Reliable Slicing

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Group Meeting
Friday, May 3, 2019

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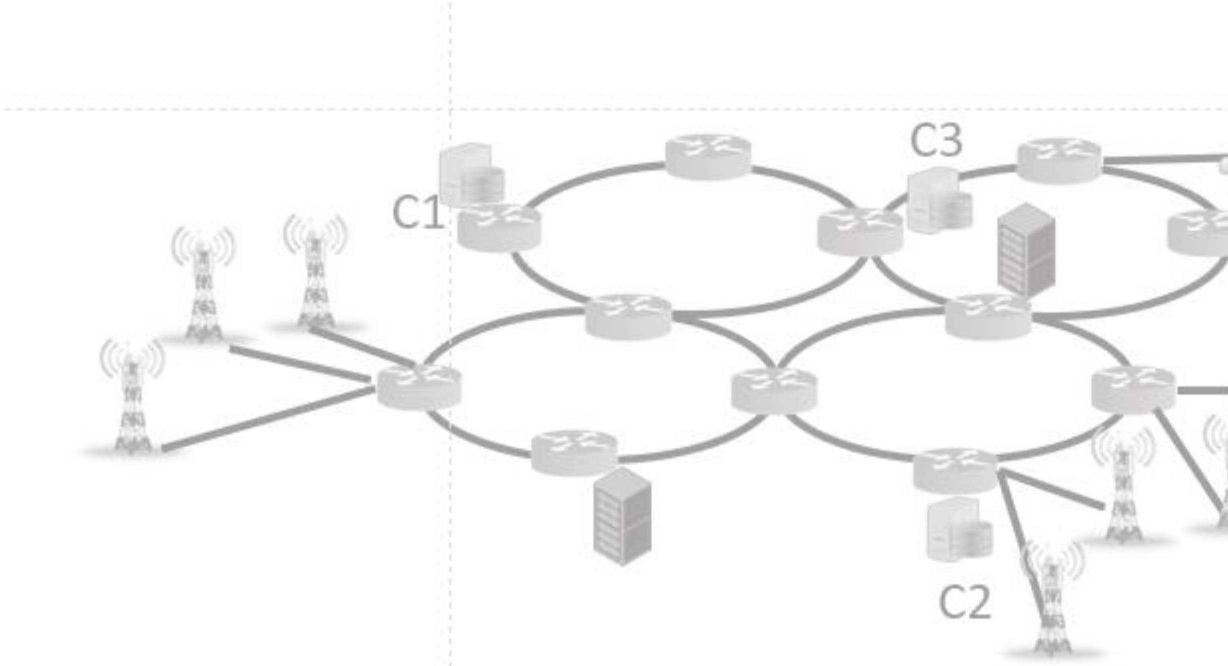
UNIVERSITY OF CALIFORNIA

Outline

- Slicing scenarios
  - Slice isolation
  - Virtualization techniques
- Slicing protection
  - PAC vs PAL
  - Protection strategies
- Problem formulation



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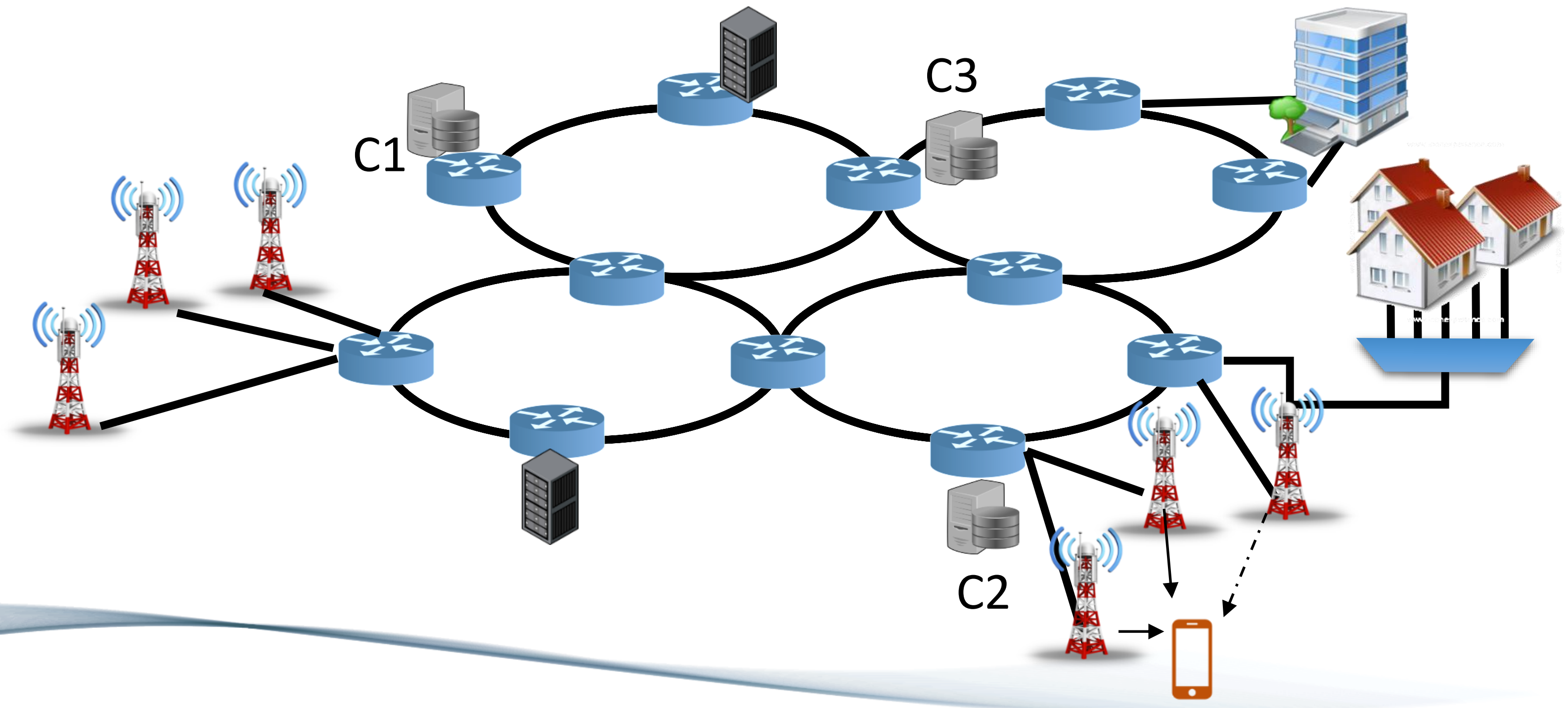
Integrated Optical-Wireless Reliable Slicing

- Can we integrate mobile network resiliency and Metro-Access network protection in mobile multi-connectivity scenarios?



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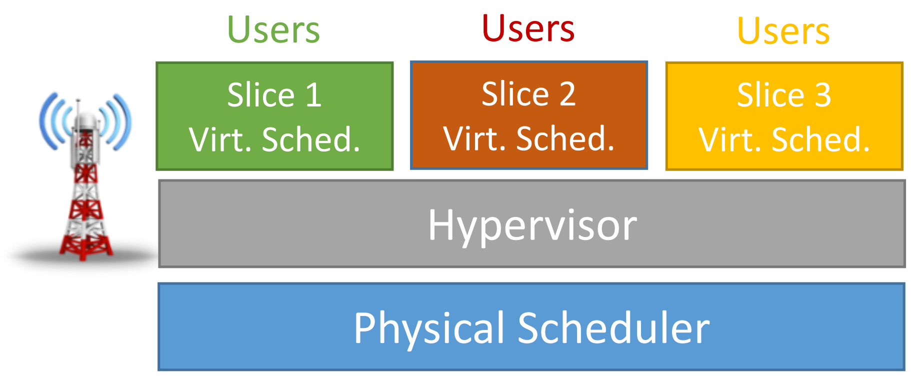
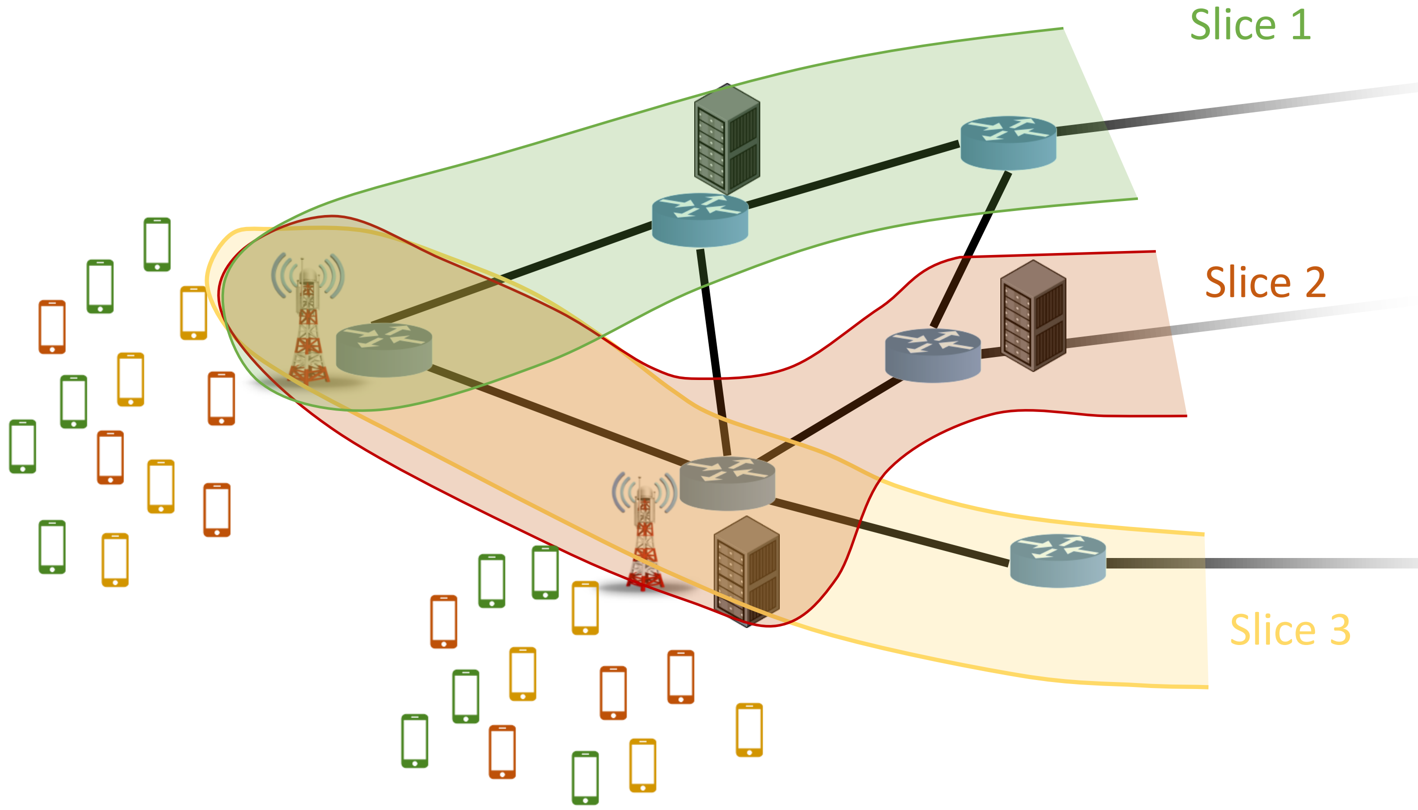
Slicing in Radio Access Networks (1)

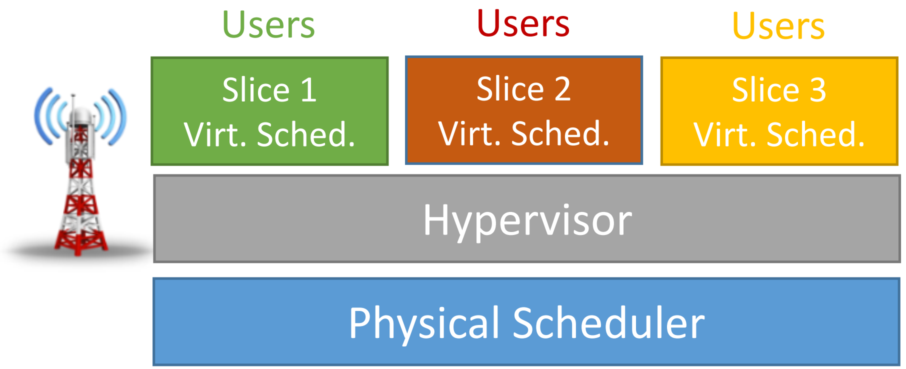
- Radio Access Network (RAN) slicing is implemented at the radio scheduler
- Each Radio Access Point should support more than one slice

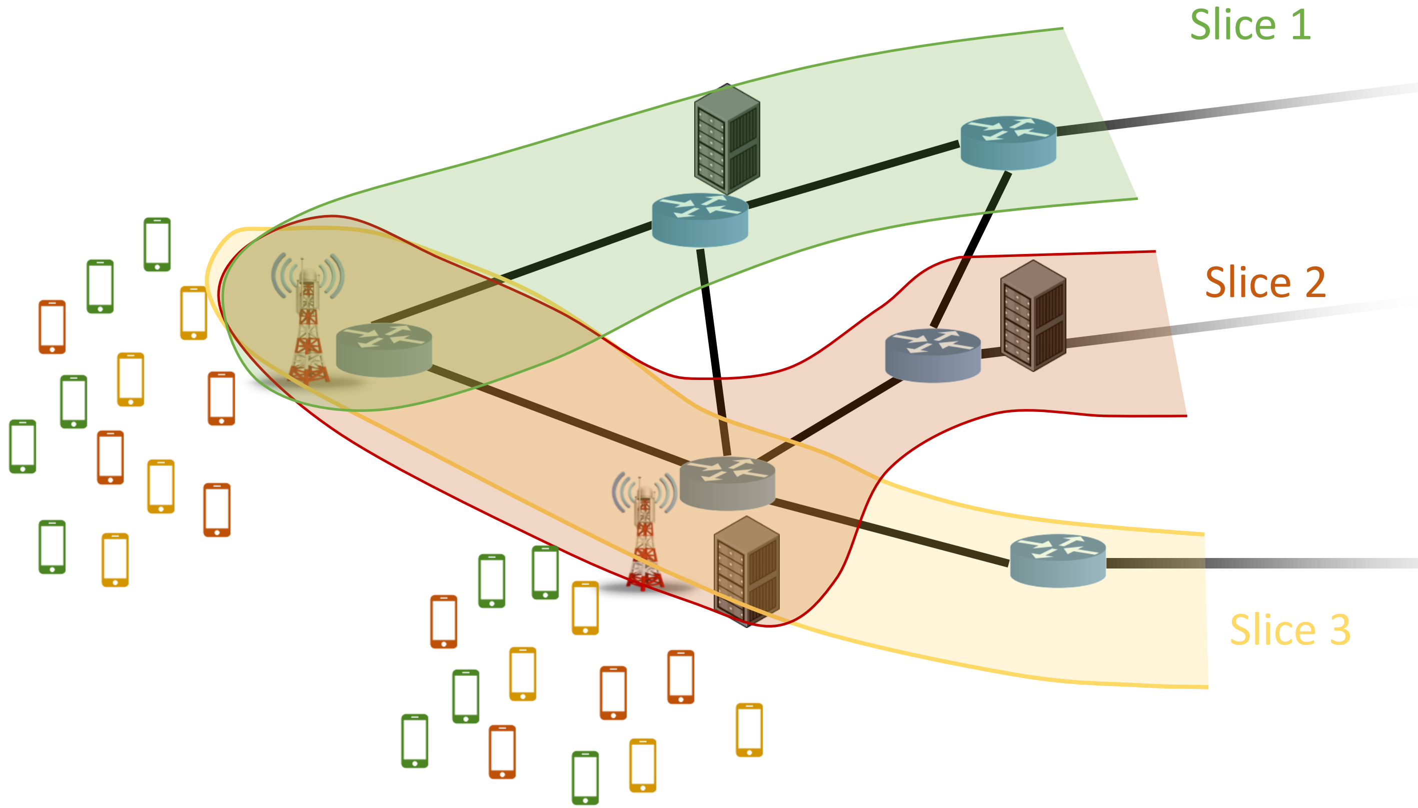




Slicing in Radio Access Networks (1)

- Radio Access Network (RAN) slicing **can be** implemented at the radio scheduler
- Each Radio Access Point should support more than one slice





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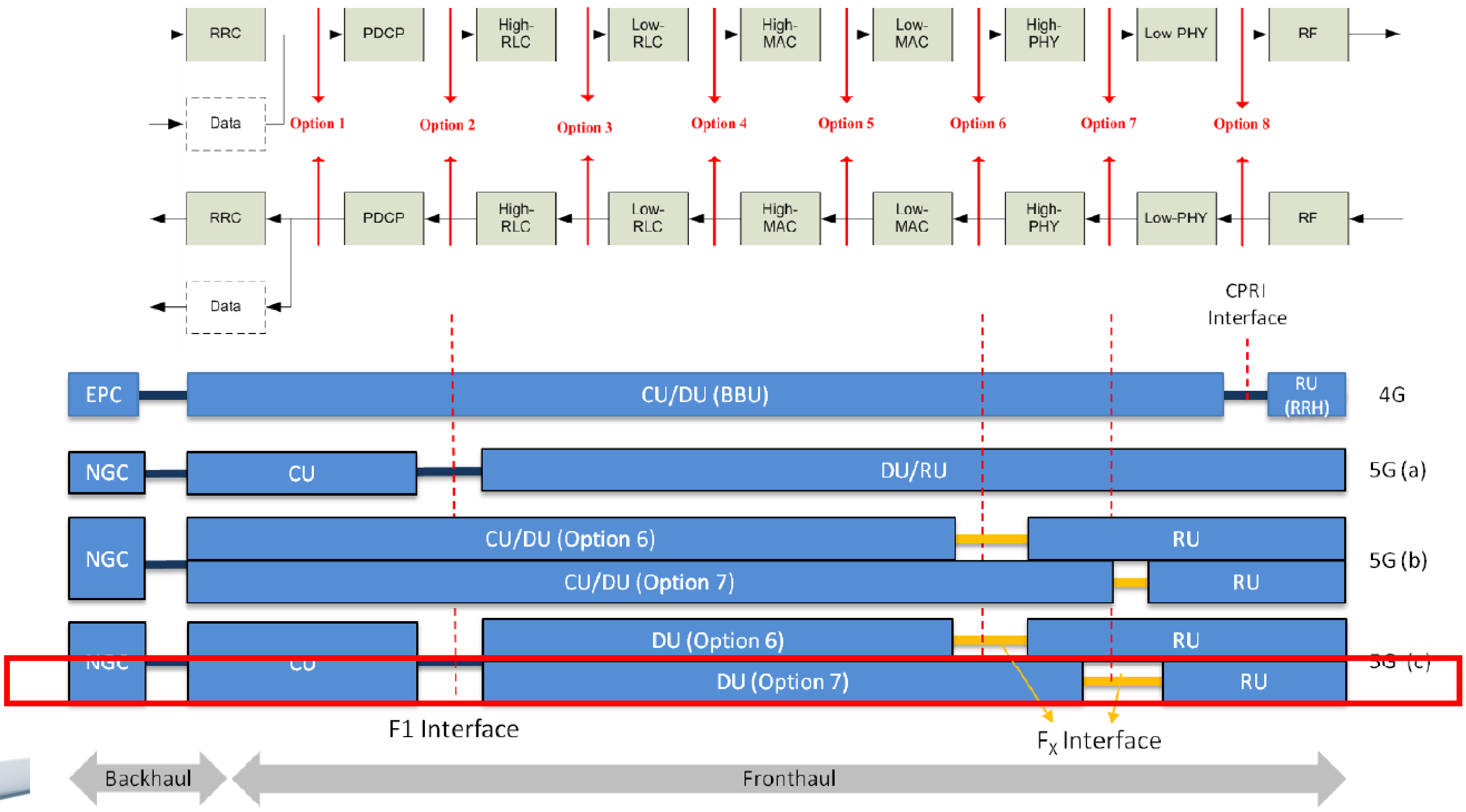
Virtual service chains for mobile network slicing



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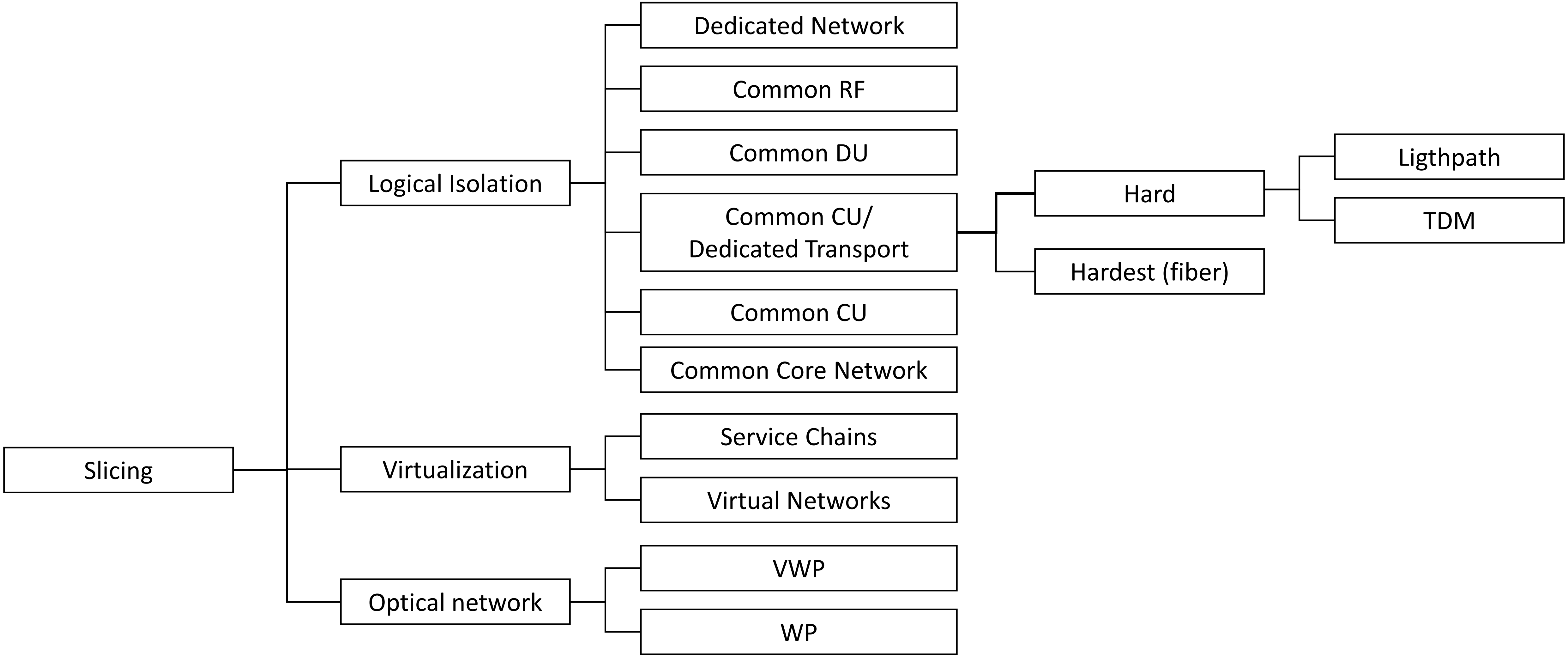
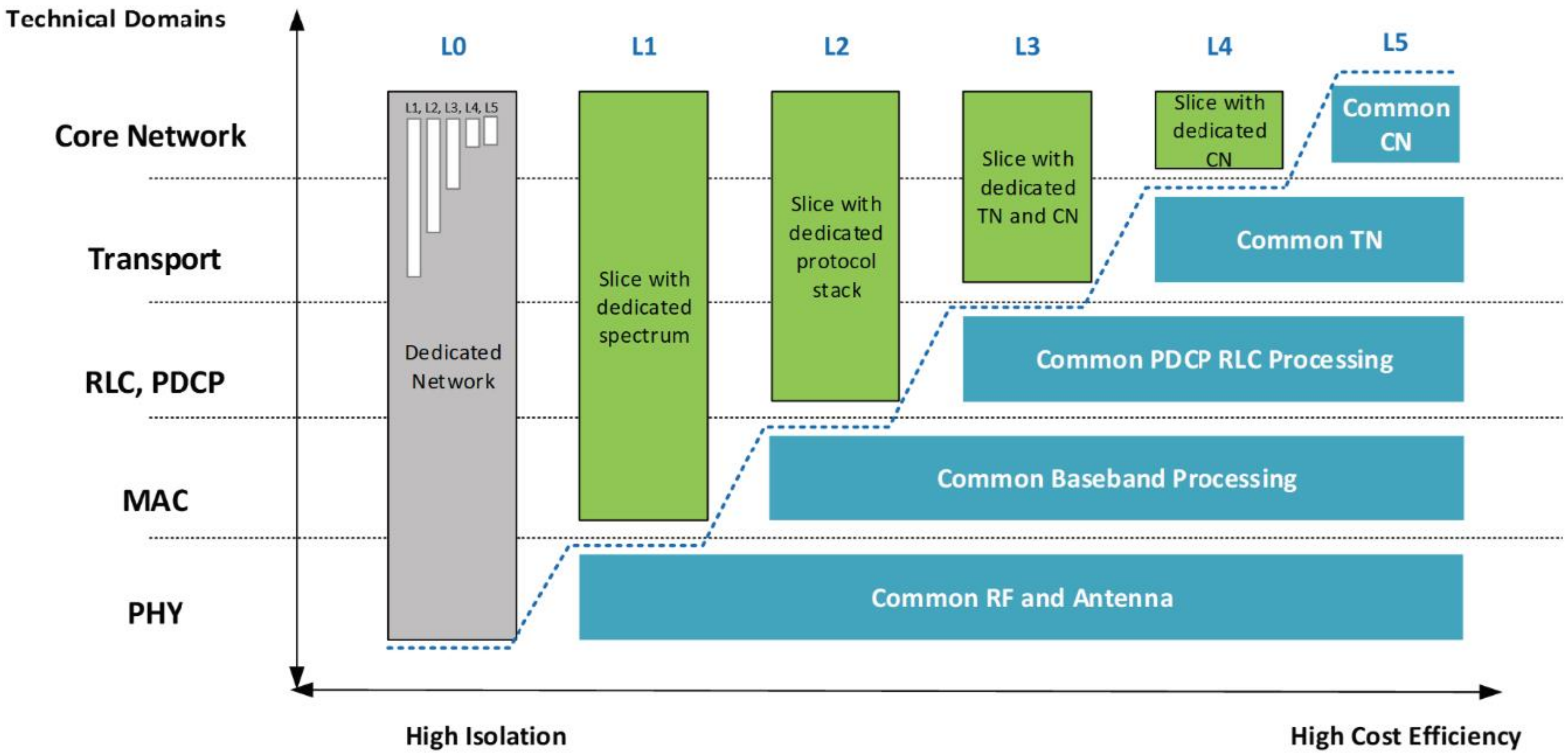
ITU-T, “Transport network support of IMT-2020/5G”, Technical Report, Feb. 2018

Slicing Overview



Slice Isolation (1)



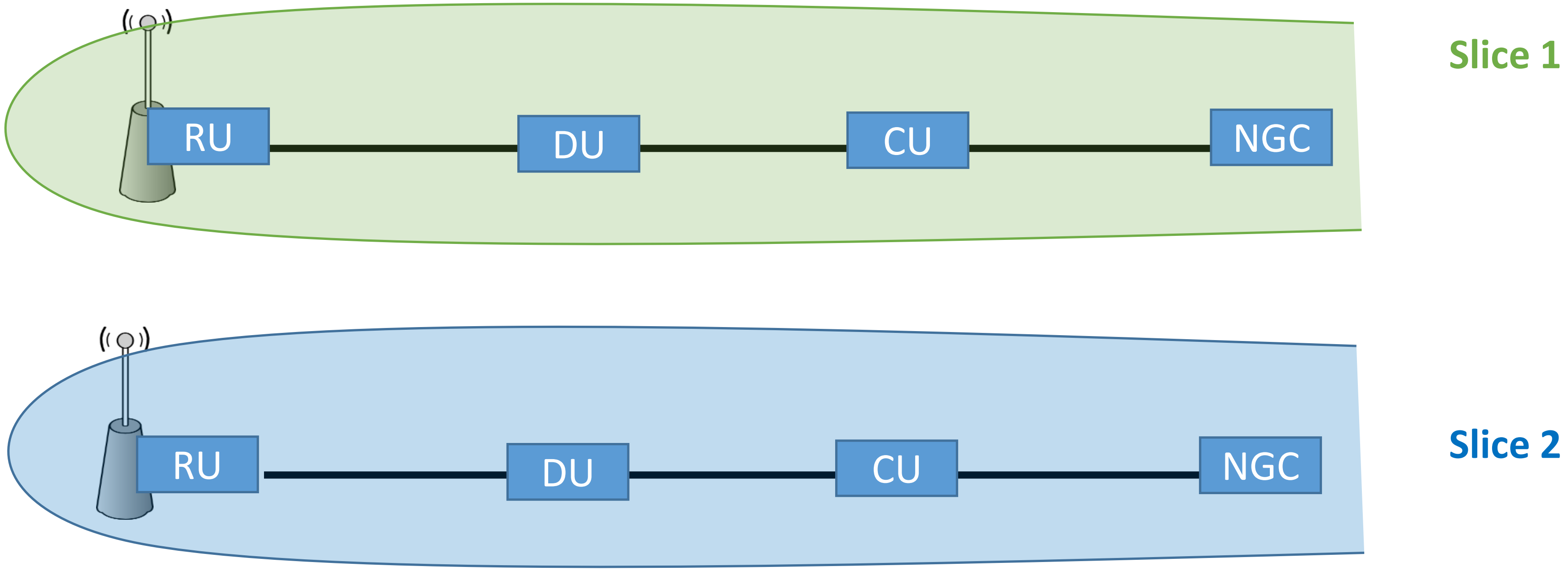
GSMA, "Network Slicing: Use Case Requirements," Technical Report, Apr. 2018

Slice Isolation (L0)

- Dedicated network
- Each slice has its own elements
- High cost

Slice 1: High Capacity – No protection req.

Slice 2: Low capacity - Reliable

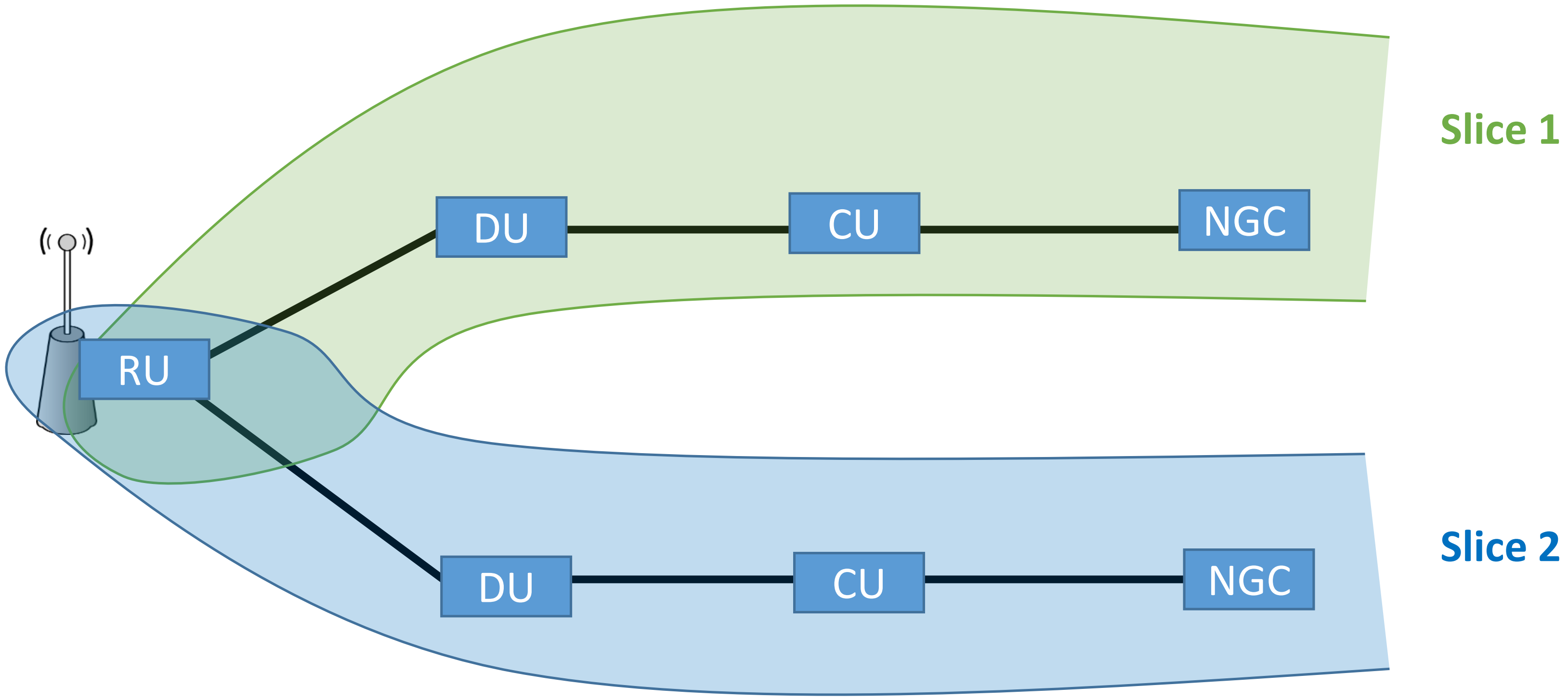


Slice Isolation (L1)

- Common Radio Unit

Slice 1: High Capacity – No protection req.

Slice 2: Low capacity - Reliable



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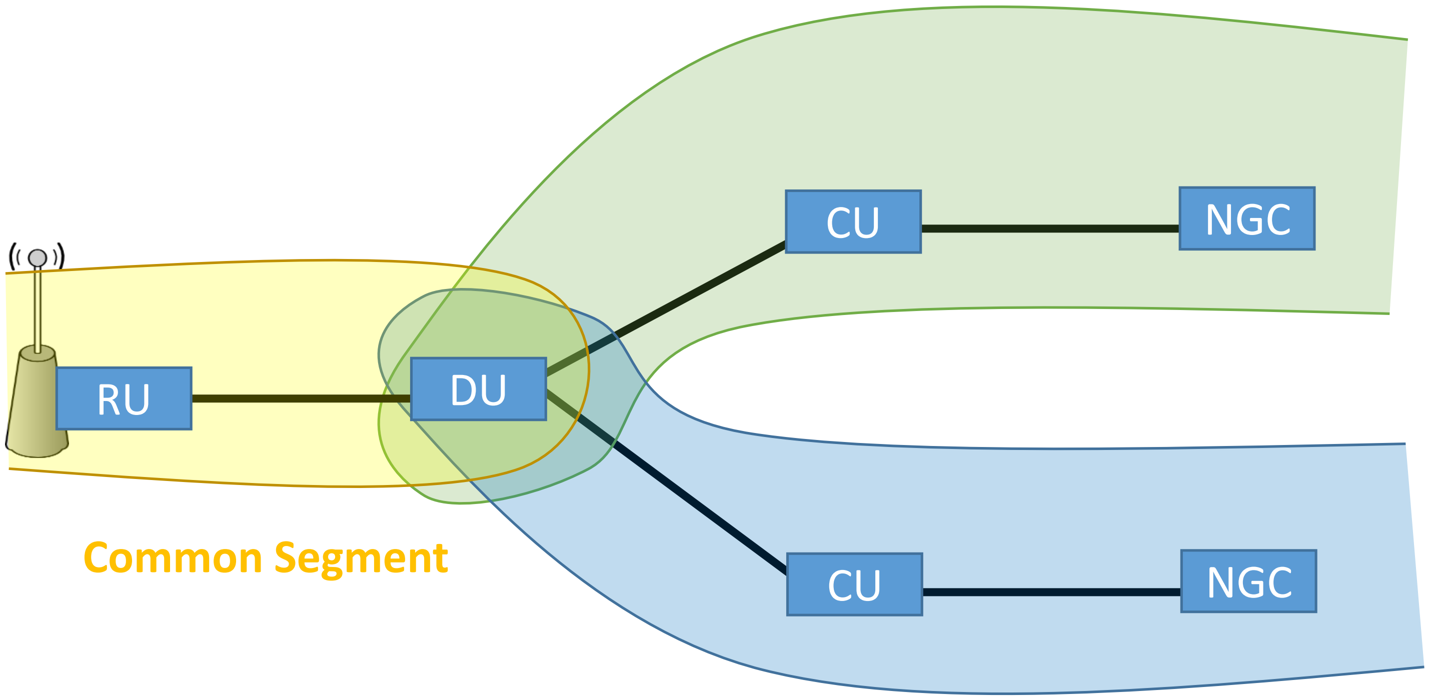
Slice Isolation (L2)

- Common Distributed Unit
- Slicing is implemented at the radio scheduler

Slice 1: High Capacity – No protection req.
Slice 2: Low capacity - Reliable

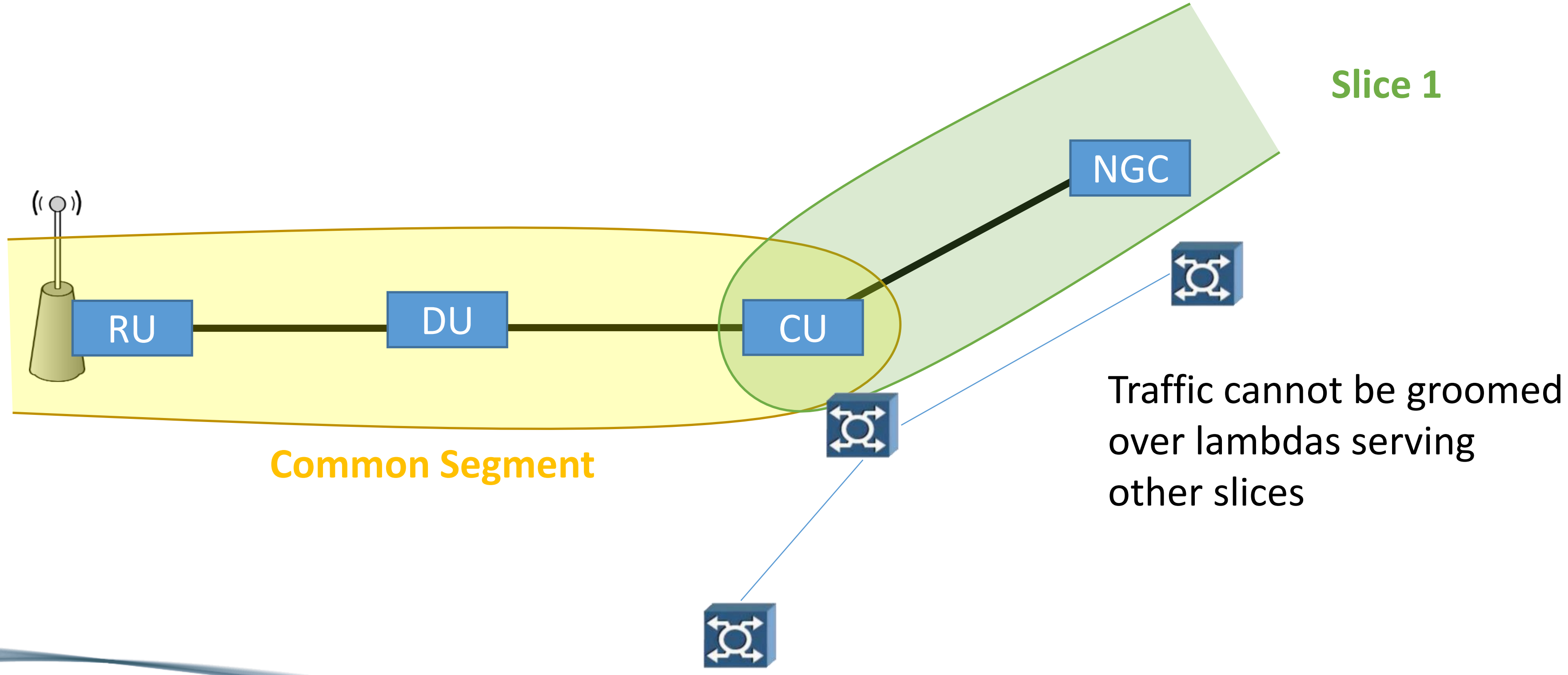


Slice Isolation (L3)

- Common Central Unit
- Dedicated physical transport network
  - Hard slicing (dedicated wavelengths, TDM resources)
  - Hardest (dedicated fibers, routing resources)

Slice 1: High Capacity – No protection req.

Slice 2: Low capacity - Reliable



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ITU-T, "Transport network support of IMT-2020/5G," Technical Report, Feb. 2018

Slice Isolation (L3)

- Common Central Unit
- Dedicated physical transport network
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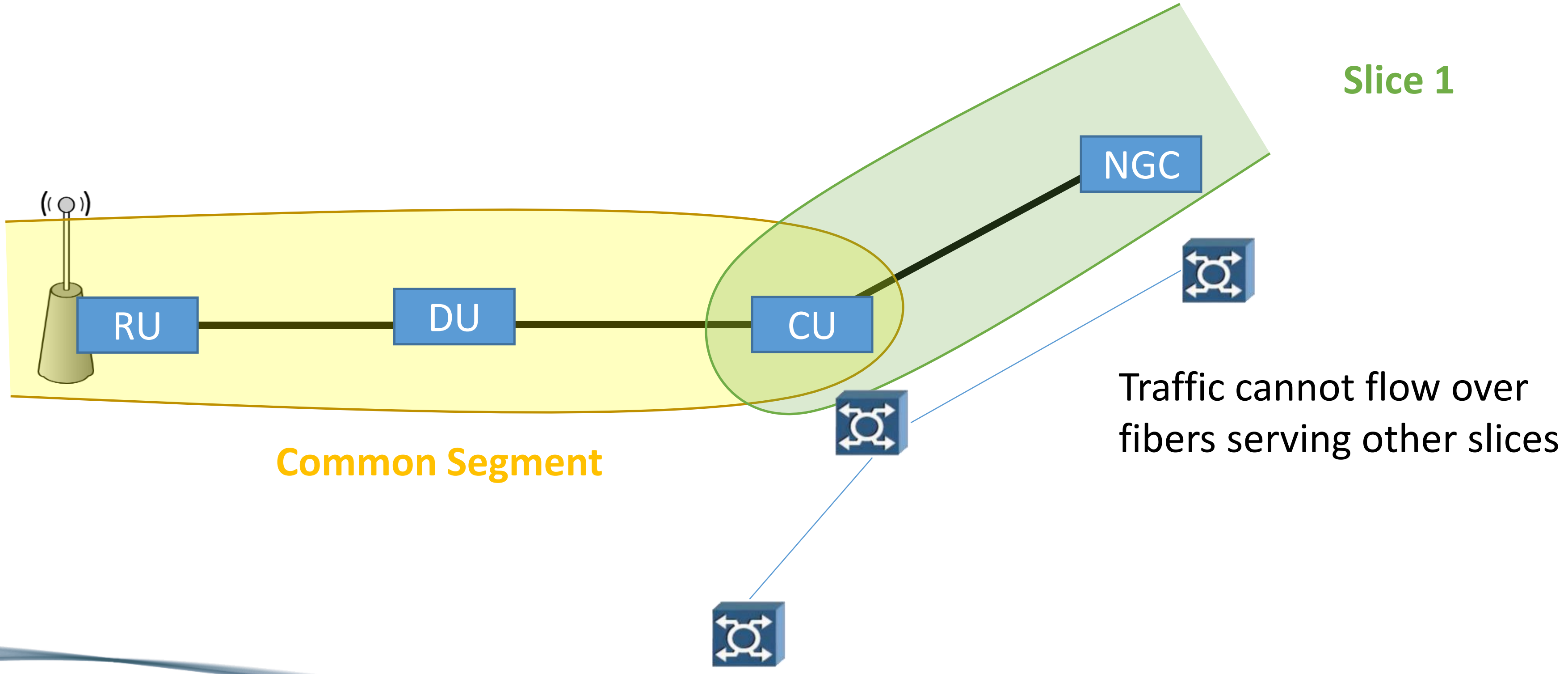
  - Hardest (dedicated fibers, routing resources)

Slice 1: High Capacity – No protection req.

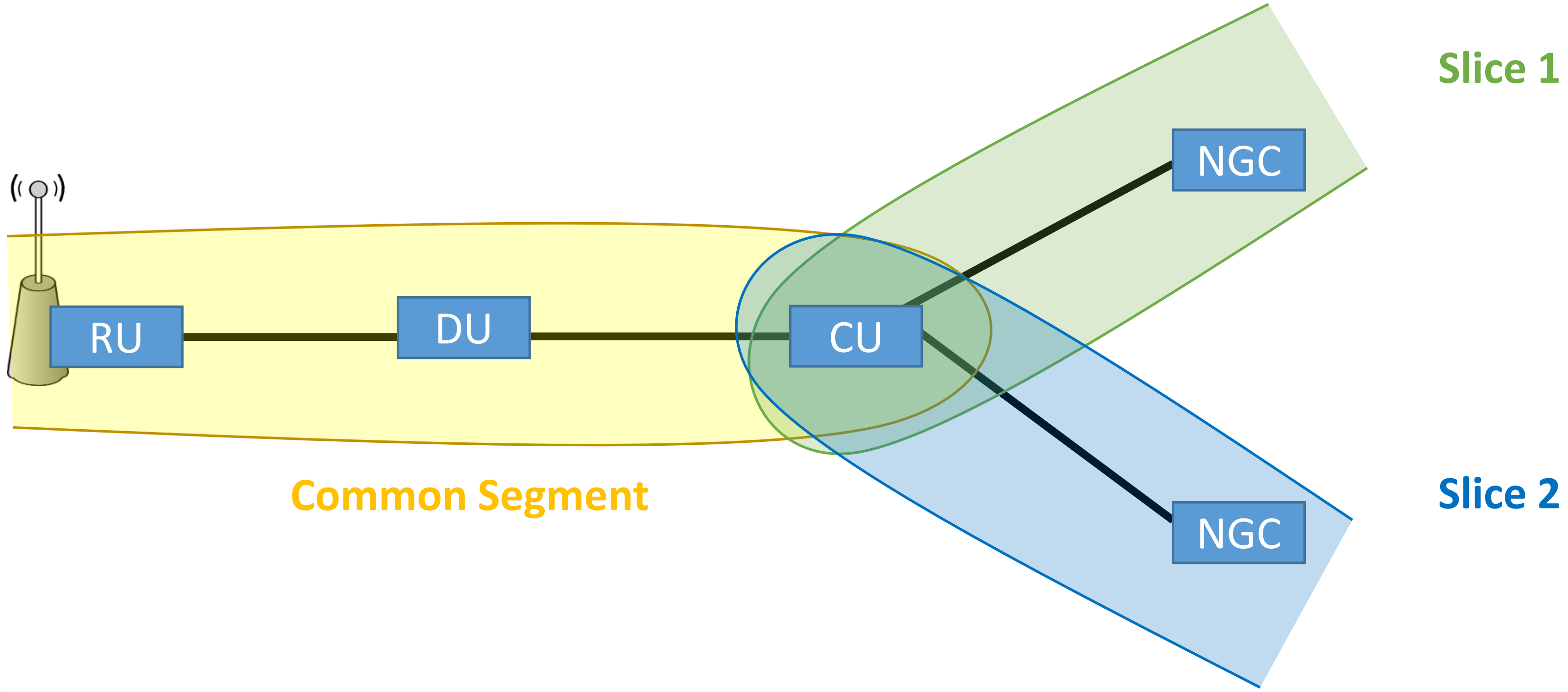
Slice 2: Low capacity - Reliable



Slice Isolation (L4)

- Common Central Unit
- Without dedicated physical transport network

Slice 1: High Capacity – No protection req.
Slice 2: Low capacity - Reliable



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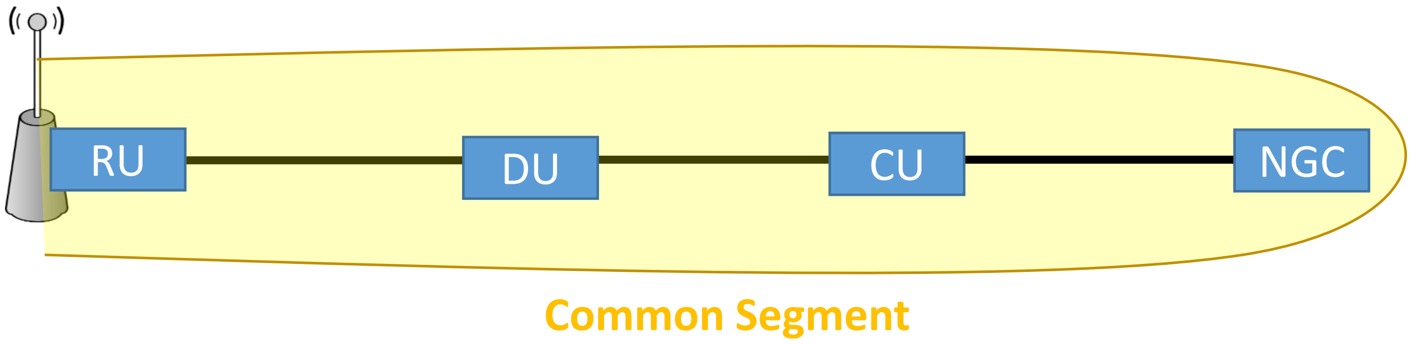
Slice Isolation (L5)

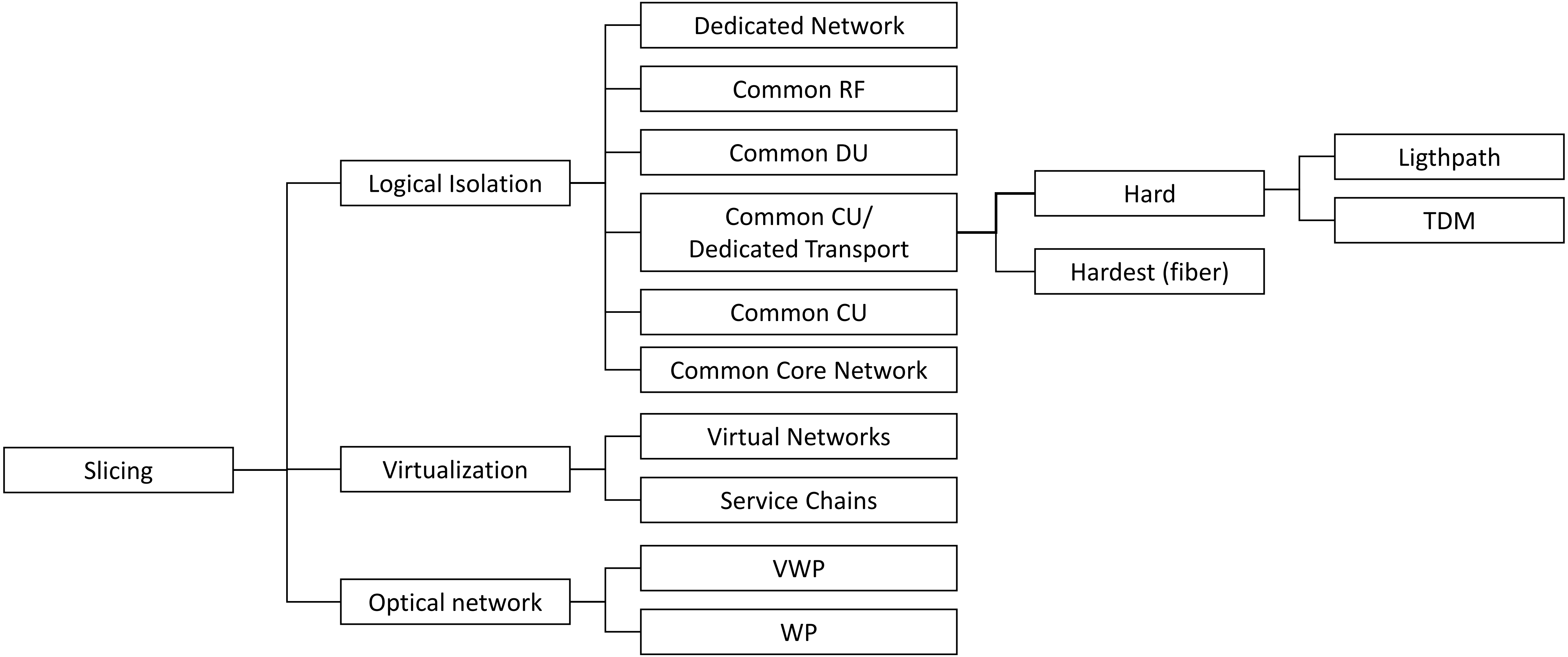
- Common Core Network
- No logical elements per slice

Slice 1: High Capacity – No protection req.

Slice 2: Low capacity - Reliable

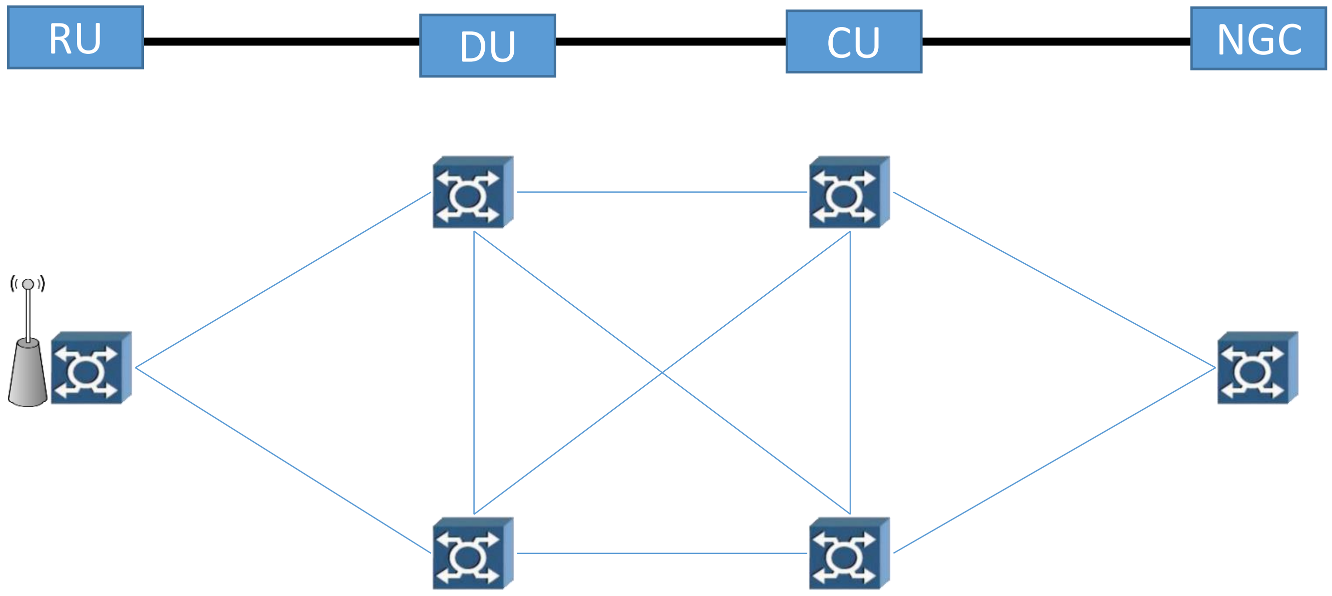


Slicing Overview



Virtual Networks vs. Service Chains (1)

- Slice:
  - Set of virtual node and virtual links with capacity requirements
  - Associated to reliability requirements
  - Dedicated transport



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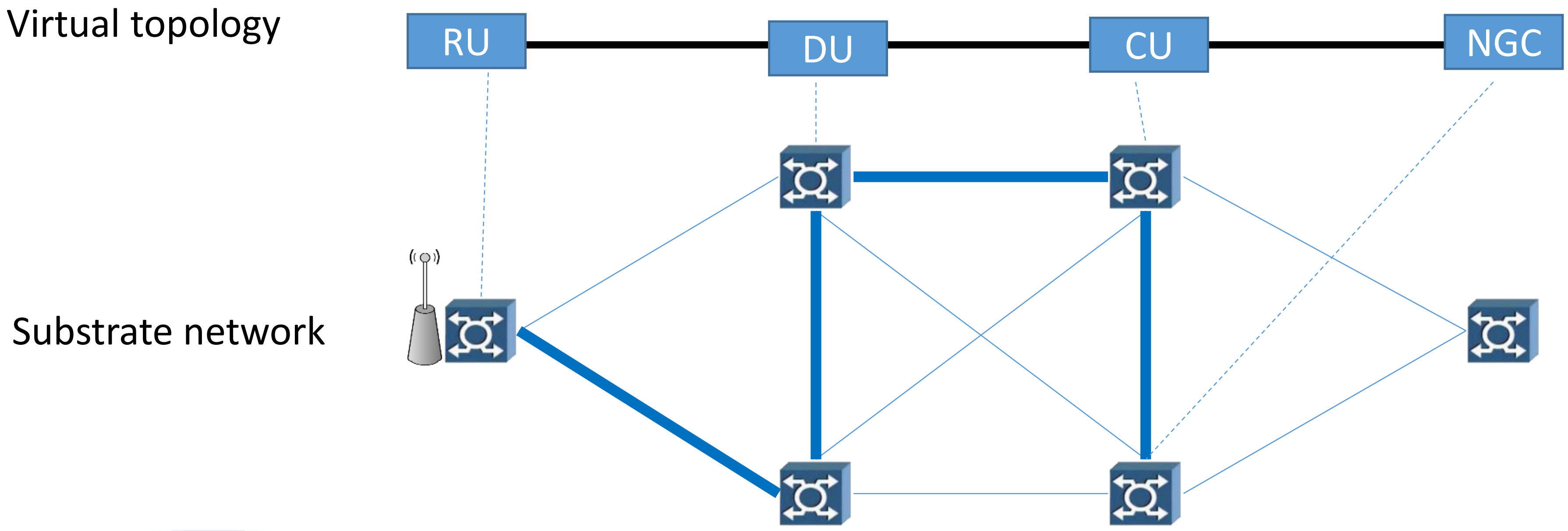
Virtual Networks vs. Service Chains (1)

- Virtual network emebedding
  - Each virtual node is mapped on a separate substrate node
  - Each virtual link is mapped to one or multiple physical links



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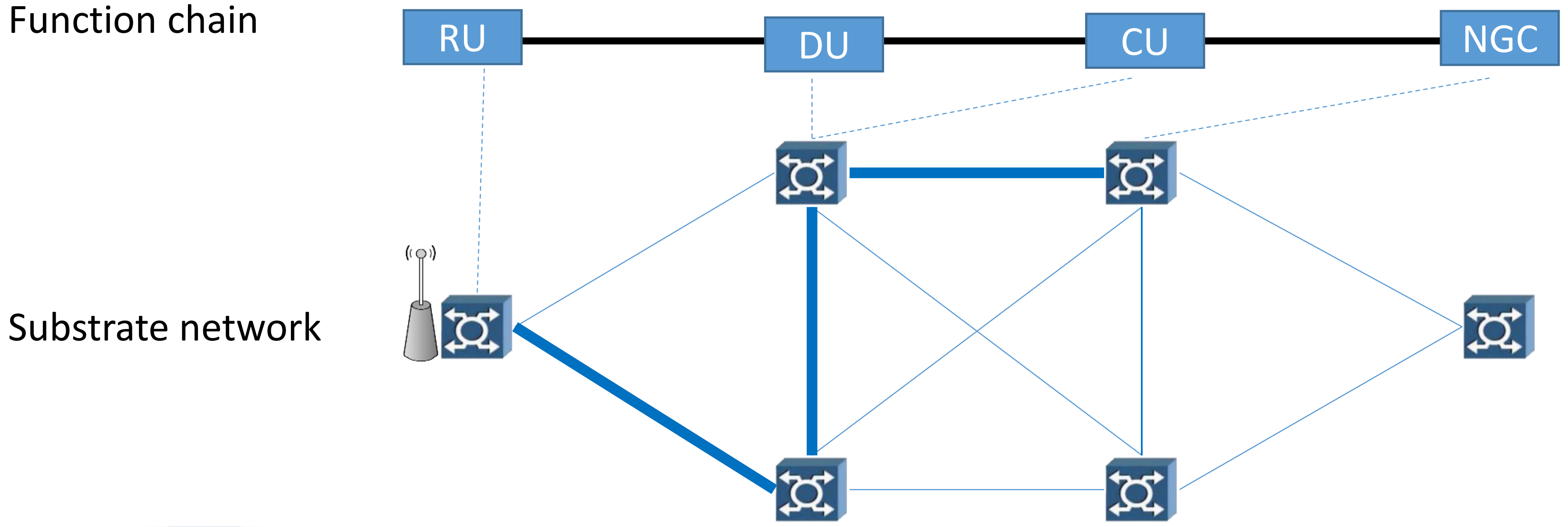
Virtual Networks vs. Service Chains (1)

- Service chains
  - Functions are provisioned to compose the service chain
  - Several functions can be mapped on the same node



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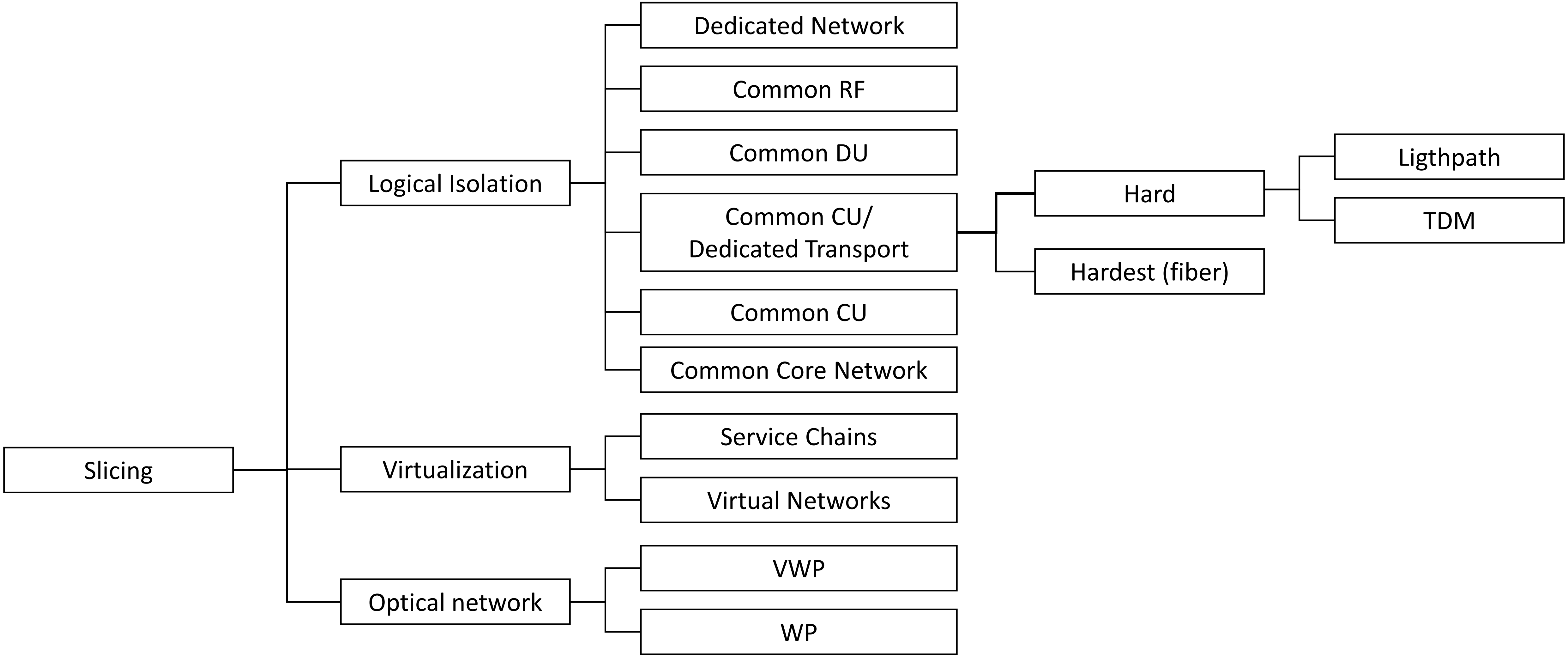
Slicing Overview



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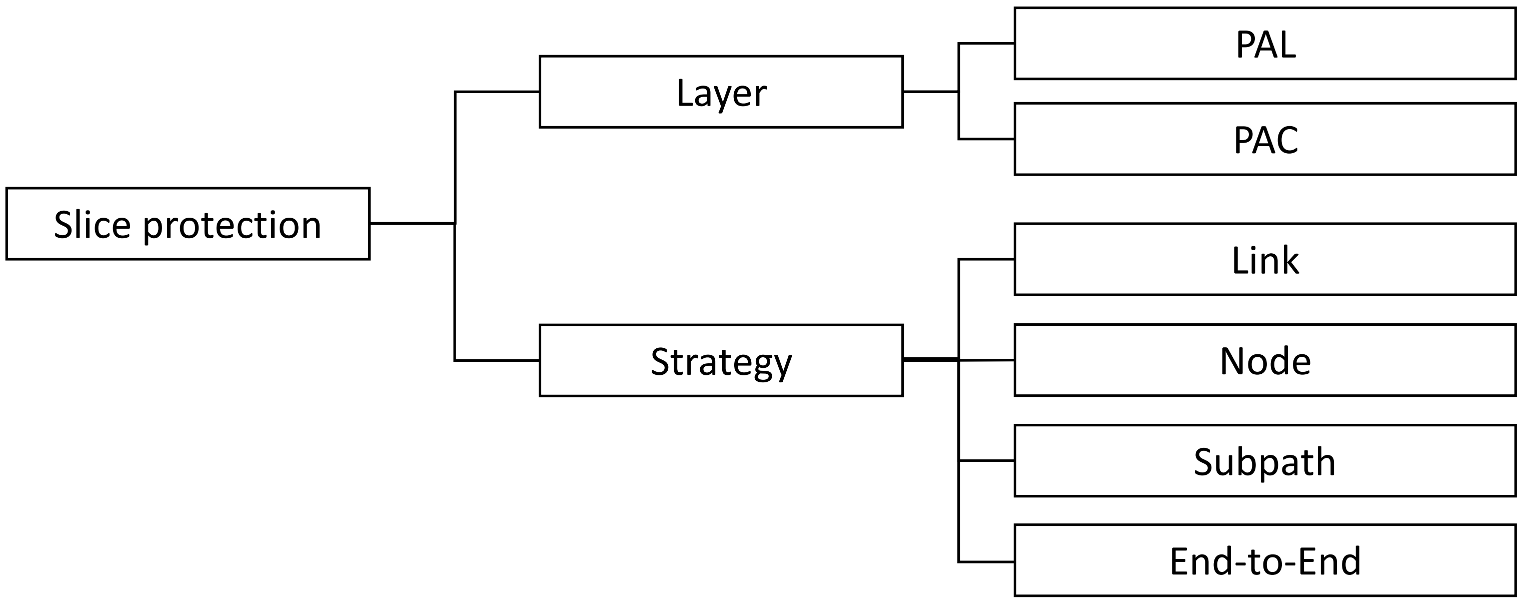
Slice Protection Overview

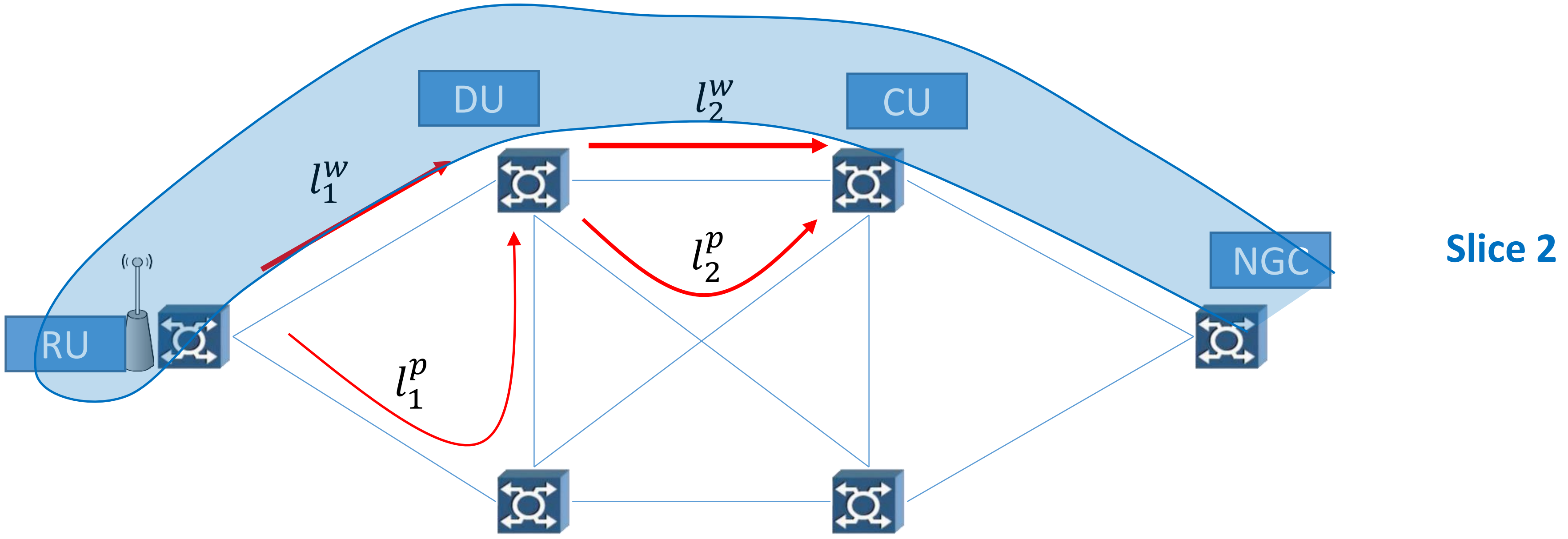


Protection at Lightpath

- Each lightpath has its own protection
  - l_i^w and l_i^p form the p-lightpath l_i
  - Slice 1 uses p-lightpaths l_1 and l_2

Slice 1: High Capacity – No protection req.

Slice 2: Low capacity - Reliable



C. Ou, K. Zhu, J. Zhang, H. Zhu, B. Mukherjee, H. Zang, and L. Sahasrabuddhe,"Traffic grooming for survivable WDM networks—dedicated protection," J. Opt. Netw., vol. 3,no. 1, pp. 50–74, Jan. 2004.

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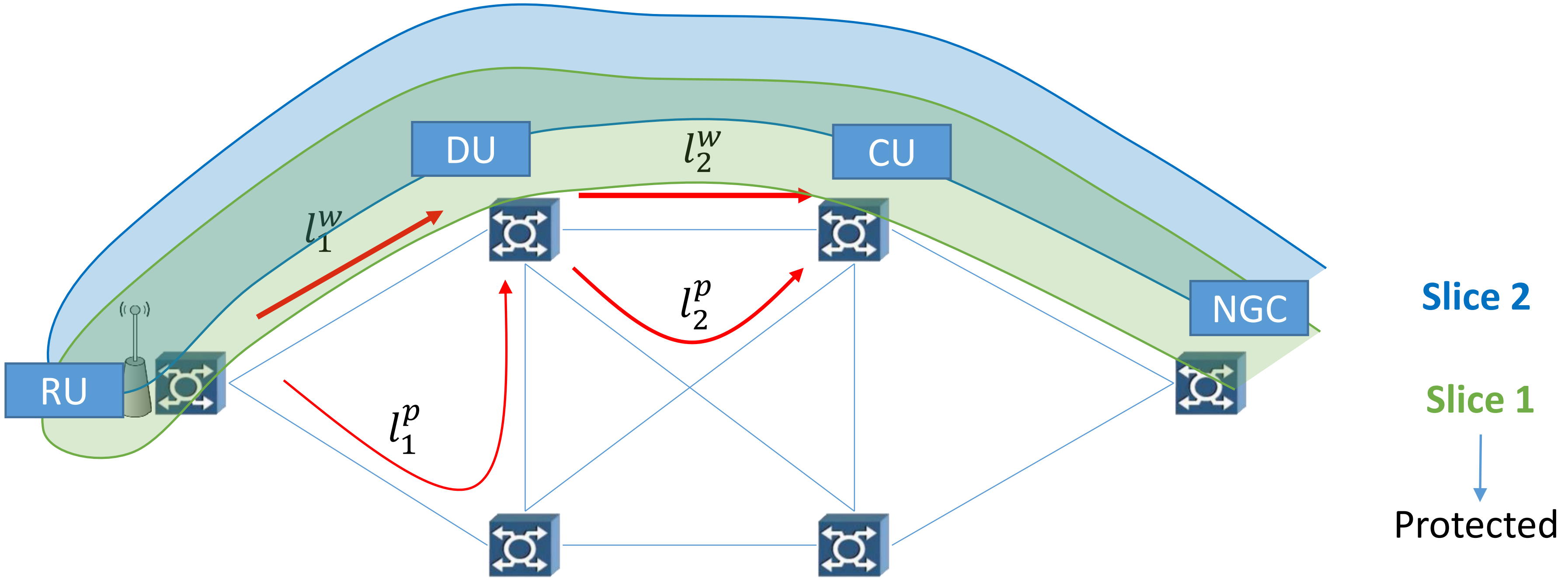
Protection at Lightpath

- Each lightpath has its own protection
  - l_i^w and l_i^p form the p-lightpath l_i
  - Slice 1 uses p-lightpaths l_1 and l_2
  - Slice 2 uses p-lightpaths l_1 and l_2 (but does not need protection)

Slice 1: High Capacity – No protection req.
Slice 2: Low capacity - Reliable



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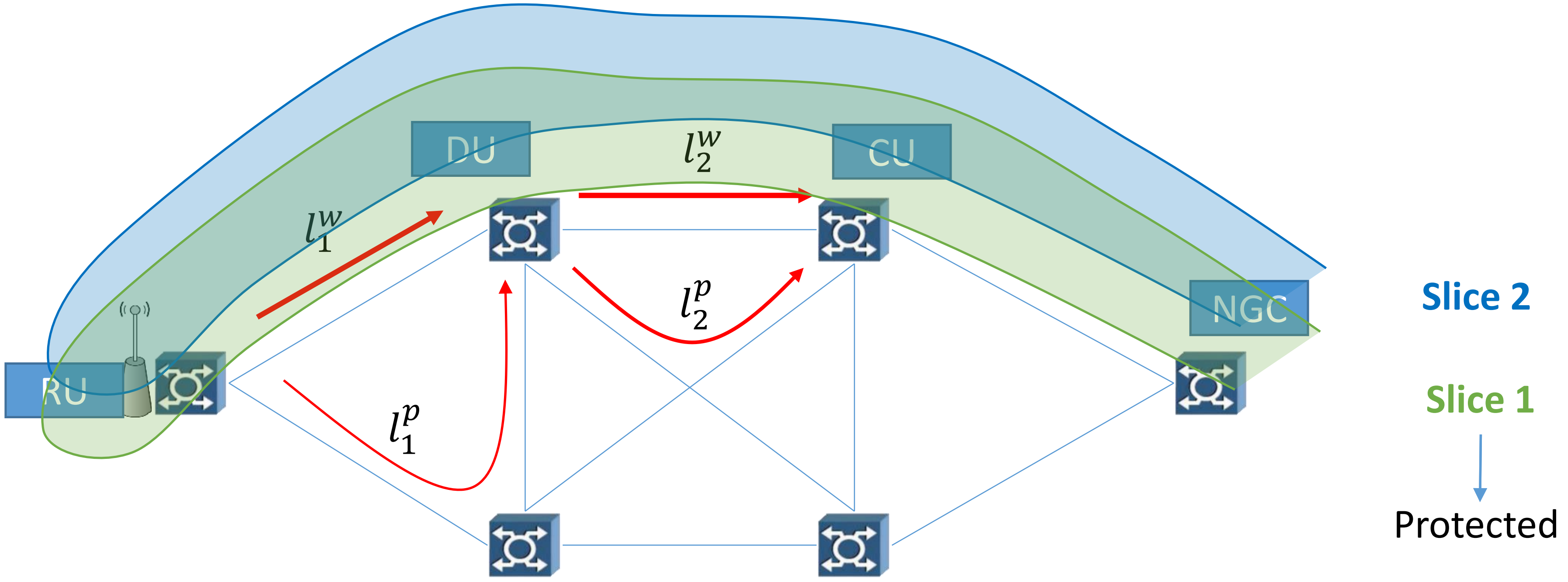
Protection at Lightpath (2)

- Each lightpath has its own protection
  - Connection unaware
  - Uses bandwidth unefficiently
  - Minimises the number of grooming ports

Slice 1: High Capacity – No protection req.
Slice 2: Low capacity - Reliable



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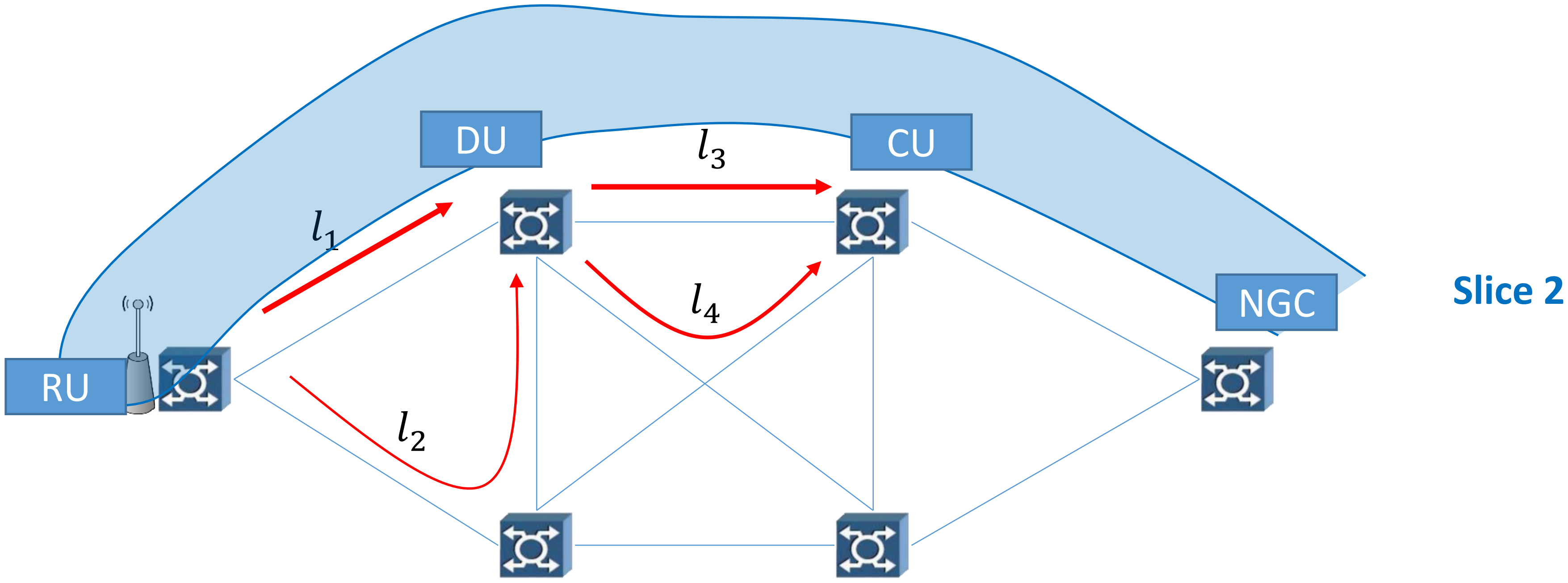
Protection at Connection

- Each lightpath is a separated entity
  - Slice 1 uses lightpaths l_1 and l_3 as working
    - l_2 and l_4 as protection

Slice 1: High Capacity – No protection req.
Slice 2: Low capacity - Reliable



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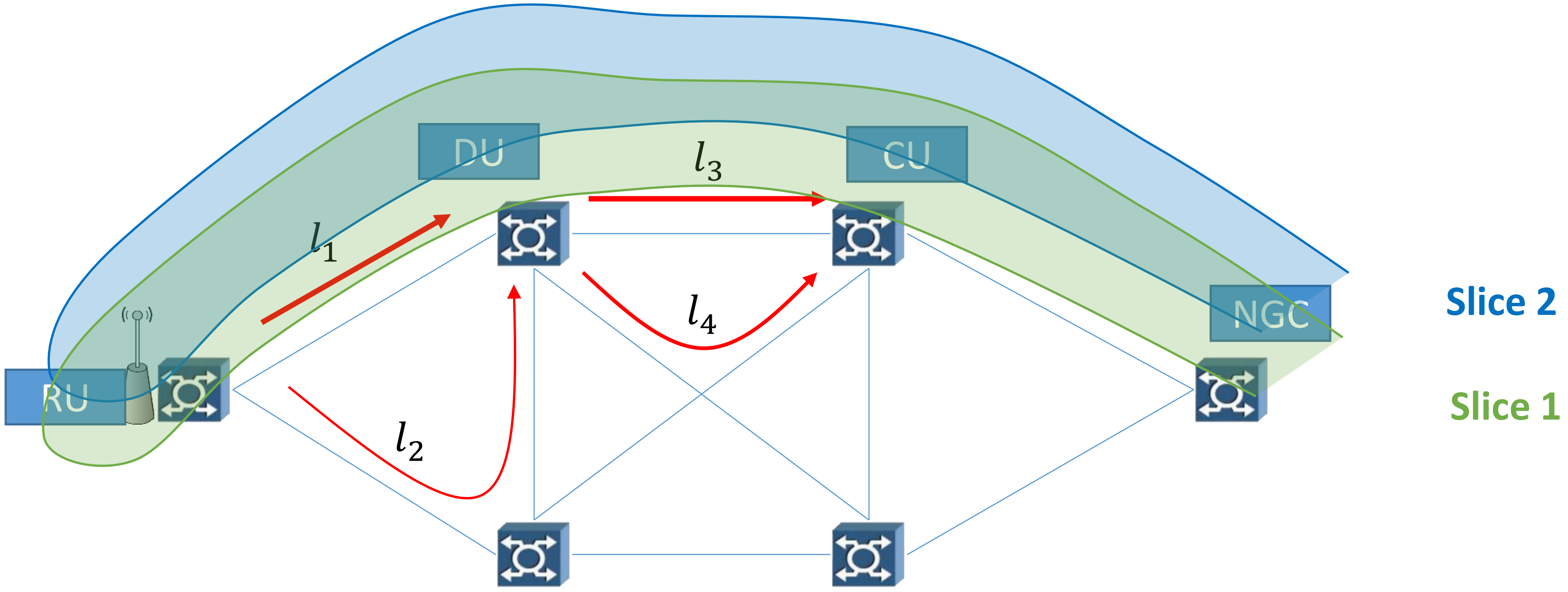
Protection at Connection

- Each lightpath is a separated entity
  - Slice 1 uses lightpaths l_1 and l_3 as working
    - l_2 and l_4 as protection
  - Slice 2 uses only lightpaths l_1 and l_3 as working

Slice 1: High Capacity – No protection req.
Slice 2: Low capacity - Reliable



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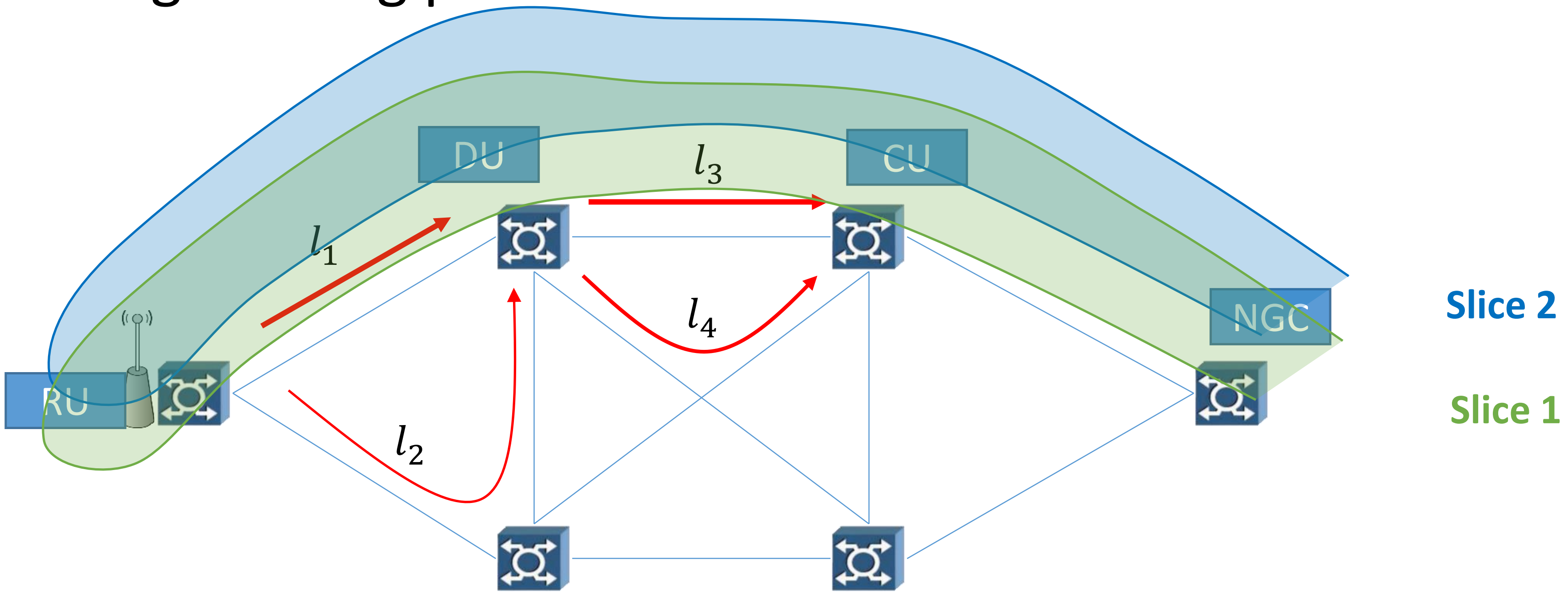
Protection at Connection

- Each lightpath is a separated entity
- Connection-aware
- Packs connections more efficiently
- Higher number of grooming ports

Slice 1: High Capacity – No protection req.

Slice 2: Low capacity - Reliable



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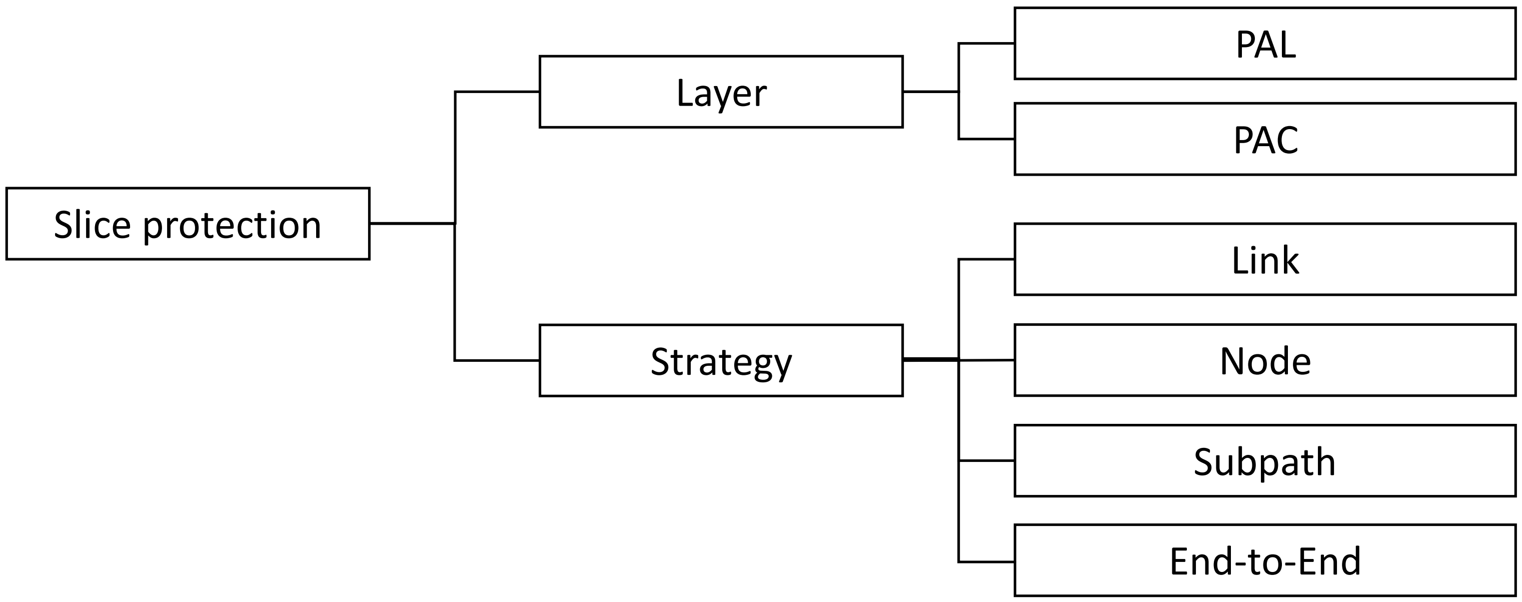
Slice Protection Overview

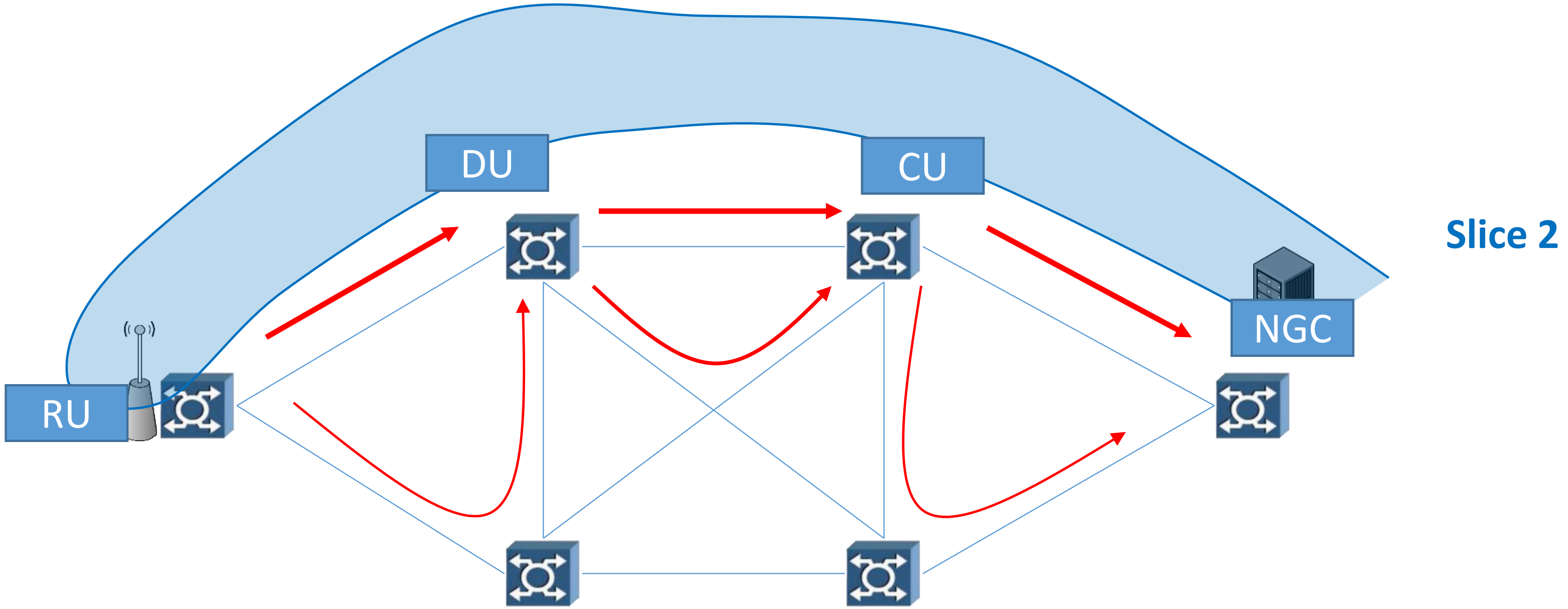


Protection strategy

- Link protection

Slice 1: High Capacity – No protection req.

Slice 2: Low capacity - Reliable



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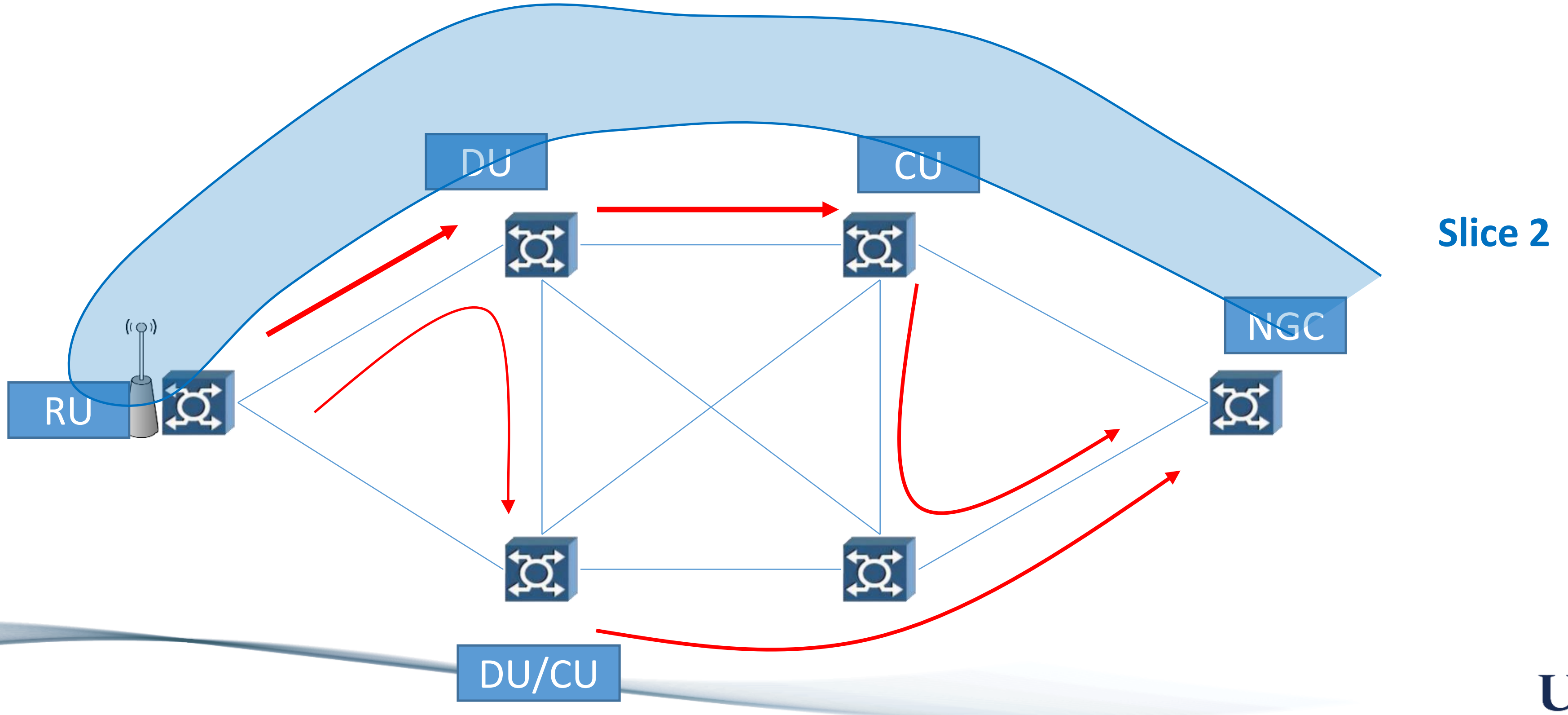
Protection strategy

- Node protection

Slice 1: High Capacity – No protection req.

Slice 2: Low capacity - Reliable



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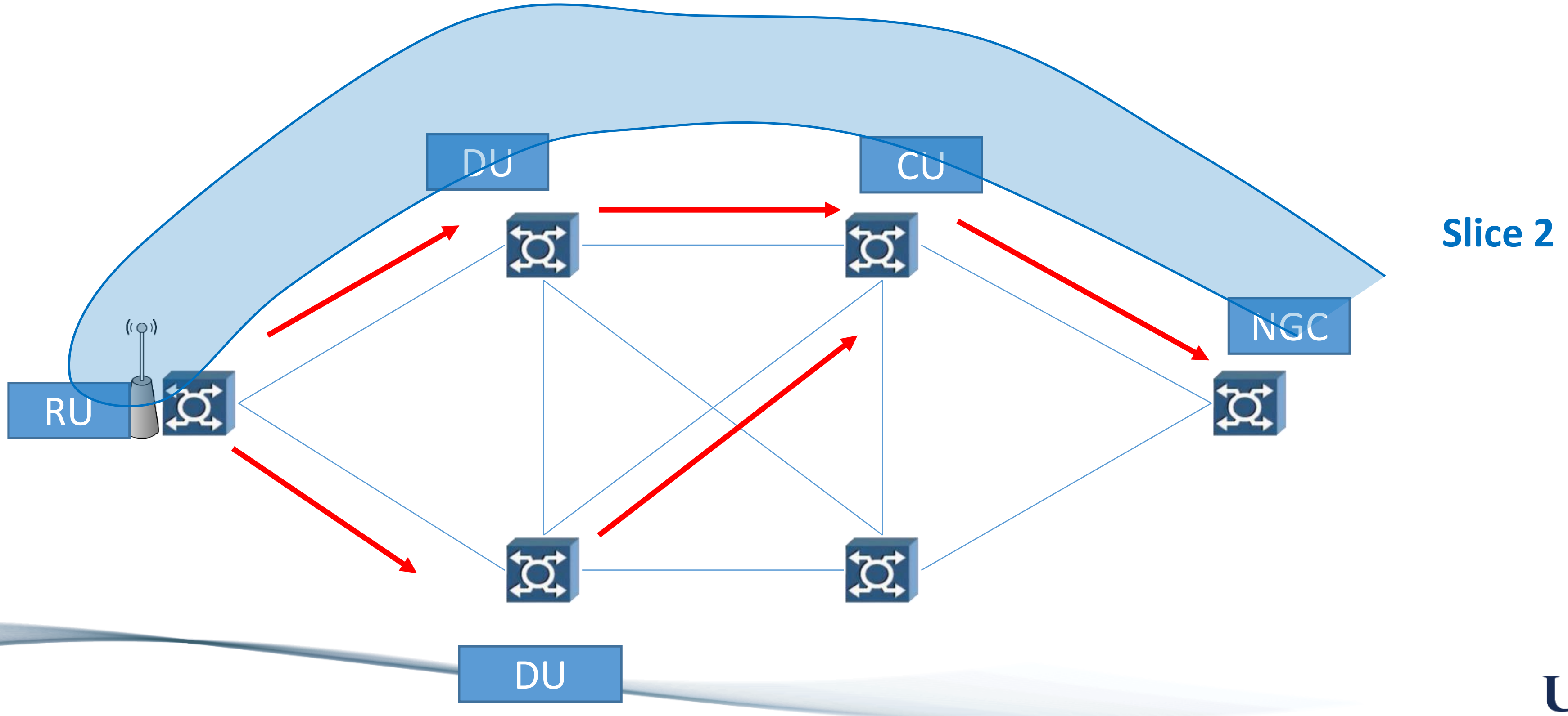
Protection strategy

- Subpath protection

Slice 1: High Capacity – No protection req.
Slice 2: Low capacity - Reliable

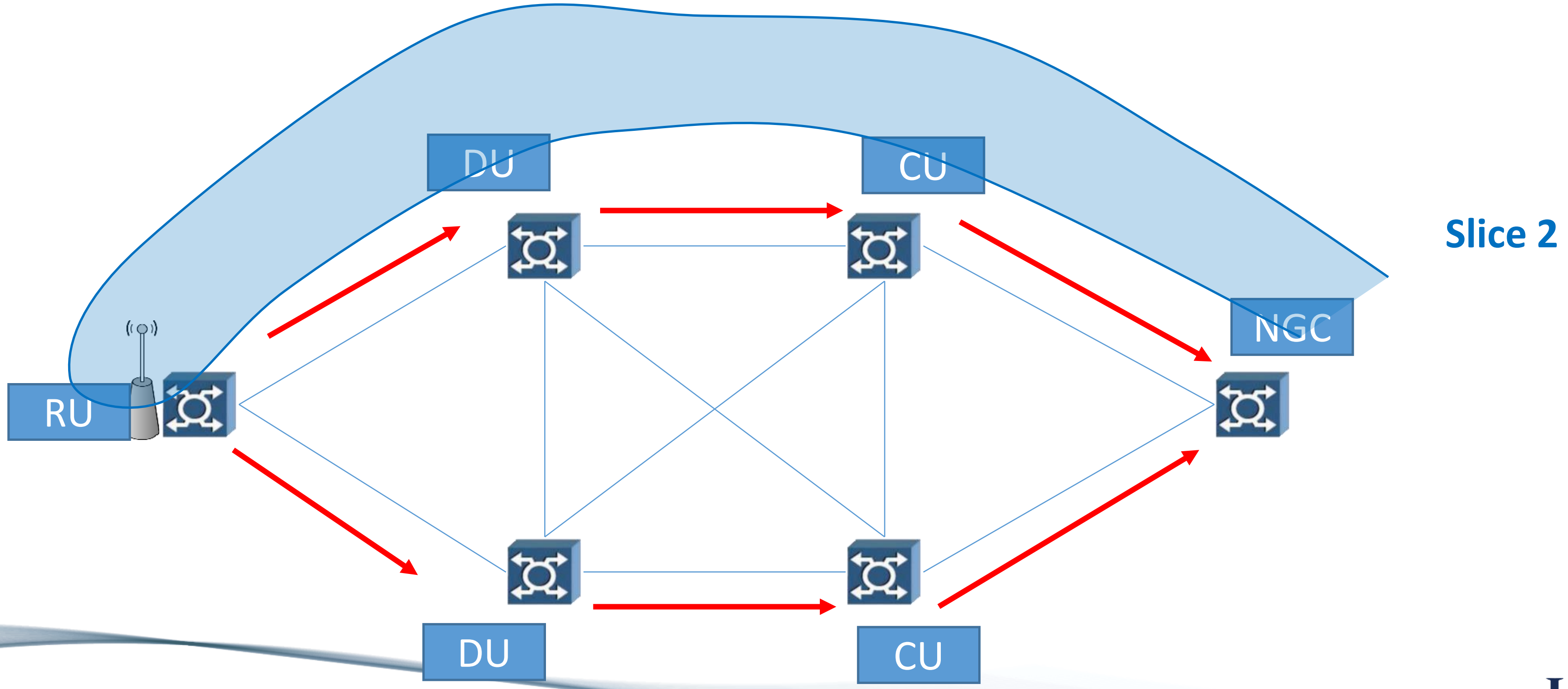


Protection strategy

- End to end protection

Slice 1: High Capacity – No protection req.

Slice 2: Low capacity - Reliable



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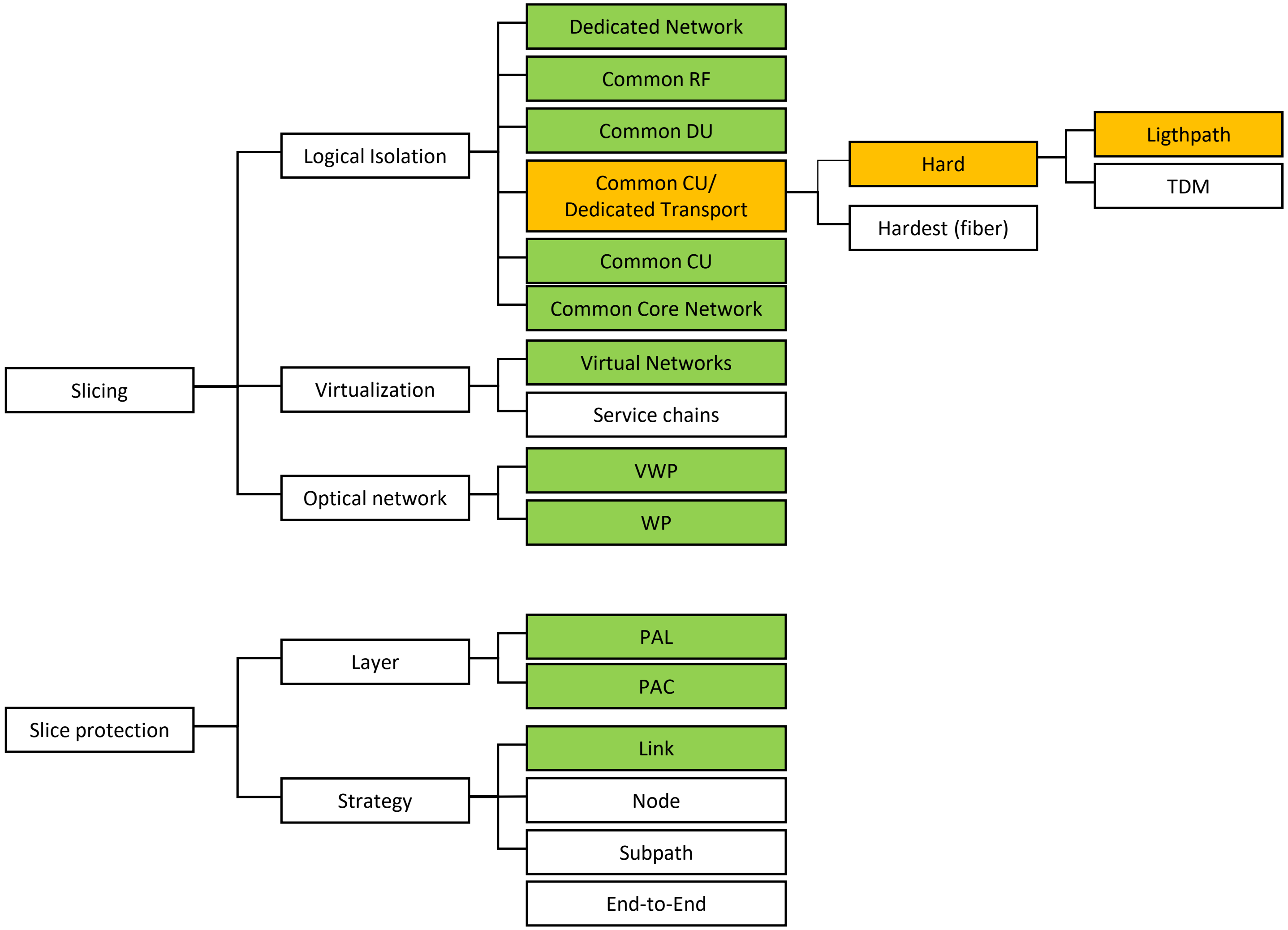
Reliable Slicing Overview



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Problem definition

- Parameters

N_P	Set of physical nodes in the network
N_V	Set of virtual functions. We assume N_V = {RU, DU, CU, NGC}
N_S	Set of slice requests
F_{mn}	No. of fibers interconnecting physical nodes m and n
W	No. of wavelengths per link
C	Capacity of each wavelength
K_u	Computational capacity required by deployment of virtual function u on a physical node
C_n	Computational capacity of physical node n
M_{un}	1 if virtual function u can be deployed at physical node n
$R(s)$	$R : N_s \to \{1, 0\}$ 1 if slice s requires protection
$D(s)$	$D : N_s \to \{1, 0\}$ 1 if slice s requires dedicated transport

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Problem definition

- Variables

$z_{mn}^{s,ij}$	No. of lightpaths between physical nodes i and j passing through link (m, n) and serving slice s
$\zeta_{mn}^{s,ij}$	No. of backup lightpaths between physical nodes i and j passing through link (m, n) and serving slice s
x_{ij}^{s}	No. of lightpaths between physical nodes i and j serving slice s
ξ_{ij}^{s}	No. of backup lightpaths between physical nodes i and j serving slice s
w_{ij}^{sbe}	Capacity provisioned from physical node b to e through lightpaths going for node i to node j for slice s
ω_{ij}^{sbe}	Backup capacity provisioned from physical node b to e through lightpaths going for node i to node j for slice s
l_{be}^{s}	Capacity that needs to be provisioned from physical node b to e for slice s
h_{be}^{suv}	1 if end points of virtual link (u, v) of slice s are mapped to physical nodes b and e
y_{un}	1 if virtual function u is deployed at physical node n

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Problem definition

- Objective function:

$$\text{minimize} \sum_{s} \sum_{i,j} \sum_{m,n} z_{mn}^{s,ij}$$

- Such that:

Working

$$\sum_{\substack{j \in N_P \\ j \neq i}} w_{ij}^{sbe} - \sum_{\substack{j \in N_P \\ j \neq i}} w_{ji}^{sbe} = \begin{cases} l_{be}^s & \text{if } i = b \\ -l_{be}^s & \text{if } i = e \\ 0 & \text{otherwise} \end{cases}$$
$$\forall i, b, e \in N_P, s \in N_S$$

$$\sum_{\substack{n \in N_P \\ n \neq m}} z_{mn}^{sij} - \sum_{\substack{n \in N_P \\ n \neq m}} z_{nm}^{sij} = \begin{cases} x_{ij}^s & \text{if } m = i \\ -x_{ij}^s & \text{if } m = j \\ 0 & \text{otherwise} \end{cases}$$
$$\forall m, i, j \in N_P, s \in N_S$$

Backup

$$\sum_{\substack{j \in N_P \\ j \neq i}} \omega_{ij}^{sbe} - \sum_{\substack{j \in N_P \\ j \neq i}} \omega_{ji}^{sbe} = \begin{cases} l_{be}^s & \text{if } i = b \\ -l_{be}^s & \text{if } i = b \\ 0 & \text{otherwise} \end{cases}$$
$$\forall i, b, e \in N_P, s \in N_S : R(s) = 1$$

$$\sum_{\substack{n \in N_P \\ n \neq m}} \zeta_{mn}^{sij} - \sum_{\substack{n \in N_P \\ n \neq m}} \zeta_{nm}^{sij} = \begin{cases} \xi_{ij}^s & \text{if } m = i \\ -\xi_{ij}^s & \text{if } m = j \\ 0 & \text{otherwise} \end{cases}$$
$$\forall m, i, j \in N_P, s \in N_S : R(s) = 1$$

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Problem definition

- Such that:

$$z_{mn}^{sij} + z_{nm}^{sij} + \zeta_{mn}^{sij} + \zeta_{nm}^{sij} \leq 1 \forall i, j, m, n \in N_P, s \in N_S$$

Link disjointness (PAC)

$$\sum_{\substack{b,e \in N_P \\ s \in N_S}} w_{ij}^{sbe} \leq C \times x_{ij} \forall i, j \in N_P, s \in N_S$$

$$\sum_{\substack{b,e \in N_P \\ s \in N_S}} \omega_{ij}^{sbe} \leq C \times \xi_{ij} \forall i, j \in N_P, s \in N_S$$

$$\sum_{i,j \in N_P} (z_{mn}^{ij} + \zeta_{nm}^{ij}) \leq W \times F_{mn} \quad \forall m, n \in N_P$$

Capacity constraints

Problem definition

- Such that:

$$h_{be}^{suv} = y_{ub}^{S} \times y_{ve}^{S} \quad \forall b, e \in N_P, u, v \in N_V, s \in N_S$$

$$\sum_{n \in N_P} y_{un}^{s} = 1 \quad \forall u \in N_V, s \in N_S$$

$$\sum_{\substack{u \in N_V \\ s \in N_S}} y_{un}^{s} \times K_u^s \leq C_n \quad \forall u \in N_V, n \in N_P, s \in N_S$$

$$y_{un}^{s} \leq M_{un} \quad \forall n \in N_P, u \in N_V, s \in N_S$$

Node mapping constraints

Thank you