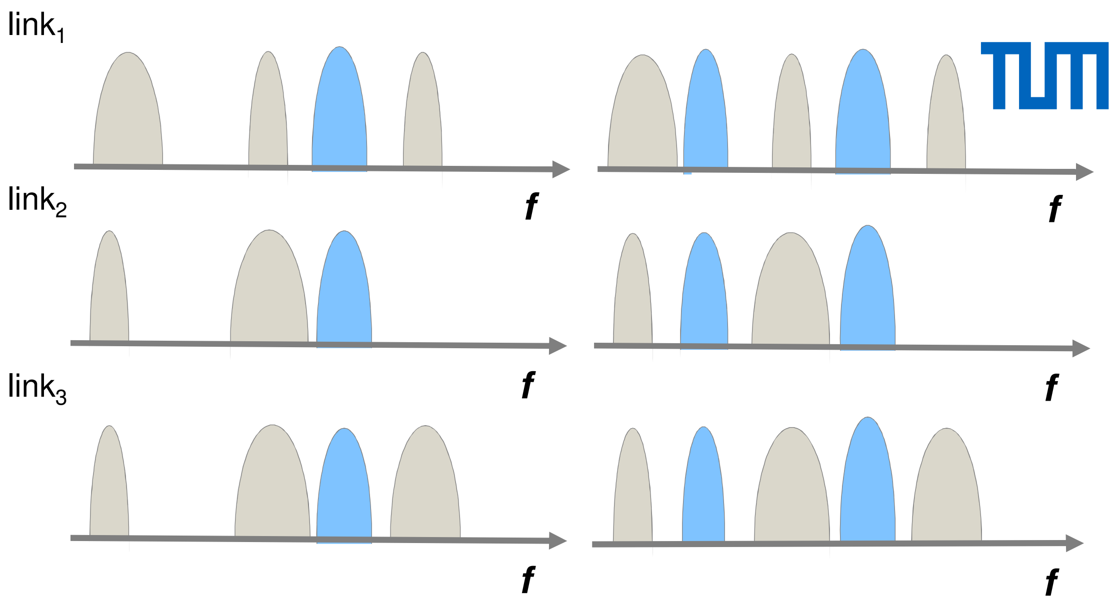
d_3=(München, Athens, 200Gbps) @2023

LP Upgrade

[1] Patri, Sai Kiree et al.: HeCSON: Heuristic for Configuration Selection in Optical Network Planning. OFC 2020

LP Addition





d_3=(München, Athens, 100Gbps) @2022

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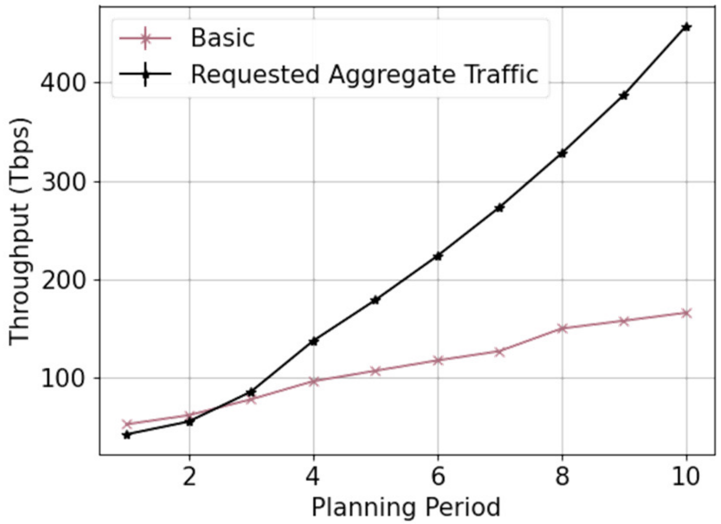
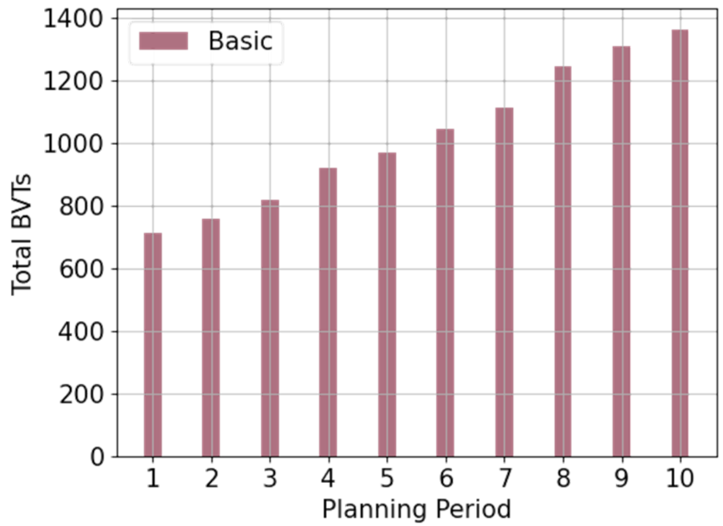
LP Upgrade

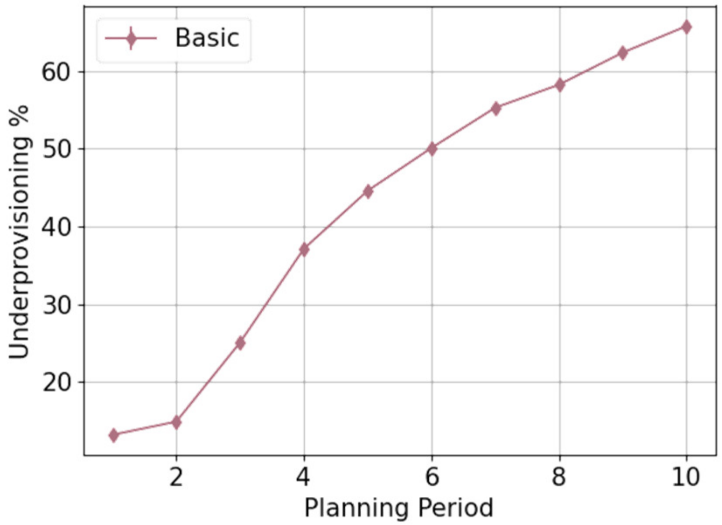
LP Addition

[2] Varasteh, Amir et al. : Evaluation of Lightpath Deployment Strategies in Flexible-Grid Optical Networks. ONDM 2021

„Basic“ RCSA Results





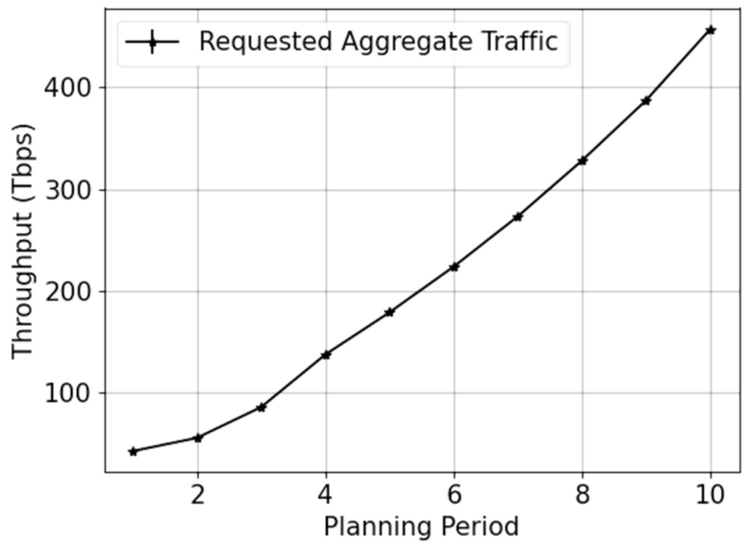


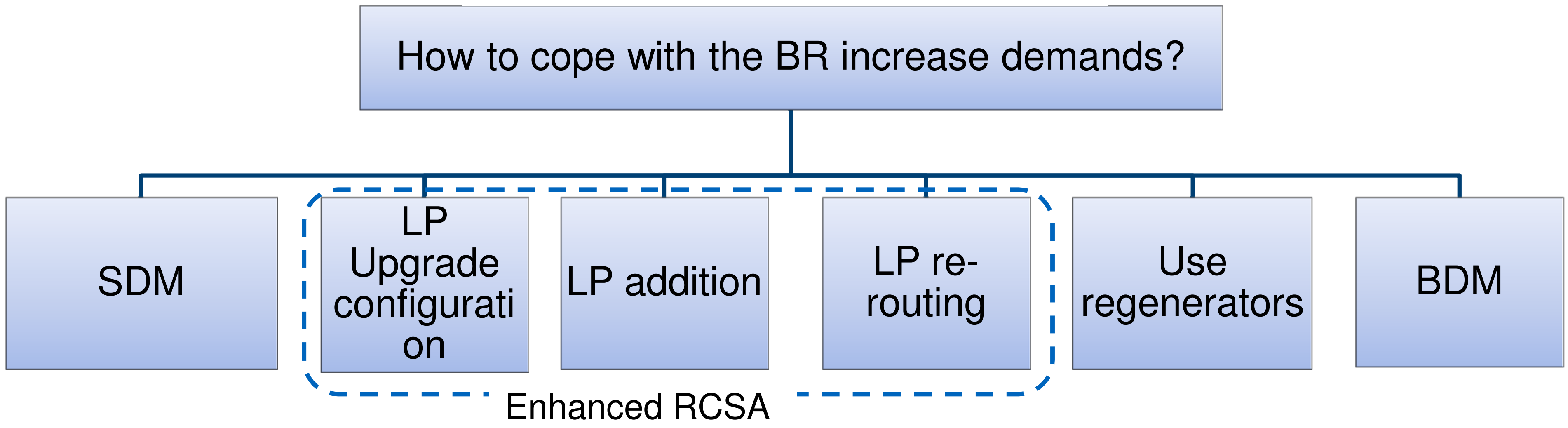
$$UP = \frac{\sum_{\forall \tilde{d} \in \tilde{D}} \left(DR_{\tilde{d}} - \sum_{\forall lp \in LP_{\tilde{d}}} DR_{lp} \right)}{\sum_{d \in D} DR_d}$$

Unable to cope with required traffic

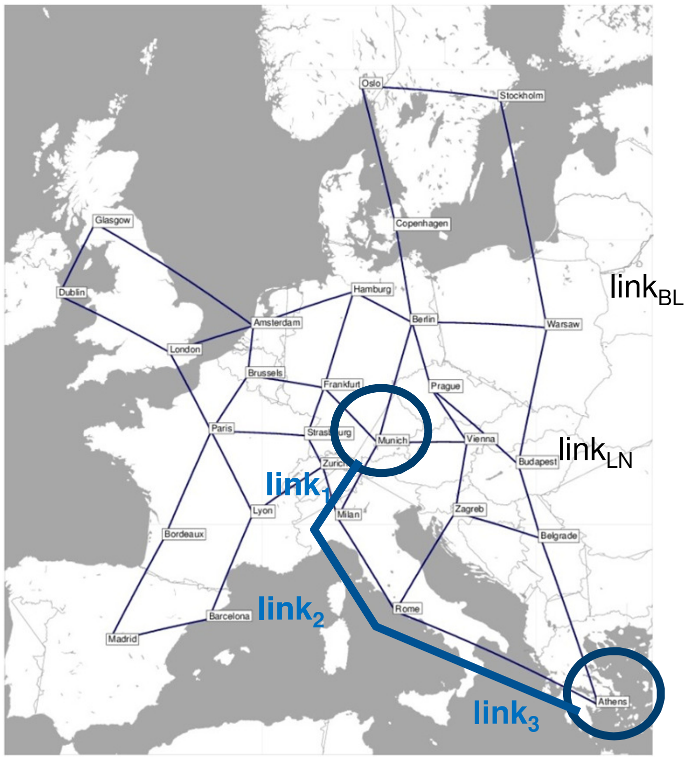
[2] Varasteh, Amir et al. : Evaluation of Lightpath Deployment Strategies in Flexible-Grid Optical Networks. ONDM 2021

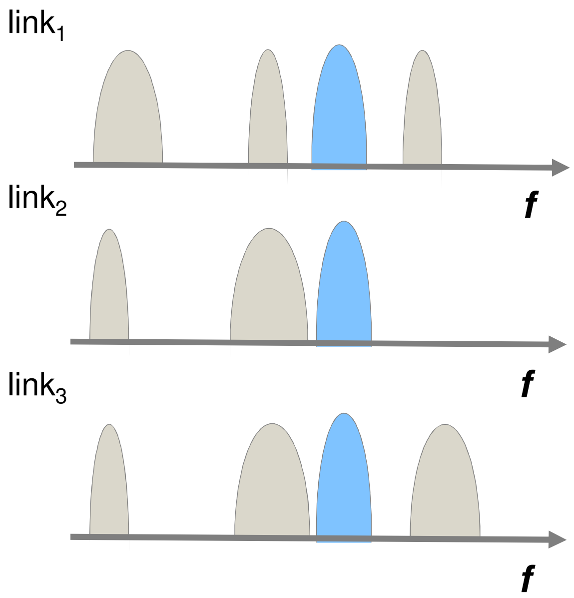
Multi-period RCSA problem





LP Reroute





d_3=(München, Athens, 100Gbps) @2022

d_3=(München, Athens, 200Gbps) @2023

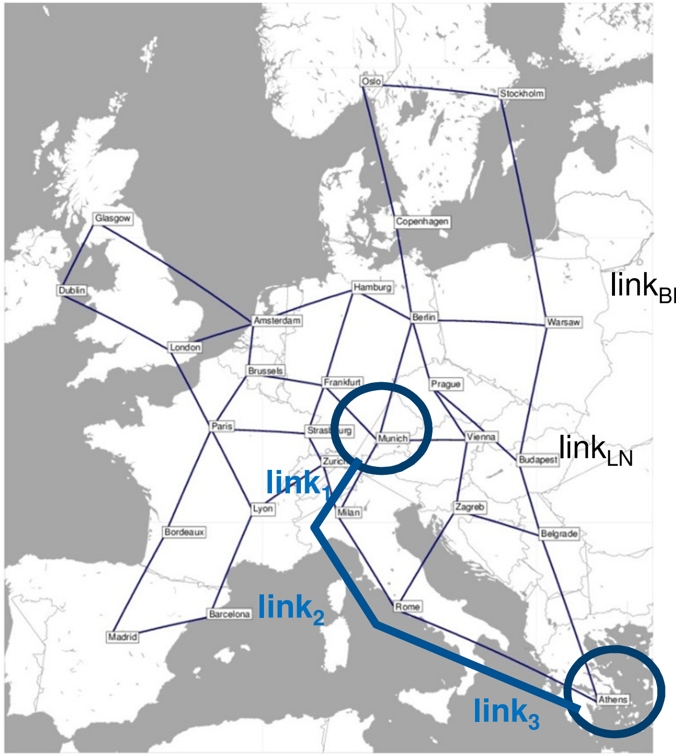
LP Upgrade

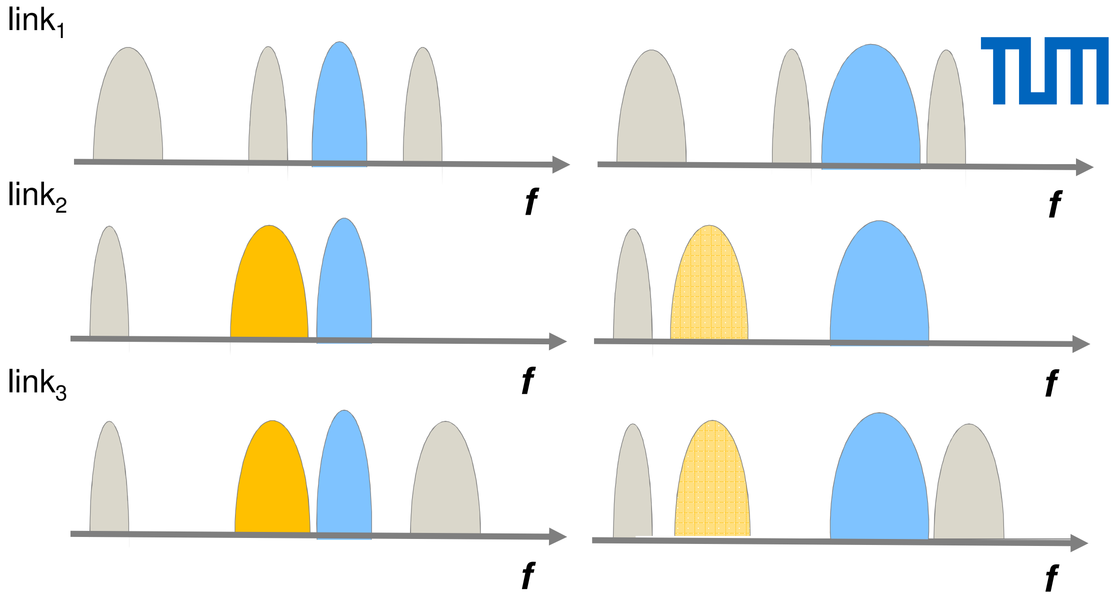
LP Addition

LP Reroute

[3] Varasteh, Amir et al. Towards Dynamic Network Reconfigurations for Flexible Optical Network Planning. OFC 2021

LP Reroute





d_3=(München, Athens, 100Gbps) @2022

d_3=(München, Athens, 200Gbps) @2023

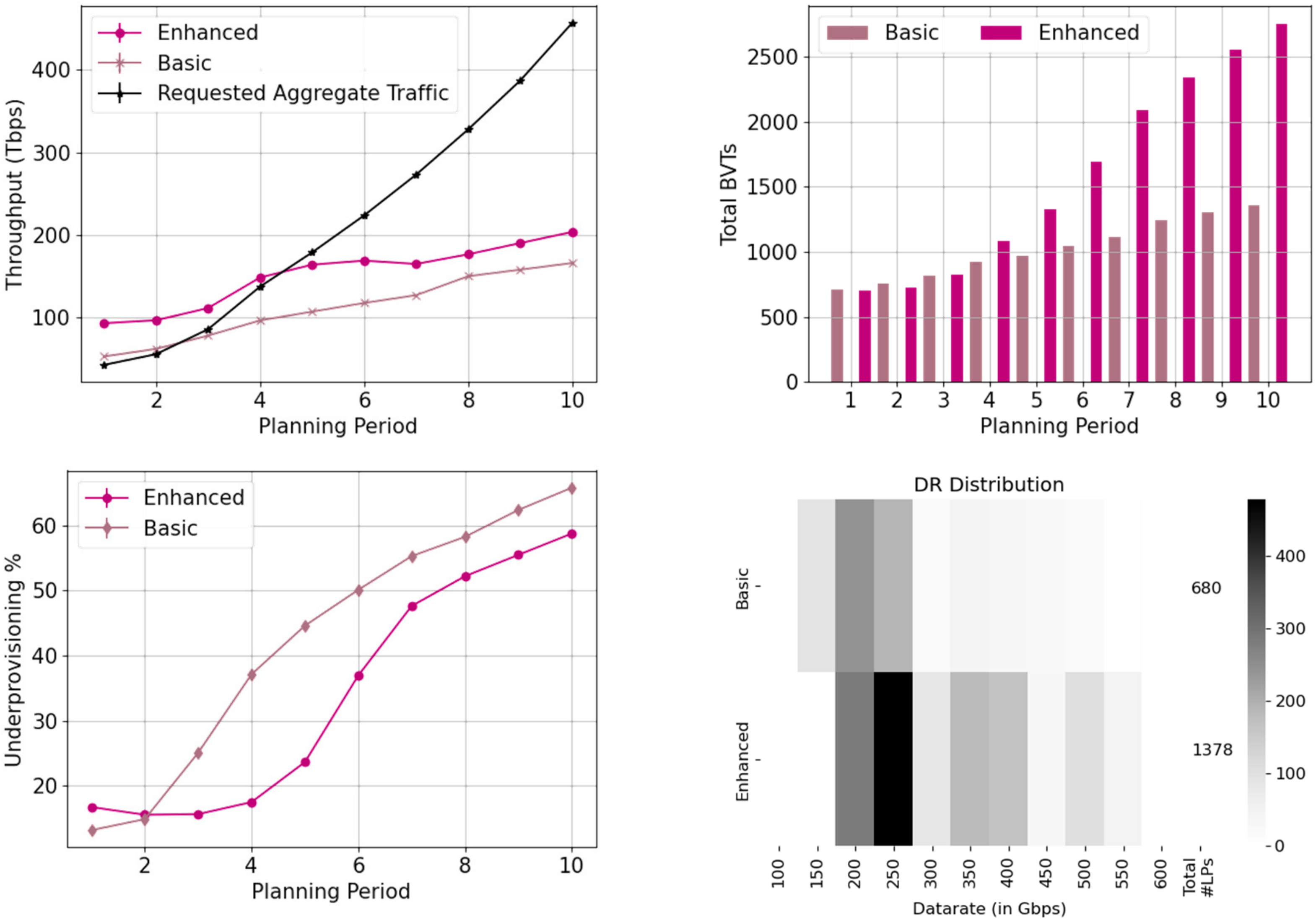
LP Upgrade

LP Addition

LP Reroute

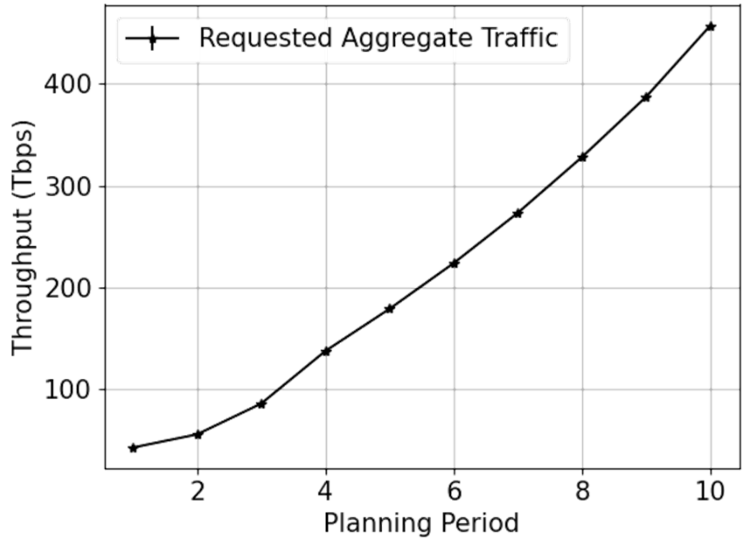
[3] Varasteh, Amir et al. *Towards Dynamic Network Reconfigurations for Flexible Optical Network Planning. OFC 2021*

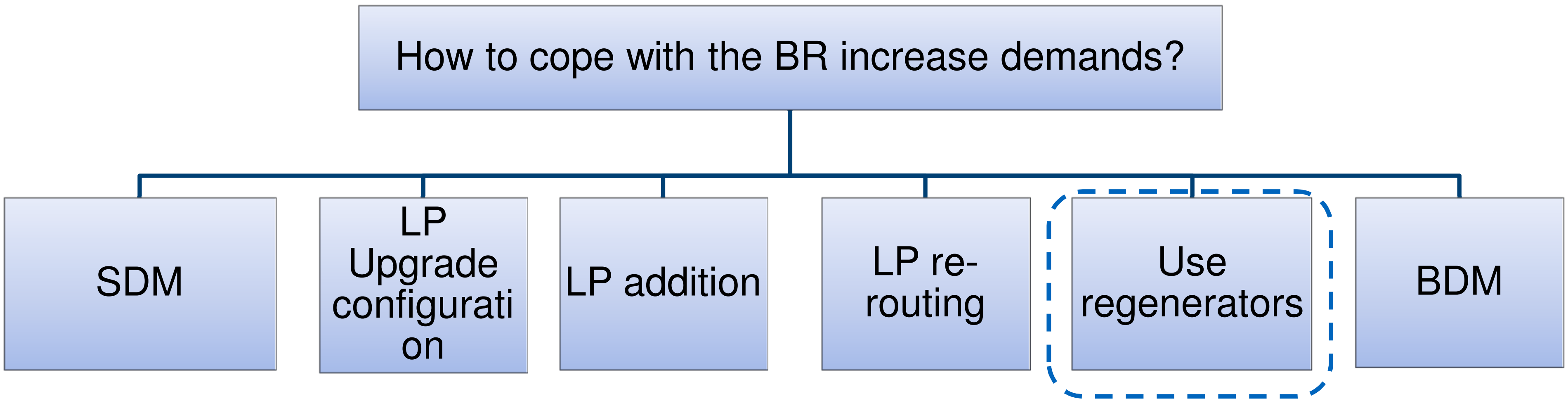
„Enhanced“ RCSA Results



Able to cope with more demands, lower underprovisioning and higher bitrates

Multi-period RCSA problem



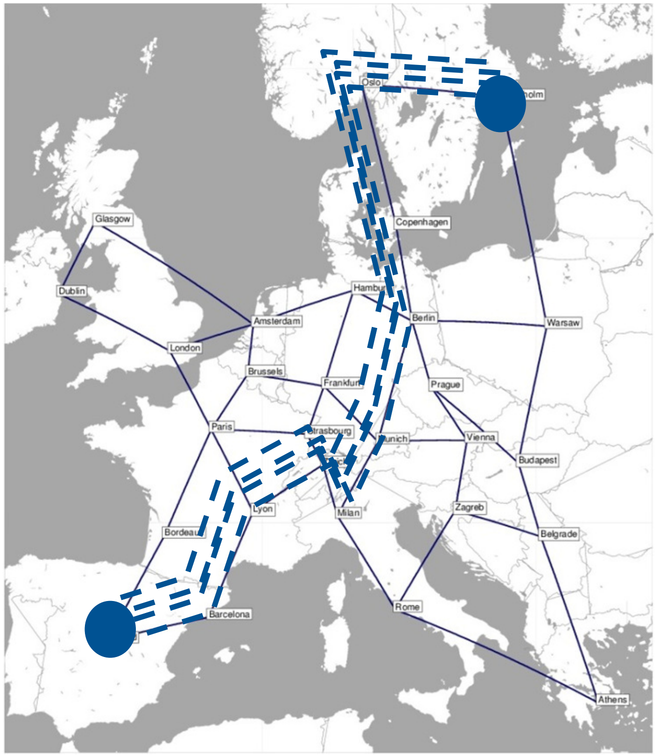


Regeneration

#Lightpaths	Bitrate [Gbps]	#BVTs
4	100	8

- Regenerators are able to:
  - Cope with long paths
  - Potentially decrease the number of BVTs

e.g., Demand: (Madrid, Stockholm,400Gbps)



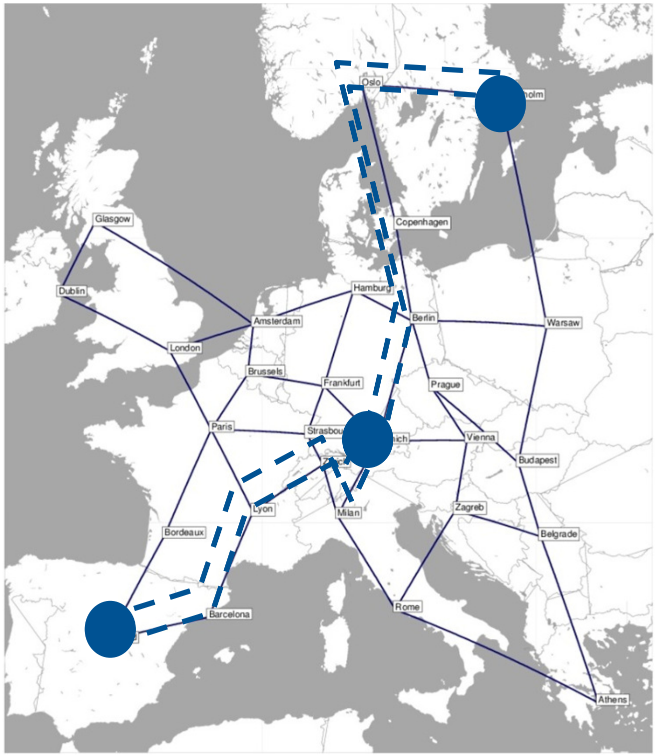
[4] Amjad, Saquib et al.: Towards Regeneration in Flexible Optical Network Planning. ONDM 2022

Regeneration

#Lightpaths	Bitrate [Gbps]	#BVTs
4	100	8
2	200	8

- Regenerators are able to:
  - Cope with long paths
  - Potentially decrease the number of BVTs

e.g., Demand: (Madrid, Stockholm,400Gbps)



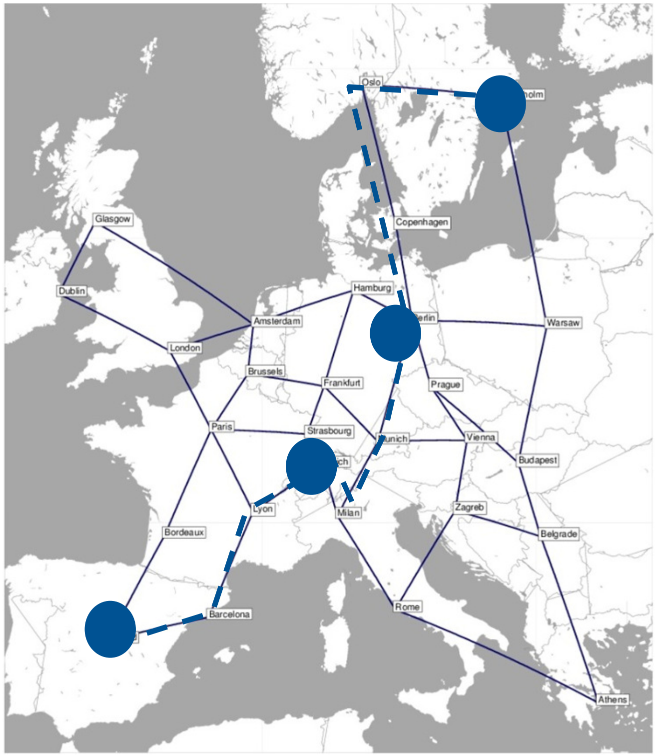
[4] Amjad, Saquib et al.: Towards Regeneration in Flexible Optical Network Planning. ONDM 2022

Regeneration

#Lightpaths	Bitrate [Gbps]	#BVTs
4	100	8
2	200	8
1	400	6

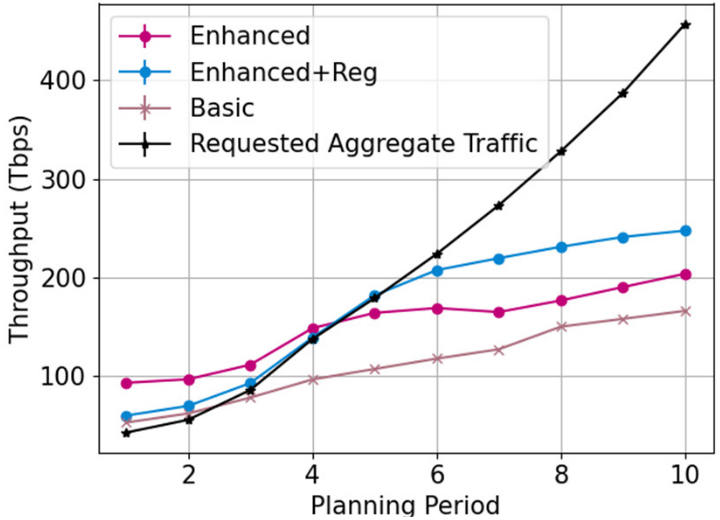
- Regenerators are able to:
  - Cope with long paths
  - Potentially decrease the number of BVTs

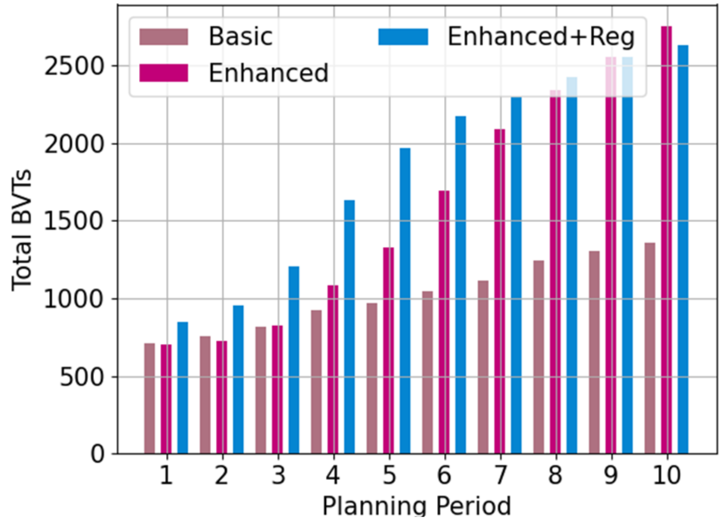
e.g., Demand: (Madrid, Stockholm,400Gbps)

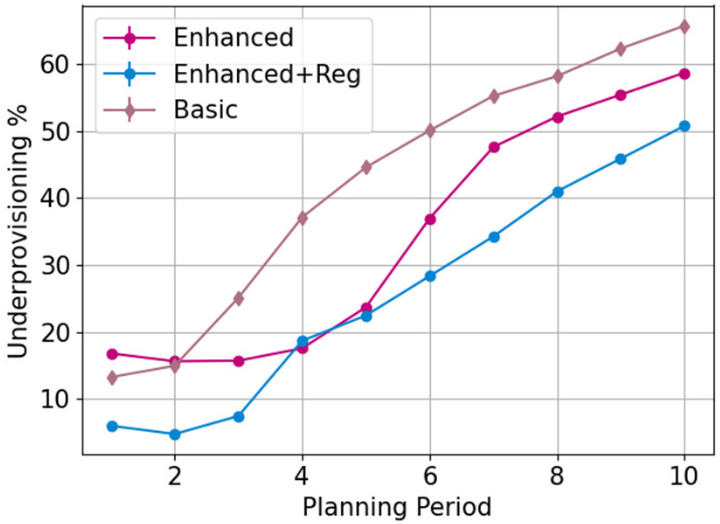


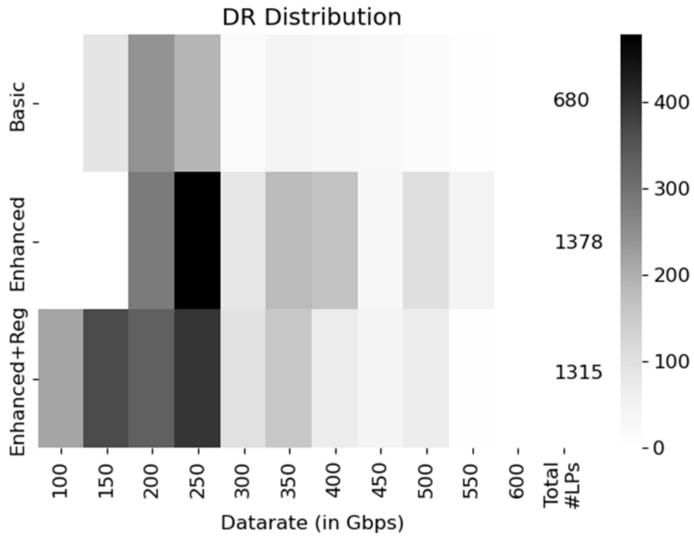
[4] *Amjad, Saquib et al.: Towards Regeneration in Flexible Optical Network Planning. ONDM 2022*

RCSA with regeneration: Results



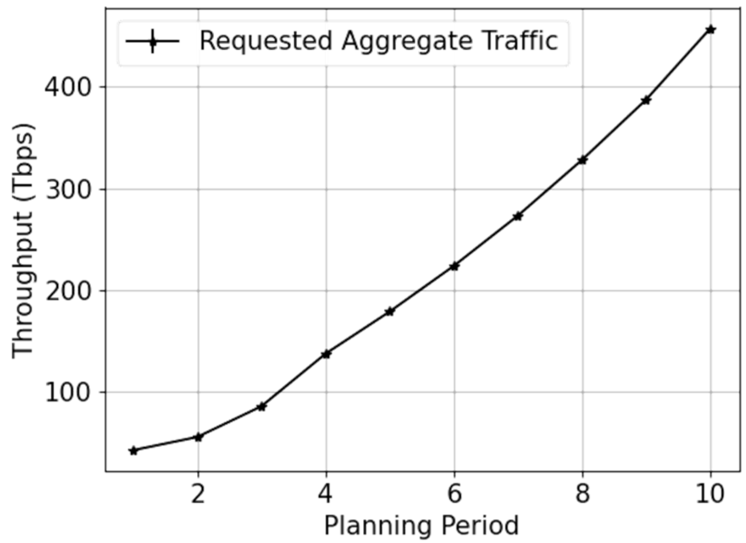


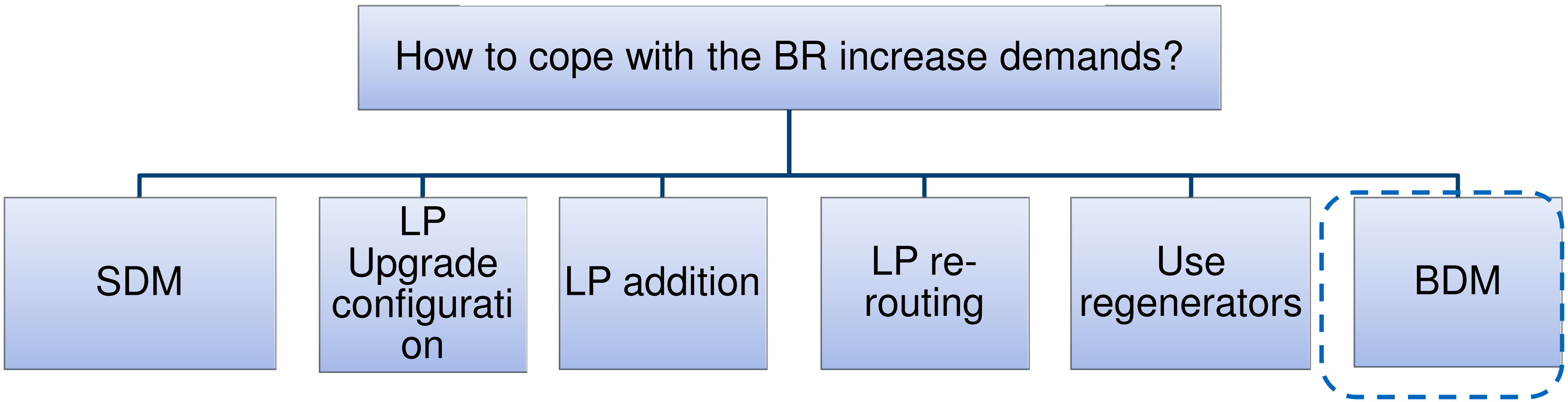




Lower underprovisioning, with lower lightpaths and BVTs

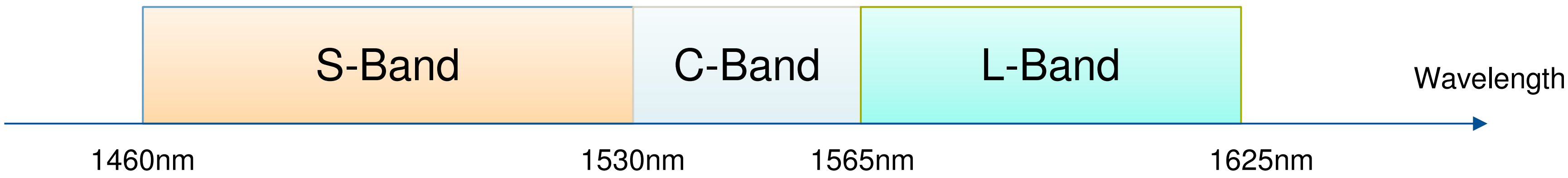
Multi-period RCSA problem





Band Division Multiplexing (BDM)

- Use of neighboring bands

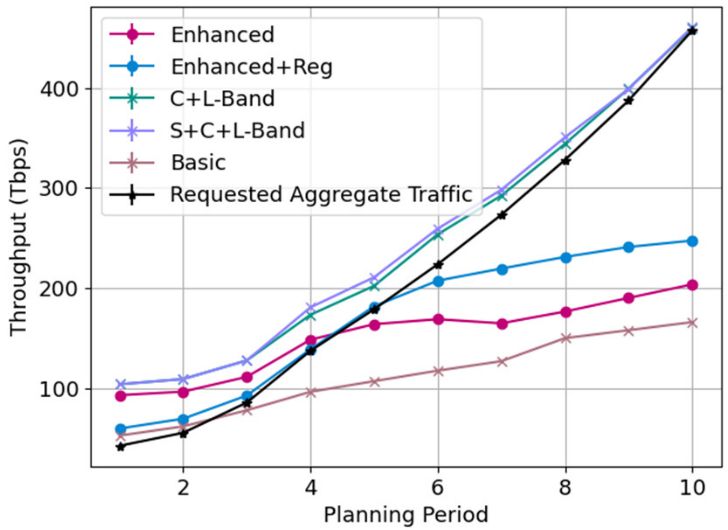


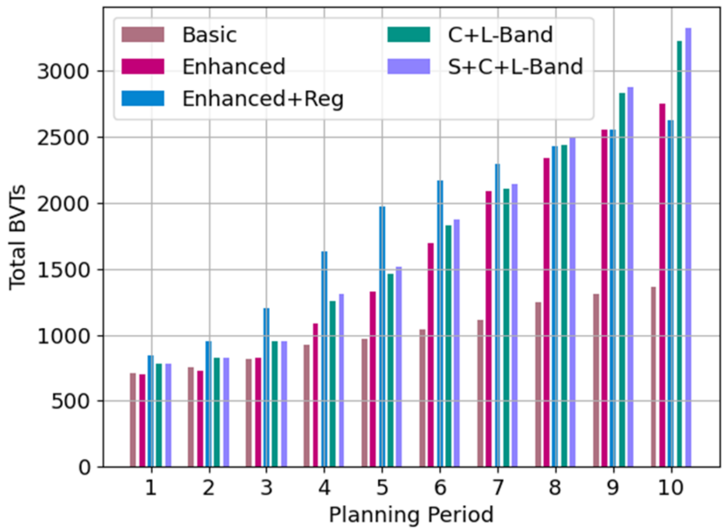
- EDFAs for C- and L- bands; TDFA for S-Band

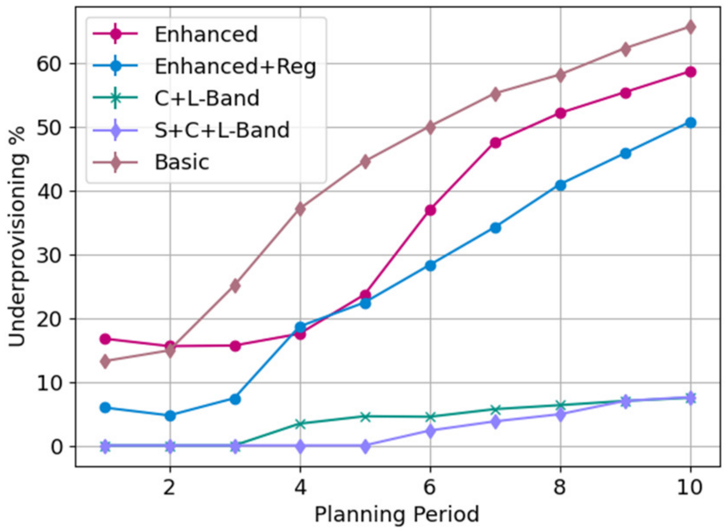
	Attenuation [dB/km]			**NF [dB]**			**Freq. Range**	**FS**		
	S	C	L	S	C	L		S	C	L
C-Band	-	.22	-	-	5.0	-	191-196 THz	-	400	-
C+L Band	-	.22	.24	-	6.0	6.0	186-196 THz	-	400	400
S+C+L Band	.25	.22	.24	7.0	6.0	6.0	186-200 THz	400	400	400

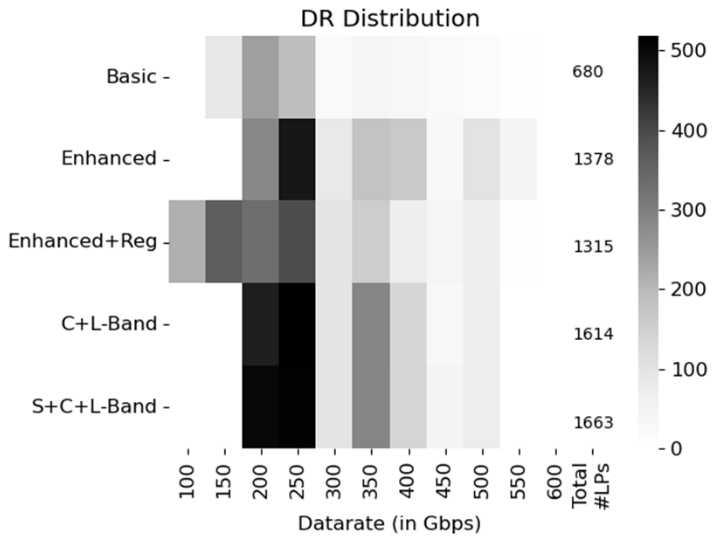
[5] Mas Machuca, Carmen et al. Long-term Capacity Planning in Flexible Optical Transport Networks. OFC 2022

BDM RCSA Results



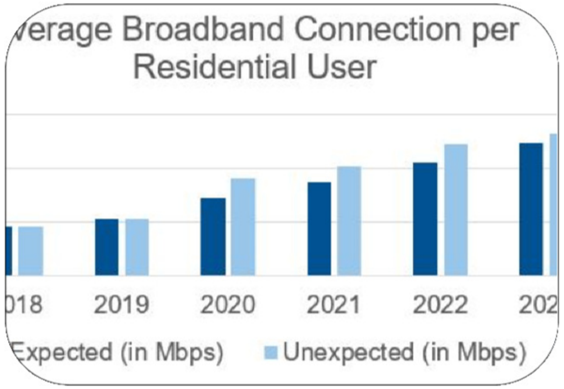




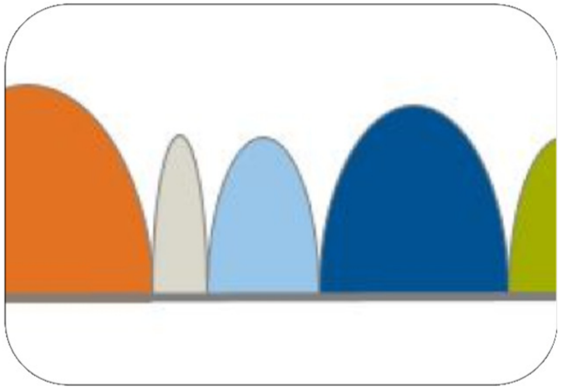


BDM achieves high throughput while reducing undersprovisioning and increasing LPs/BVTs

Conclusions



Coping with unexpected traffic increase



RCSA → increase spectraum efficiency

Aiming at reducing cost

Questions?