The Concept of Network Slicing

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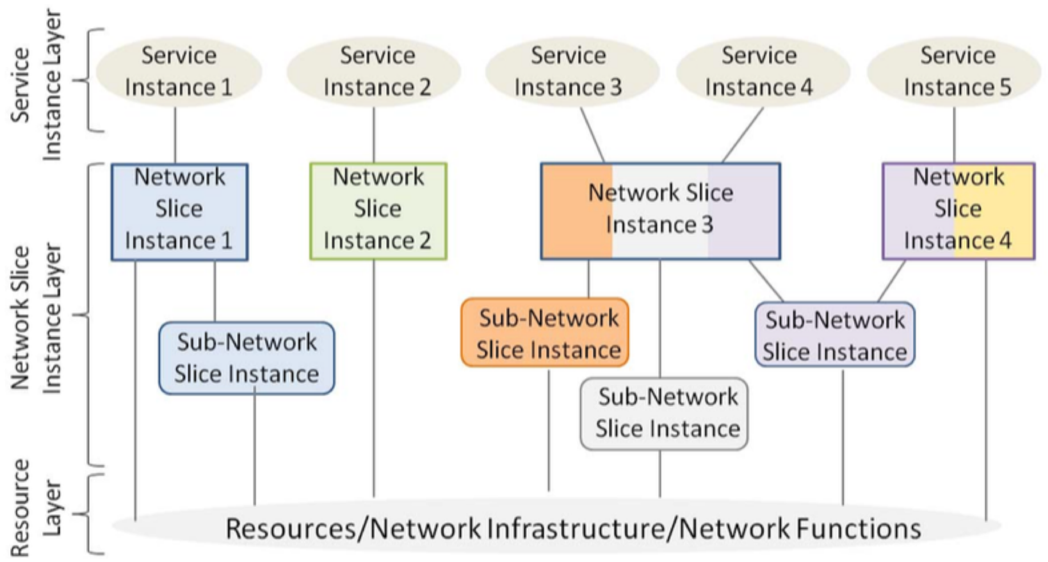
Definition

- Unlike the "one-fit-all" type of the 4G architecture, 5G is anticipated to consider diverse business demands with often conflicting requirements encouraging service innovation and programmability.
- A network slice (NS) is a virtual network that is implemented on top of a physical network in a way that creates the illusion to the slice tenants of operating its own dedicated physical network.
- SDN and NFV are promising enablers for having a programmable and flexible 5G transport network.



Network Slicing Concept [1]

[1] Afolabi, Ibrahim, Tarik Taleb, Konstantinos Samdanis, Adlen Ksentini, and Hannu Flinck. "Network slicing & softwarization: A survey on principles, enabling technologies & solutions." *IEEE Communications Surveys & Tutorials* (2018).

Advantage of Network Slicing for 5G [2]

- **Slice Isolation**: one slice won't affect operation of other slices.
- **Simplified Service Chain**: Instead of all services having same functions, in NS each service has different subset of functions. Unlike cellular network.
- **Flexible VNF Placement:** NFV introduces freedom of placement which reduces operating cost and improve performance.
- **Transparent Slice Management:** Subsets of physical resources may belong to different domains. NS provides an abstraction of physical resources and makes slice management transparent.

[2] Vassilaras, Spyridon, Lazaros Gkatzikis, Nikolaos Liakopoulos, Ioannis N. Stiakogiannakis, Meiyu Qi, Lei Shi, Liu Liu, Merouane Debbah, and Georgios S. Paschos. "The algorithmic aspects of network slicing." *IEEE Communications Magazine* 55, no. 8 (2017): 112-119.

Network Slicing Use Cases

Case	Application	Requirements
Broadband access in dense areas	Open-air event, stadium	High traffic volume, throughput (up to 10 Gb/s), ms latency
Broadband access everywhere	Minimum coverage everywhere	Guaranteed 50+ Mb/s
High user mobility	Trains, vehicles, aircrafts, and drones	Connectivity in 3D and at over 500 km/h
Massive Internet of Things	Sensors, smart wearables, and meters	Diverse RATs, low power, 1 million connections per km^2
Extreme real-time communications	Robotic control and autonomous cars	Sub-ms latency, reliability, mobility
Ultra-reliable communications	Smart grid, eHealth, and public safety	Redundancy, ms latency

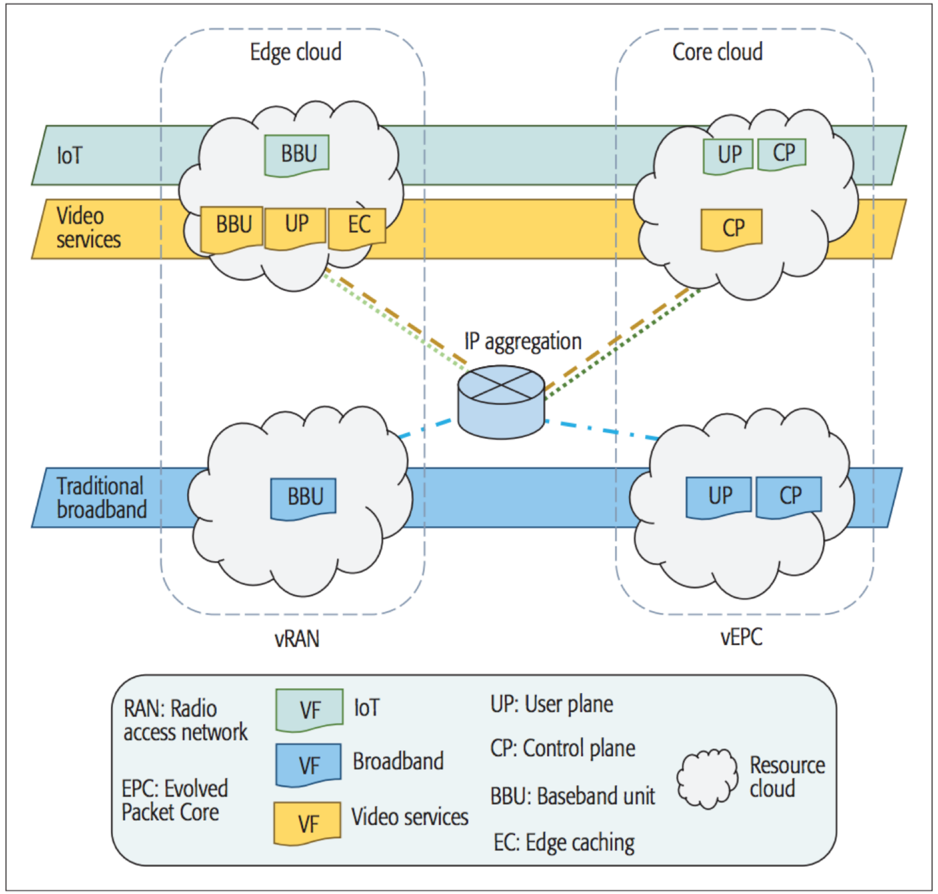
Diverse performance requirements can be realized by different network slicing [2].

[2] Vassilaras, Spyridon, Lazaros Gkatzikis, Nikolaos Liakopoulos, Ioannis N. Stiakogiannakis, Meiyu Qi, Lei Shi, Liu Liu, Merouane Debbah, and Georgios S. Paschos. "The algorithmic aspects of network slicing." *IEEE Communications Magazine* 55, no. 8 (2017): 112-119.

Service Specific Resource Allocation [2]

- Traditional voice and broadband services require complicated control plane functionalities such as authentication and mobility management, placed at the core cloud.
- IoT services could be implemented with a simplified control plane; for example, a smart meter service that monitors the energy consumption of houses does not require mobility management functionality.
- Video delivery services can be optimized if user plane and caching functionality is available at the edge cloud, which reduces backhaul traffic and improves user experience.

Service Specific Resource Allocation



. Network slices supporting indicative applications with diverse requirements. Each slice consists of different VNFs, which can be placed on different physical network domains.

Network slicing enables service-specific resource allocation, which leads to a simplified, smaller, and cost-efficient network.

[2] Vassilaras, Spyridon, Lazaros Gkatzikis, Nikolaos Liakopoulos, Ioannis N. Stiakogiannakis, Meiyu Qi, Lei Shi, Liu Liu, Merouane Debbah, and Georgios S. Paschos. "The algorithmic aspects of network slicing." *IEEE Communications Magazine* 55, no. 8 (2017): 112-119.

Operations Related to NS [2]

- Planning of slice requirements (by enterprise)
- Creation of slice (by network operator)
- Intra-slice network management (by enterprise)
- Orchestration of different slices (by network operator)

Dynamic Slicing [3]

Static Slicing: each virtual network (VN) is assigned a fixed portion of the physical network(PN) resources for its entire service time. Resource corresponding to peak requirement.

Not efficient utilization of PN resources

Dynamic slicing: In VN mapping phase a VN is assigned a resource slice with just enough resources to match current service needs. By monitoring the resource requirements of each VN a slice can be scaled up/down by a orchestrator. Tenants are oblivious of this change in ideal case. However, in practical tenants may experience *service degradation.*

Raza, Muhammad Rehan, Matteo Fiorani, Ahmad Rostami, Peter Öhlen, Lena Wosinska, and Paolo Monti. "Dynamic slicing approach for multi-tenant 5G transport networks." *Journal of Optical Communications and Networking* 10, no. 1 (2018): A77-A90.

Motivation [3]

- Dynamic slicing is flexible and resource efficient.
- It is more than just VN mapping/reconfiguration problem. Tenants are provided with programmatic APIs to control the provisioned slices.
- Most of the earlier works address design problems only

  - All PN requests are known in advance and objective is to embed on PN using minimum resources. Else, there is no notion of reconfiguration even if it is dynamic.

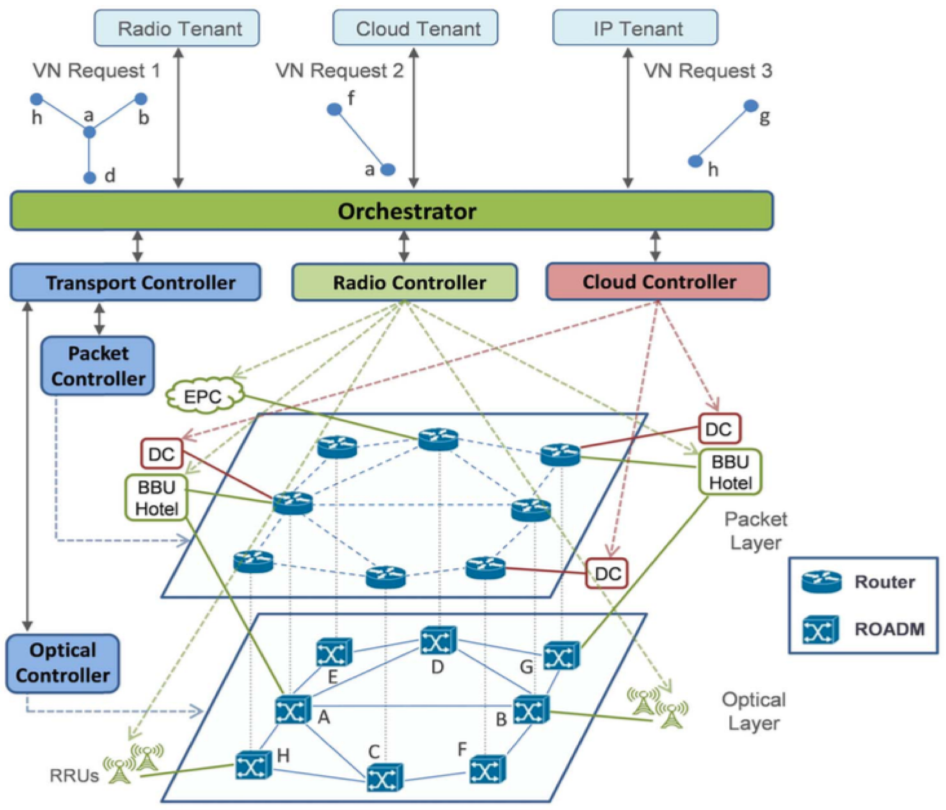
- Dynamic reconfiguration of PN resources can be realized by using SDN-based control plane.

Proposed Network Slicing Concept [3]

This work focuses on strategies for provisioning and maintaining network slices considering

1. Dynamic arrival/departure of VN requests
2. Temporal variation of VN resource requirements
3. VN reconfiguration is needed when
    a. Congestion (lack of resources in PN)
    b. Failure in PN

System Architecture [3]



System architecture. DC, data center; RRU, remote radio unit; BBU, baseband unit; EPC, evolved packet core; VN, virtual network; ROADM, reconfigurable optical add–drop multiplexer.

IP over WDM provides connectivity services to other domains. Transport controller manages the operations in the packet and optical layer by jointly interacting with packet and optical Controllers.

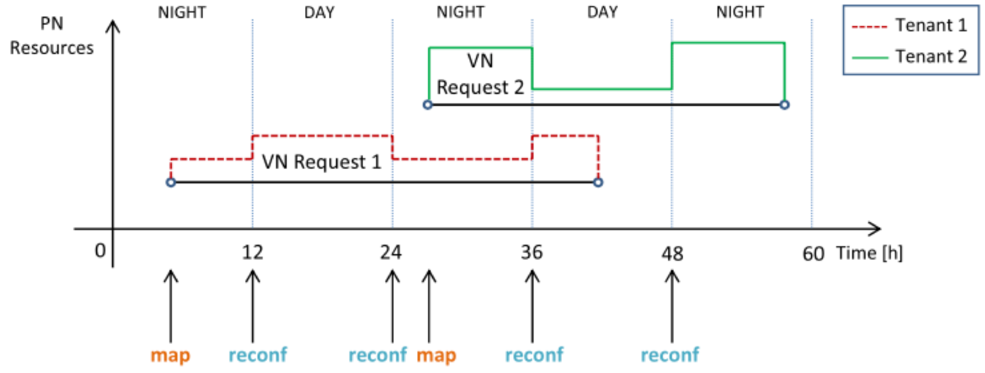
Radio domain provides mobile broadband services. It relies on the connectivity services of the transport network.

The cloud domain comprises of datacenters (DCs) which provide compute and storage services. Cloud controller manages the DC resources and operations of intra-DC network.

Orchestrator Layer: network provider is in charge of slice provisioning and reconfiguration, cross domain management and life-cycle orchestration of services.

Temporal Variation [3]

- Radio and IP tenants have peak resource requirements during daytime. Cloud tenants requires during nighttime.
- Conventional slicing approach will allocate fixed amount of resources for entire duration
- Dynamic slicing can scale down the slices whose VNs do not need currently as well as newly released resources can be allocated to VNs which require more resources.



Dynamic slicing considering VN requests from two different tenants.

Proposed Method [3]

VN Mapping: find set of PN resources (link capacity and compute/storage units) that satisfies the VN request requirements. Allocate new VNs onto already established lightpaths. If not possible add minimum number of new lightpaths to support the requirements. Otherwise, VN request rejected.

VN Reconfiguration: match as close as possible the variations of VN resources requirements, while limiting as much as possible the number of lightpath reconfigurations, lightpath re-routing, in order to not interrupt existing services.

Proposed Method [3]

- Degradation : during the VN reconfiguration phase, if the resources needs to be scaled up but there is not enough resources(high load condition). In this case service provided can be degraded, D.

$$D = \frac{\int_{t_1}^{t_1+T} C_{\text{req}}(t) - \int_{t_1}^{t_1+T} C_{\text{prov}}(t)}{\int_{t_1}^{t_1+T} C_{\text{req}}(t)},$$

Where C_{req} denotes total required capacity

C_{Prov} denoted total provided capacity

Mixed ILP for Dynamic Slicing [3]

MILP_map : *Minimizes the wavelength resource usage in the PN*

1. MILP_map considers the existing routes and capacity
2. Does not change the existing mapping while establishing new VN requests
3. Tries to allocate onto any previously established lightpath
4. Otherwise adds a minimum number of new lightpath

Output: node mapping, link mapping, routes and capacity used by all lightpath, update on the current status of PN resources

Mixed ILP for Dynamic Slicing [3]

MILP_reconf : *it aims to minimize the degradation of VNs currently mapped in PN, the number of lightpath reconfigurations and wavelength resource usage.*

Resize

Remap : over lightpaths already existing in PN

Degrade

Heuristic Algorithm for Dynamic Slicing [3]

The grooming graph has an electrical and an optical layer with 3 types of edges.

1. Lightpath (LP) edge
2. Wavelength (WL) edge
3. Transponder (TP) edge

The edge weights are selected so that the number of newly established lightpaths to support VN capacity requirements is minimized.

Heuristic_map [3]

- When a tenant requests a VN, the algorithm generates all possible node mapping over PN. If the capacity requirement of virtual link (c_v) is less that physical wavelength capacity (w), the virtual link is provisioned. Otherwise, c_v is split into several chunks (c_p)less than or equal to w. A grooming graph is constructed to provision c_p.
- The graph computes shortest path between source destination node of virtual link v.
- The weight of TP edge is chosen to be high to avoid new lightpath, and using already existing lightpaths
- If the VN are provisioned successfully, the algorithm computes the average number of wavelengths (u) in PN corresponding to node mapping m and finally choses the node mapping m that results in the minimum value of u.

Heuristic_map [3]

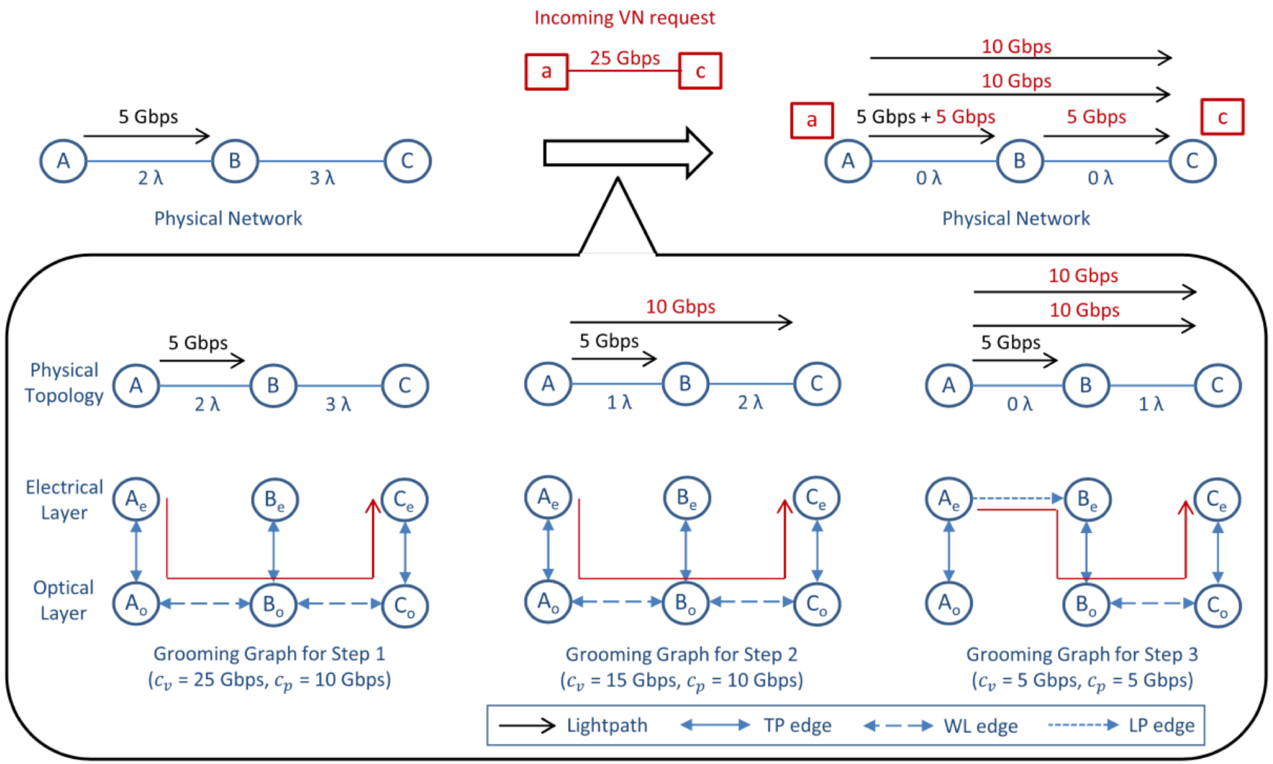


Fig. 4. Example of how to provision a virtual link using the grooming graph concept (assuming wavelength capacity of 10 Gbps).

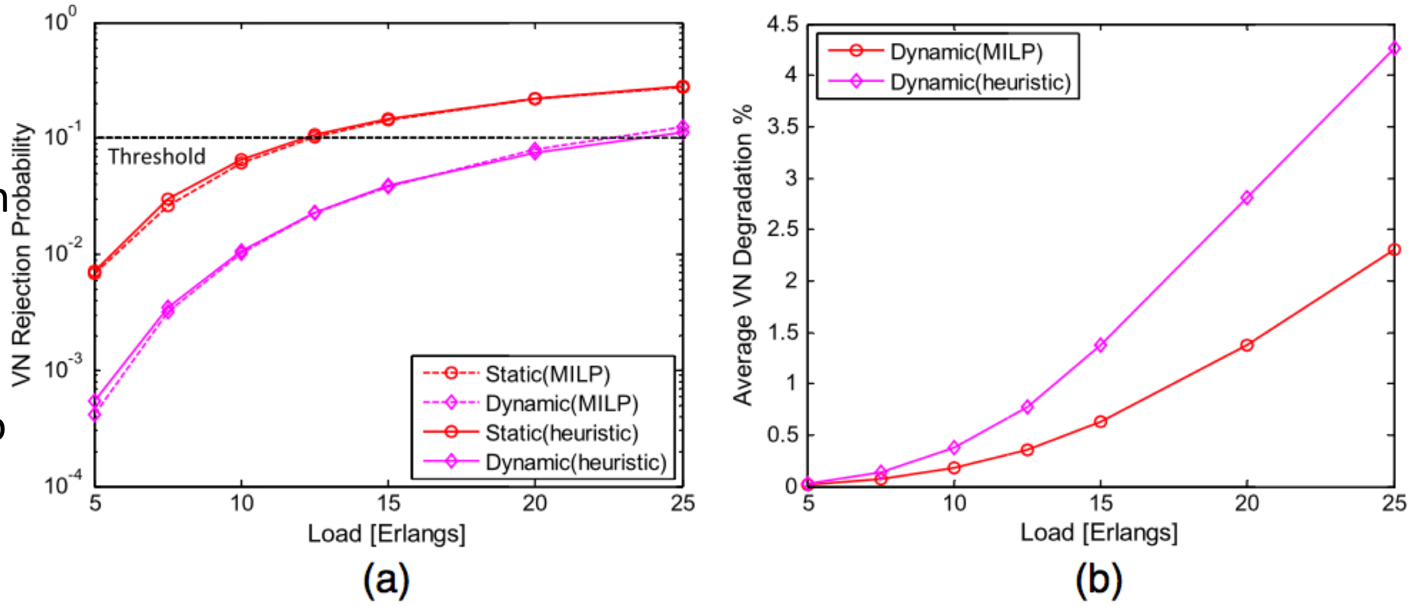
Heuristic_reconf [3]

- When switching between day and nighttime the algorithm sets the usage of currently established lightpath to zero and stores the information about their routes in PN.
- Then it selects one VN and tries to provision first the virtual link with largest capacity requirement.
- Capacity requirement is split into chunks and LP edge is given much lower weight than TP edge. The usage of the lightpaths are updated.
- If no path found then the service is degraded by an amount equal to the capacity that could not be provided.

Results [3]

It can be seen that dynamic slicing reduces the VN rejection probability by approximately 5 times when the network is in medium to high load conditions

Moreover, the results of the MILP formulations and of the heuristic algorithms are very close to each other. This indicates that the proposed heuristic algorithms are well designed and give close to optimal results .



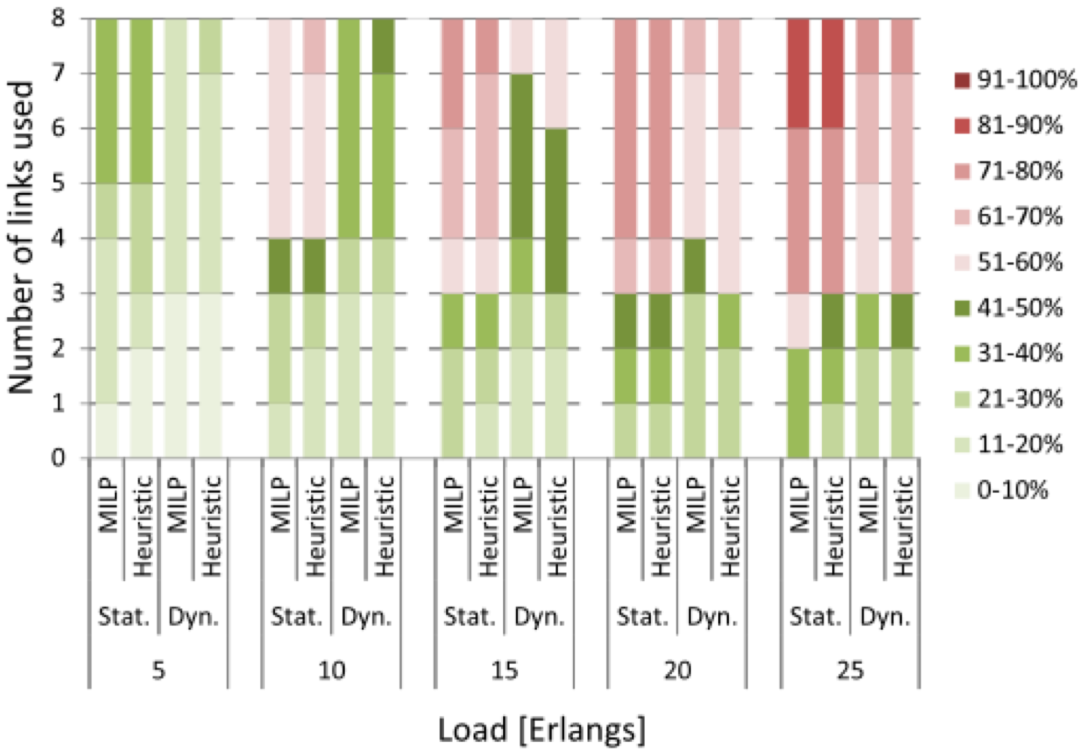
The gains in terms of VN rejection probability with dynamic slicing come at the expense of VN degradation.

This value is very small for low loads and tends to increase at high loads

Results [3]

Fig shows how many wavelengths are used on average in each of the eight fiber links of the PN

The proposed dynamic slicing approach is able to reduce the number of congested fiber links.



(c)

Conclusion

- This paper evaluates the benefits of dynamic slicing, where VNs corresponding to different tenants are reconfigured according to the temporal variations of their capacity requirements.
- Different from existing works, their approach leverages on advanced orchestration functionalities to intelligently assign and redistribute resources among the slices of different tenants.
- In the considered scenarios, it has been observed that dynamic slicing can improve the VN rejection probability by more than 1 order of magnitude.
- On the other hand, using dynamic slicing may result in the degradation of some services. However, the paper shows that service degradation is very small, and within acceptable levels for both the network providers and the tenants.

References

[1] Afolabi, Ibrahim, Tarik Taleb, Konstantinos Samdanis, Adlen Ksentini, and Hannu Flinck. "Network slicing & softwarization: A survey on principles, enabling technologies & solutions." *IEEE Communications Surveys & Tutorials* (2018).

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