Nonblocking Conditions for Flex-grid OXC-Clos Networks

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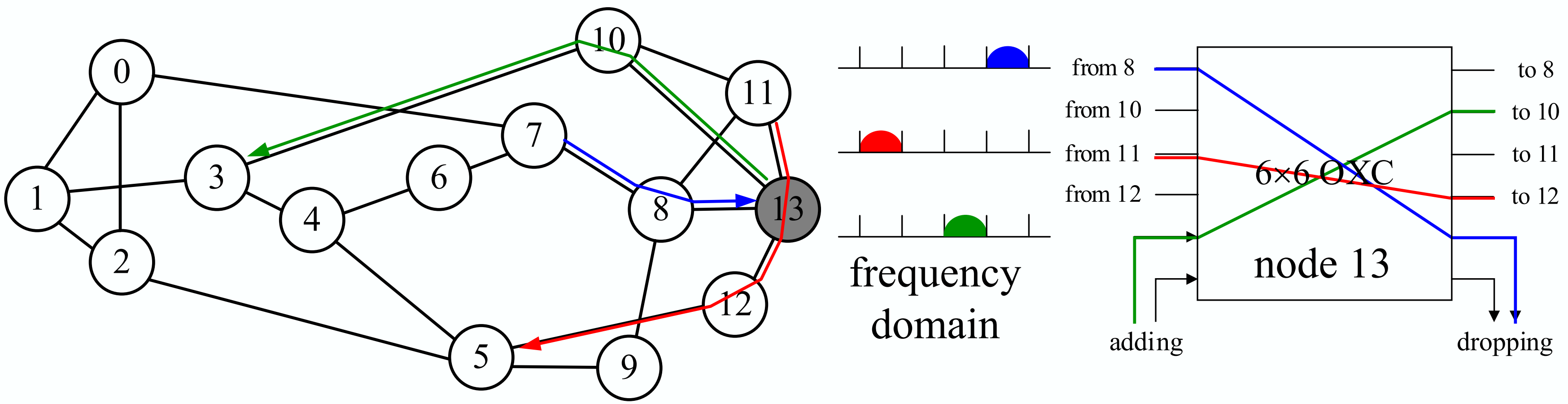
Outline

- Background
- Preliminary
- WSNB Conditions
- Conclusions

Optical Cross-Connect (OXC)

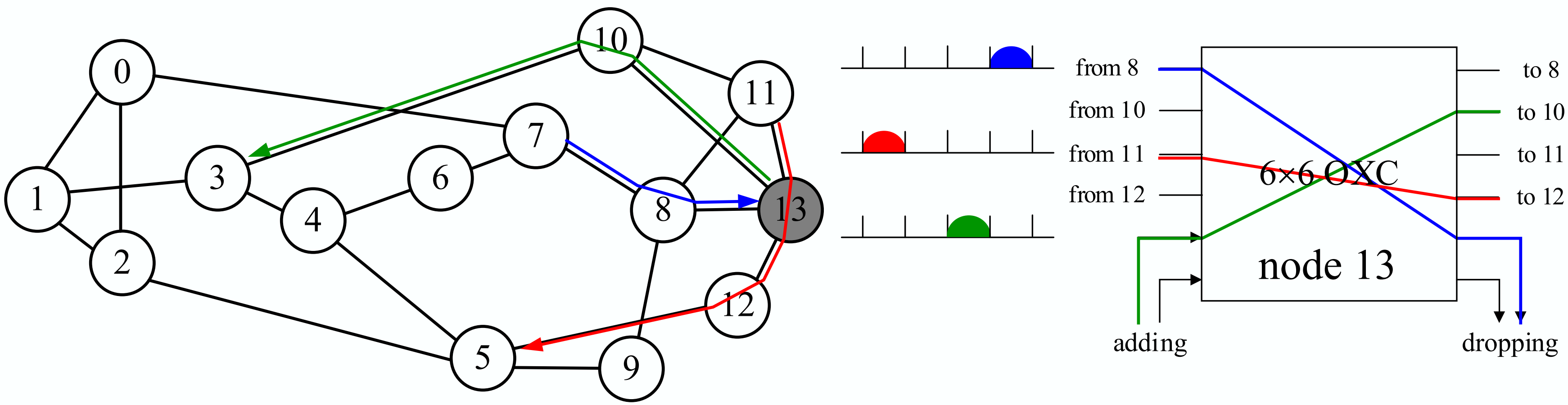
- Optical nodes of optical networks

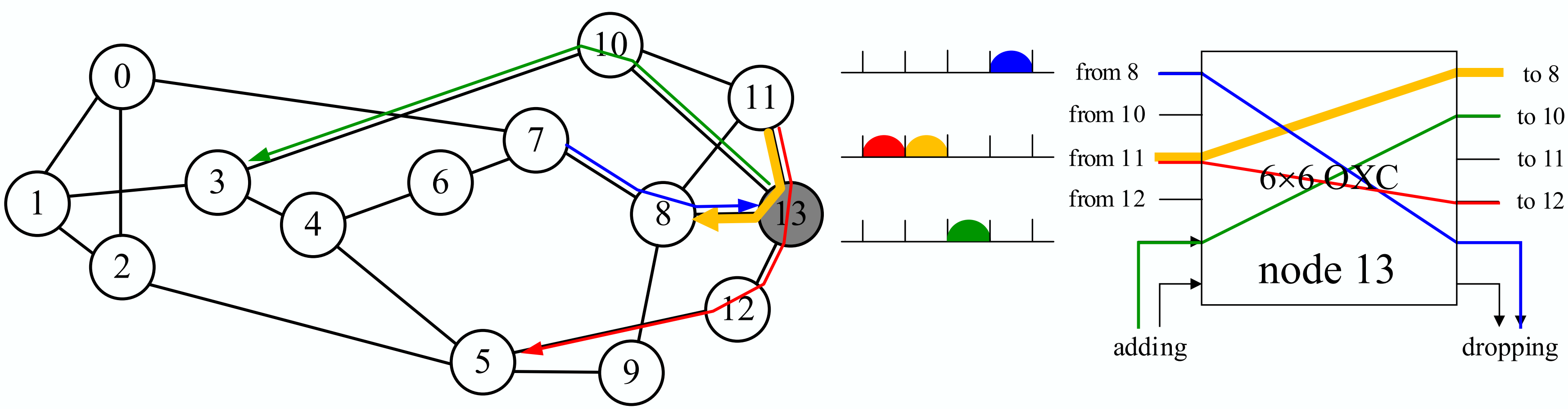


- Functions
  - Optical bypassing
  - Adding a wavelength to remote node
  - Dropping a wavelength to local switch

Strictly Nonblocking (SNB) Property

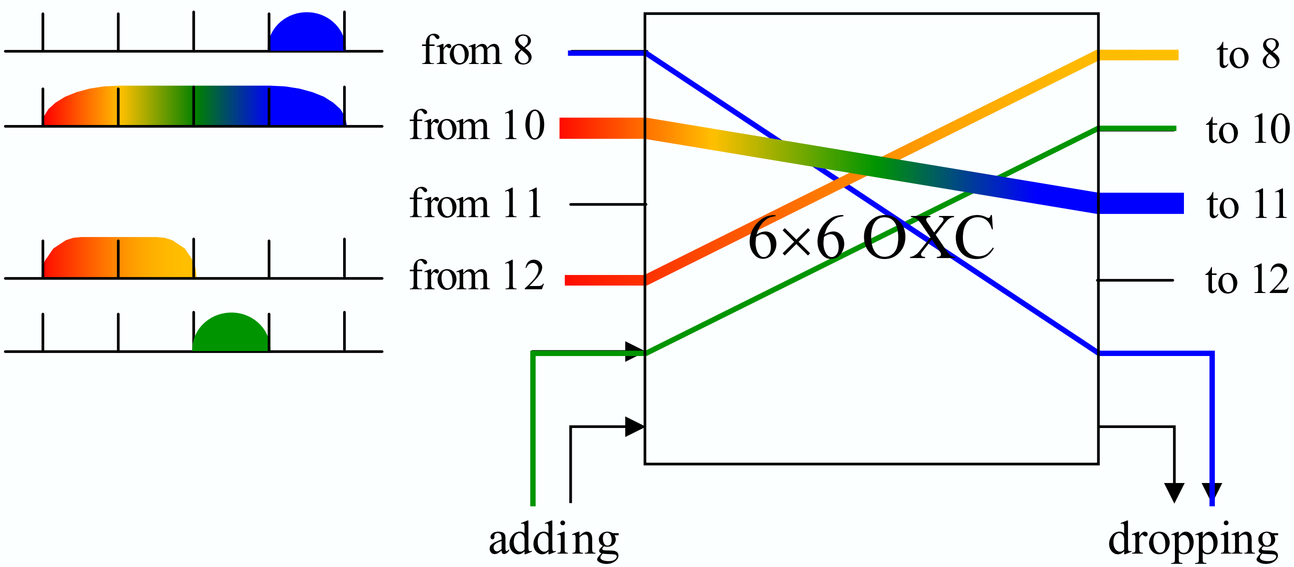
- Can always set up new lightpaths (LPs) without rearranging existing LPs



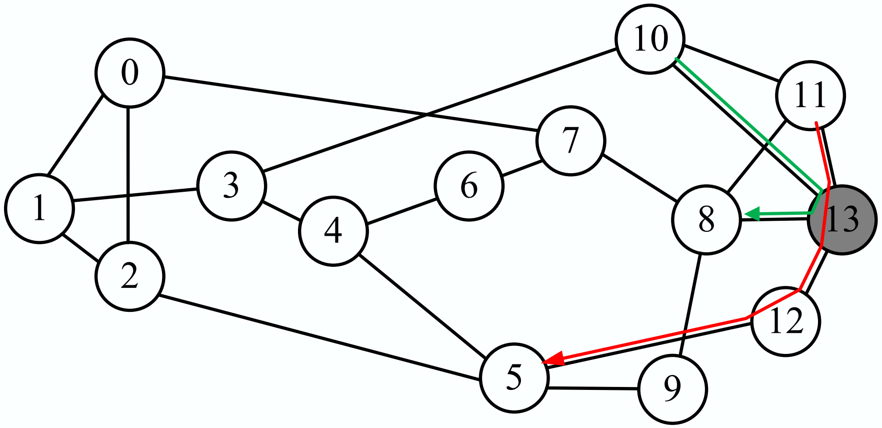


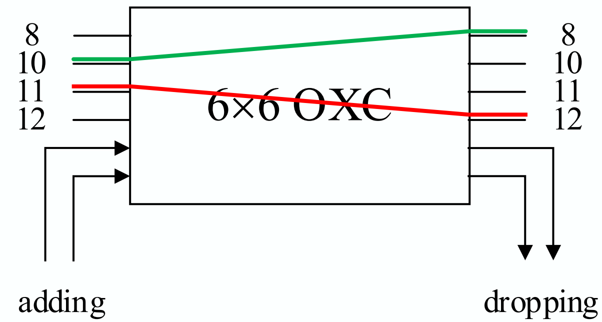
OXC can Support Flexible Grids

- Can perform SNB switching even when LPs of different bandwidths coexist

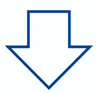


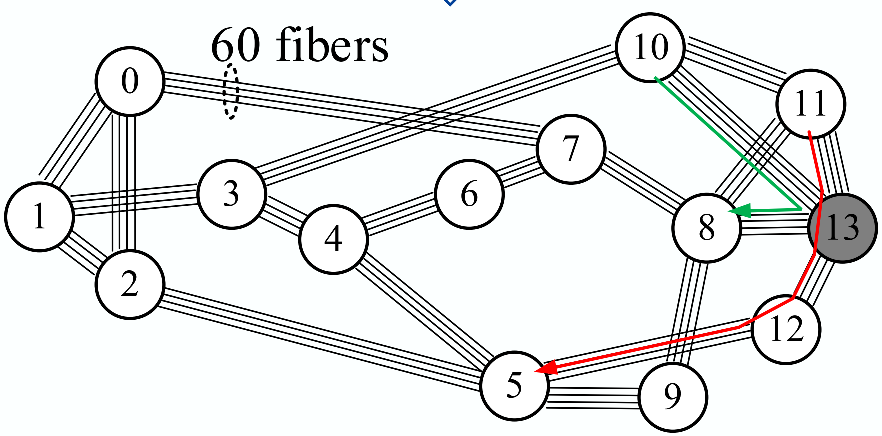
OXC has to Scale Fast in the Future

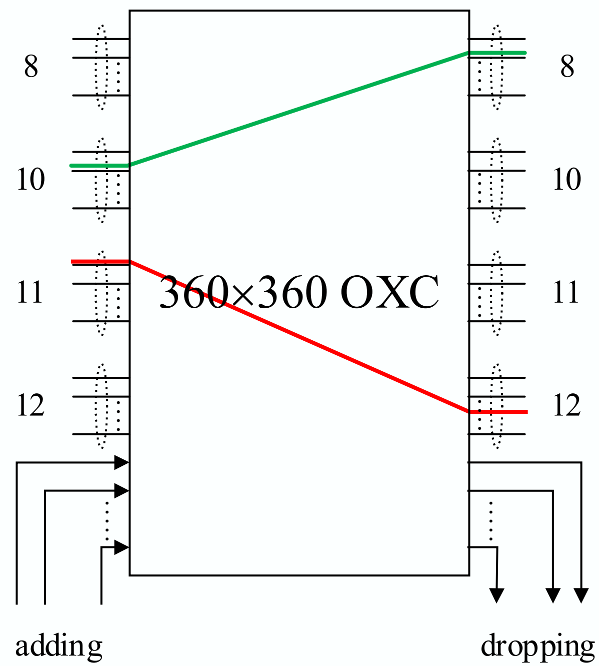




1 fiber/link in 2017



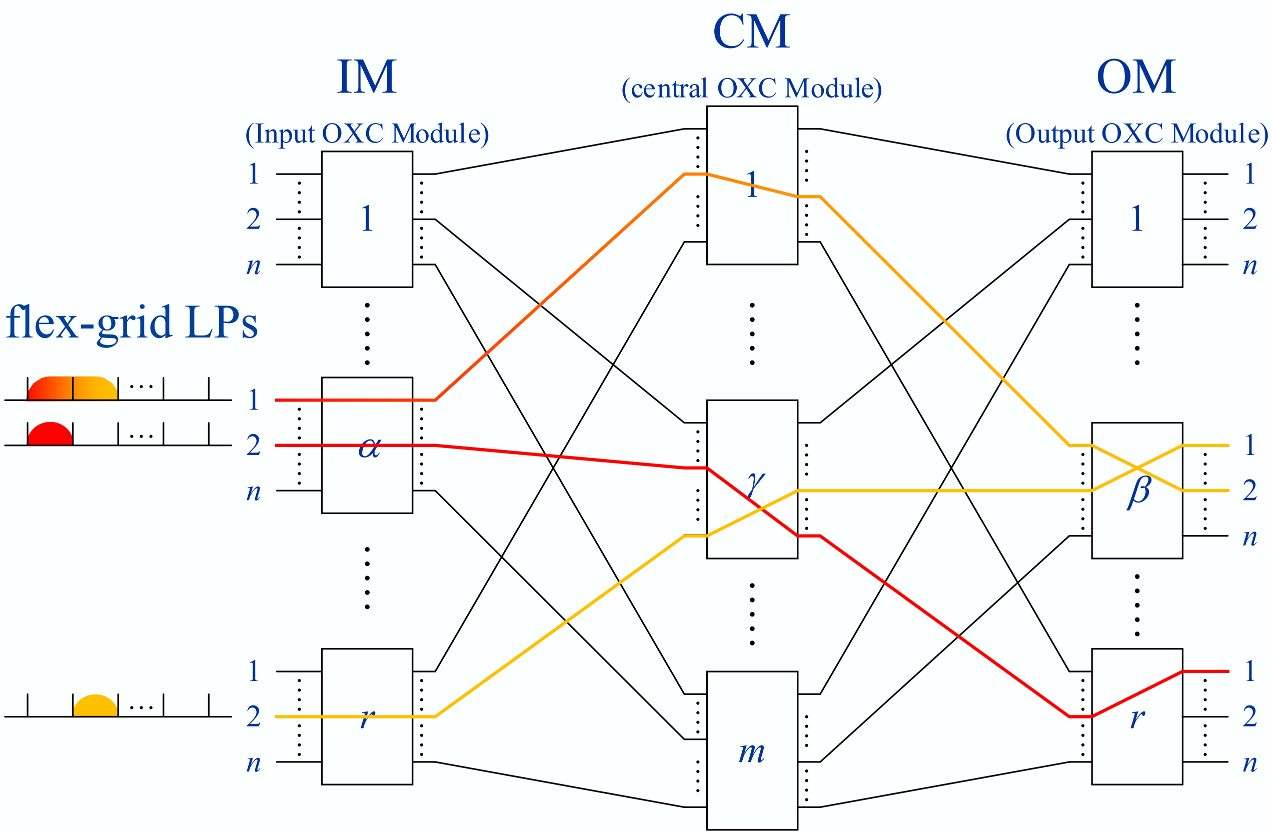




6~80 fibers/link in 2027

P. J. Winzer, D. T. Neilson, and A. R. Chraplyvy, *Optics express*, vol. 26, no. 18, pp. 24 190–24 239, 2018.

Scaling OXC using Clos Networks



OXC-Clos Network $\mathcal{C}(n, r, m)$

- Problem
  - Nonblocking conditions of Classical Clos networks are INVALID for OXC-Clos networks

Our Work

- Derive nonblocking conditions, under which new LPs can be set up without rearrangements
- Propose a granularity differential routing (GDR) strategy, that can
  - remarkably reduce # of needed CMs
  - have no computation and operation overheads

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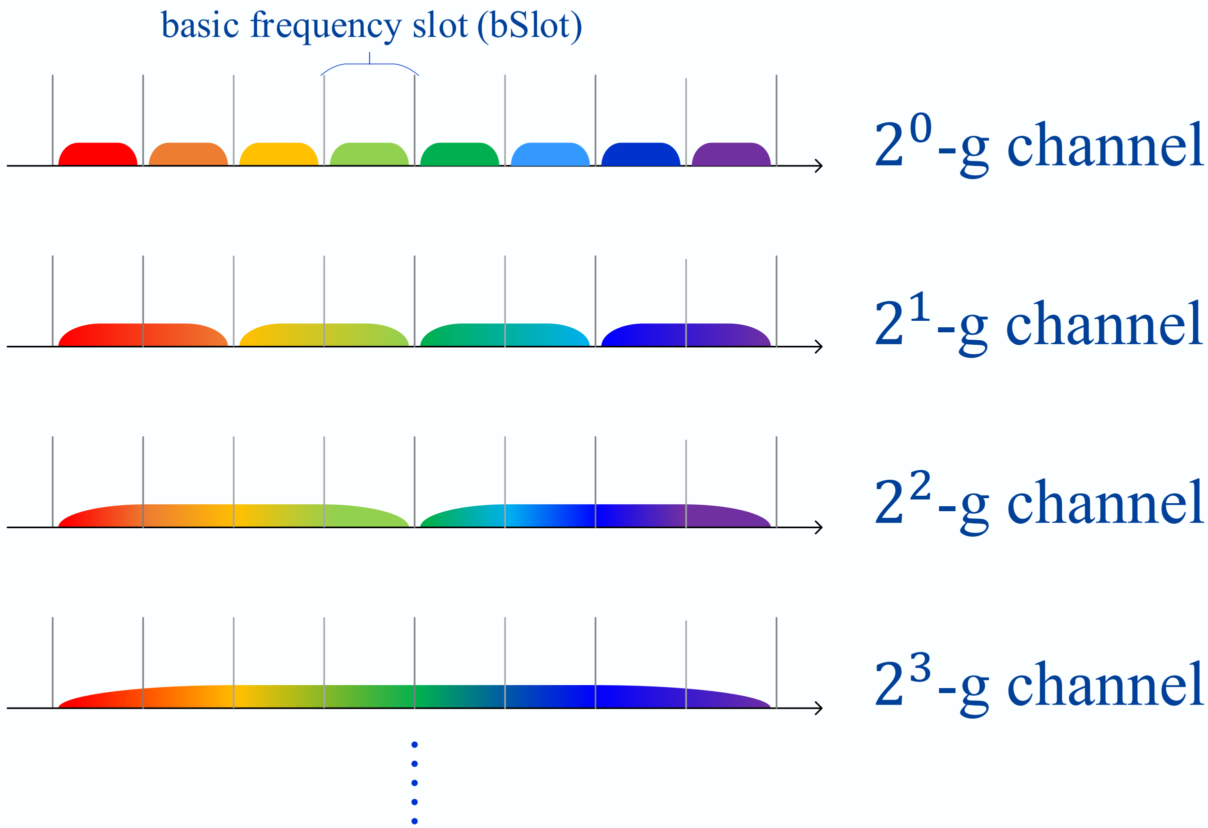
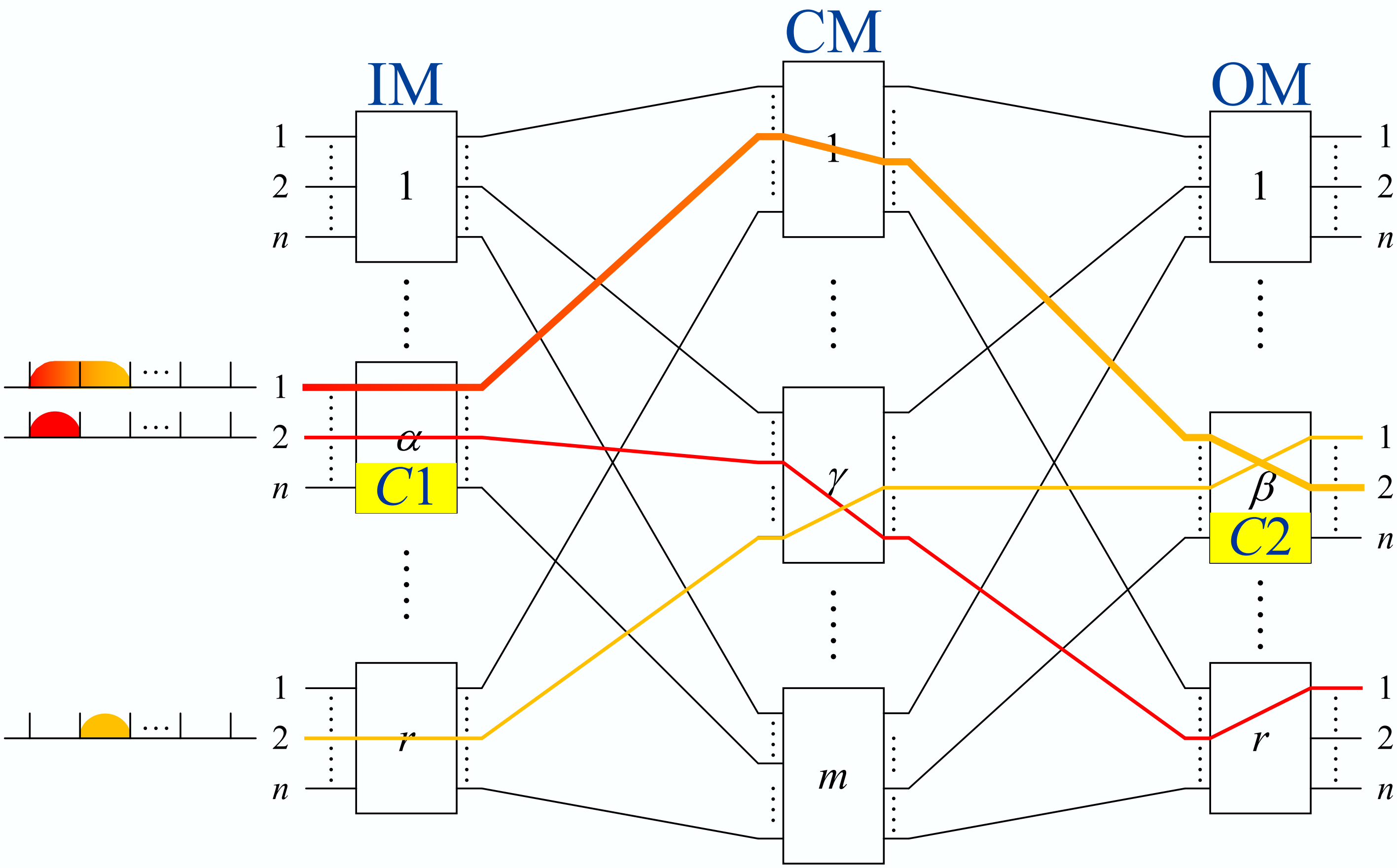
Granularity

- 2^k-g channel: 2^k ADJACENT bSlots, $k = 0,1,\cdots$
  - Different types of channels are pre-defined from left to right



- 2^i-g LP: LP using a 2^i-g channel

Routing Constraints



- LPs overlapping in spectrum can't use a CM, if
  - $C1$. they start from the same IM
  - $C2$. they head to the same OM

Problem of Classical Theory

- SNB condition of classical Clos network

$$m \geq 2n - 1$$

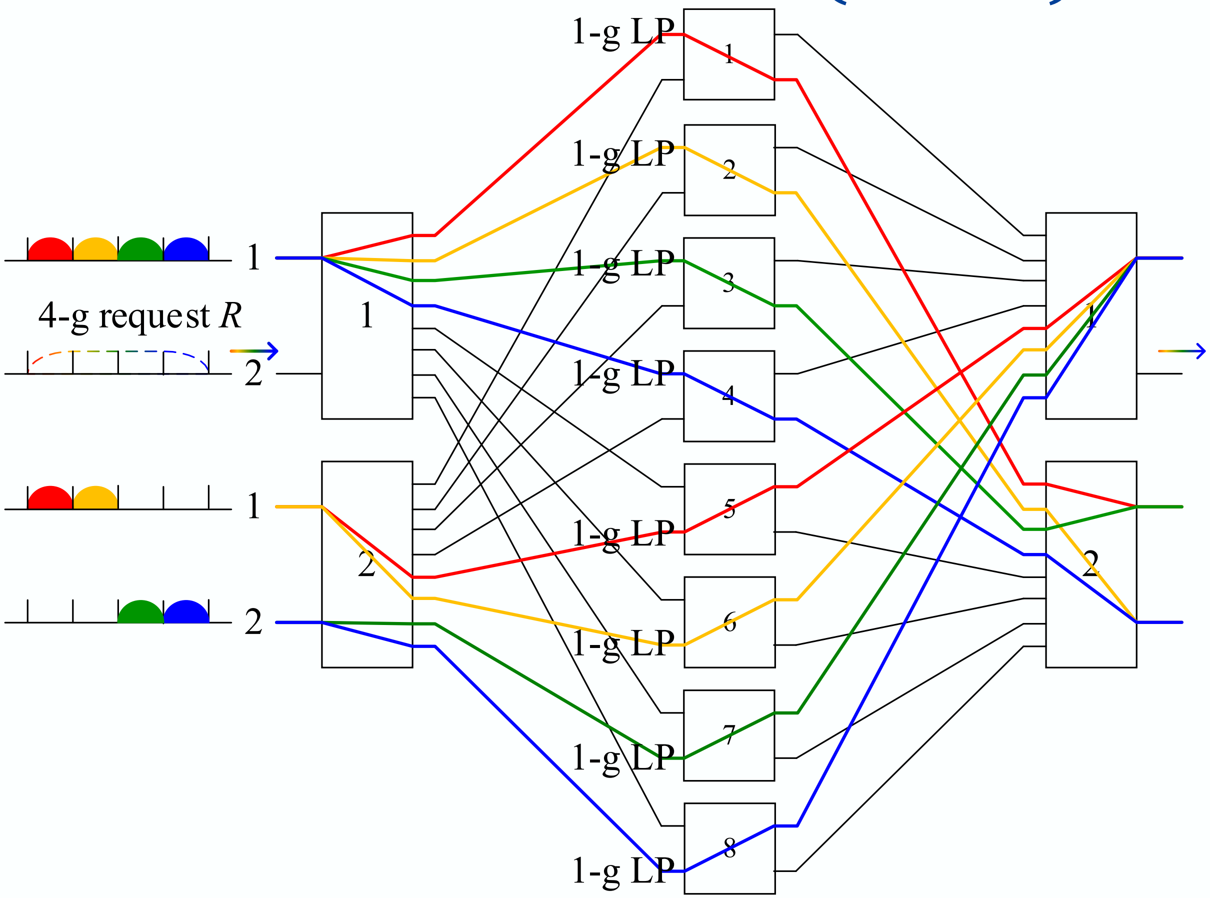
is invalid in the flex-grid context

  - n: # of inputs/outputs of each IM/OM
  - m: # of CMs

Theorem 1

- $\mathcal{C}$ carrying K types of LPs is SNB iff

$$m \geq 2^K(n-1)+1$$



CM ABUSE:
8 1-g LPs use 8 CMs, though some of them can share a CM

Cost is too high to be practical for application!

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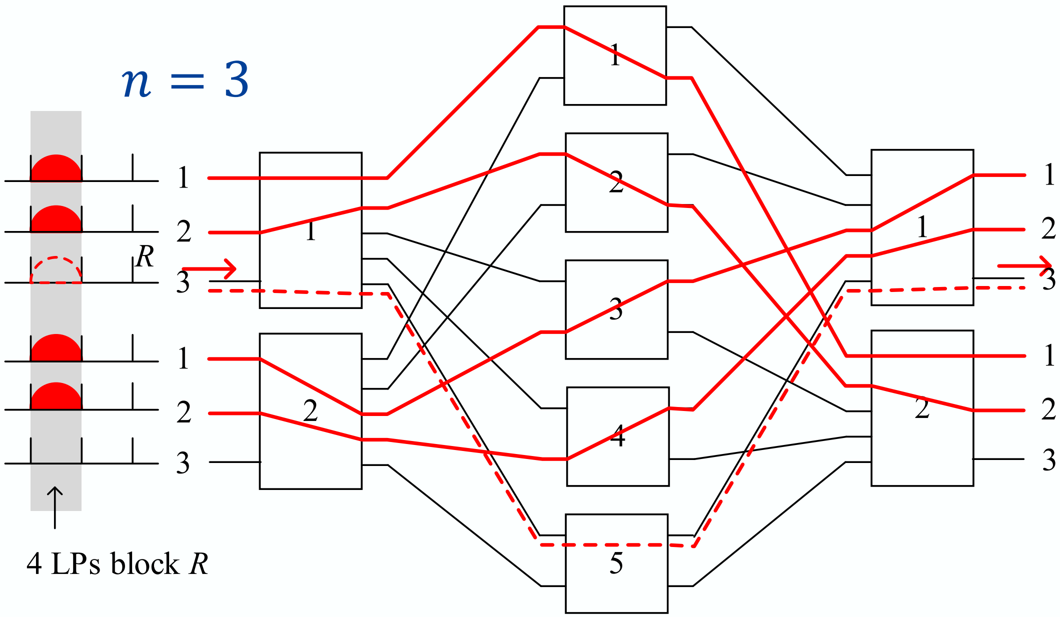
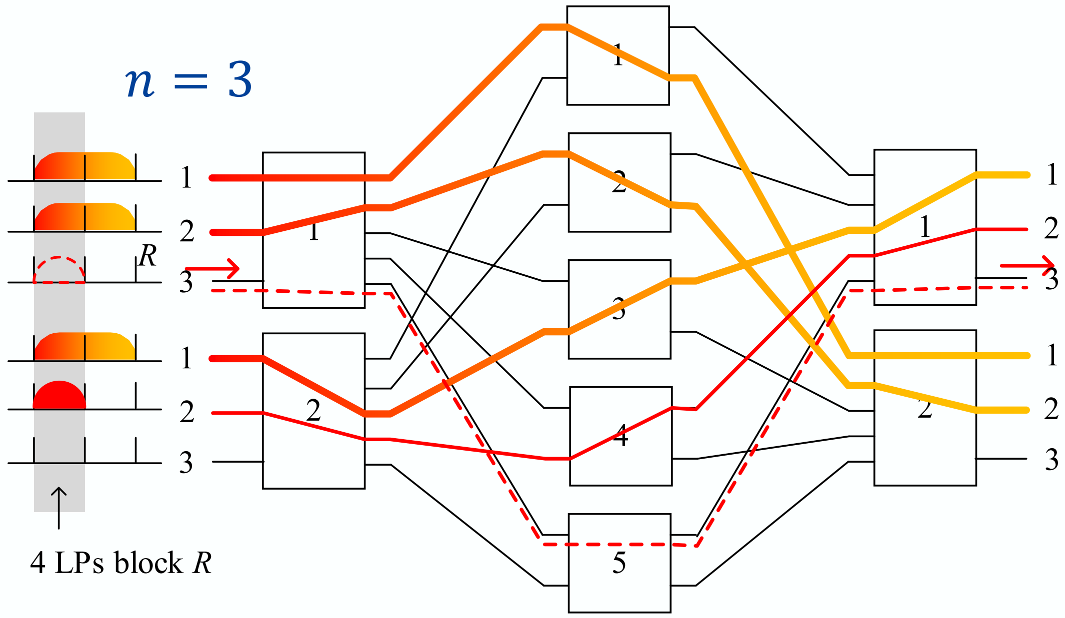
Lemma 1

- $\mathcal{C}$ is SNB for 1-g LPs, iff $m \geq 2n - 1$
  - Example: $n = 3$ and $r = 2$ ($m \geq 2n - 1 = 5$ is enough)



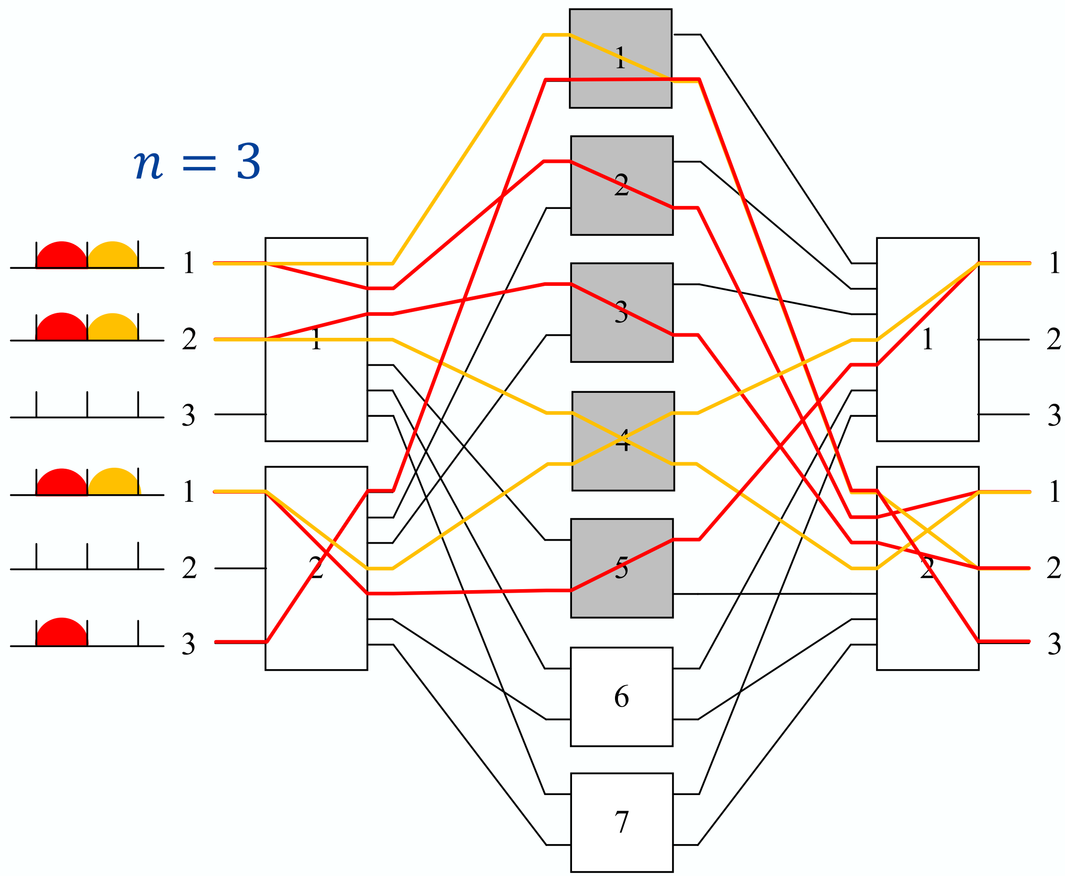
Lemma 1 Holds even if 2-g LPs are Present

- $\mathcal{C}$ is SNB for 1-g LPs, iff $m \geq 2n - 1$
  - Example: $n = 3$ and $r = 2$ ($m \geq 2n - 1 = 5$ is enough)



Routing Strategy for 1-g LPs

- Specify a set of CMs $\boldsymbol{M}_0 = \{1,2\cdots,2n-1\}$ for 1-g LPs, to prevent the abuse of CM

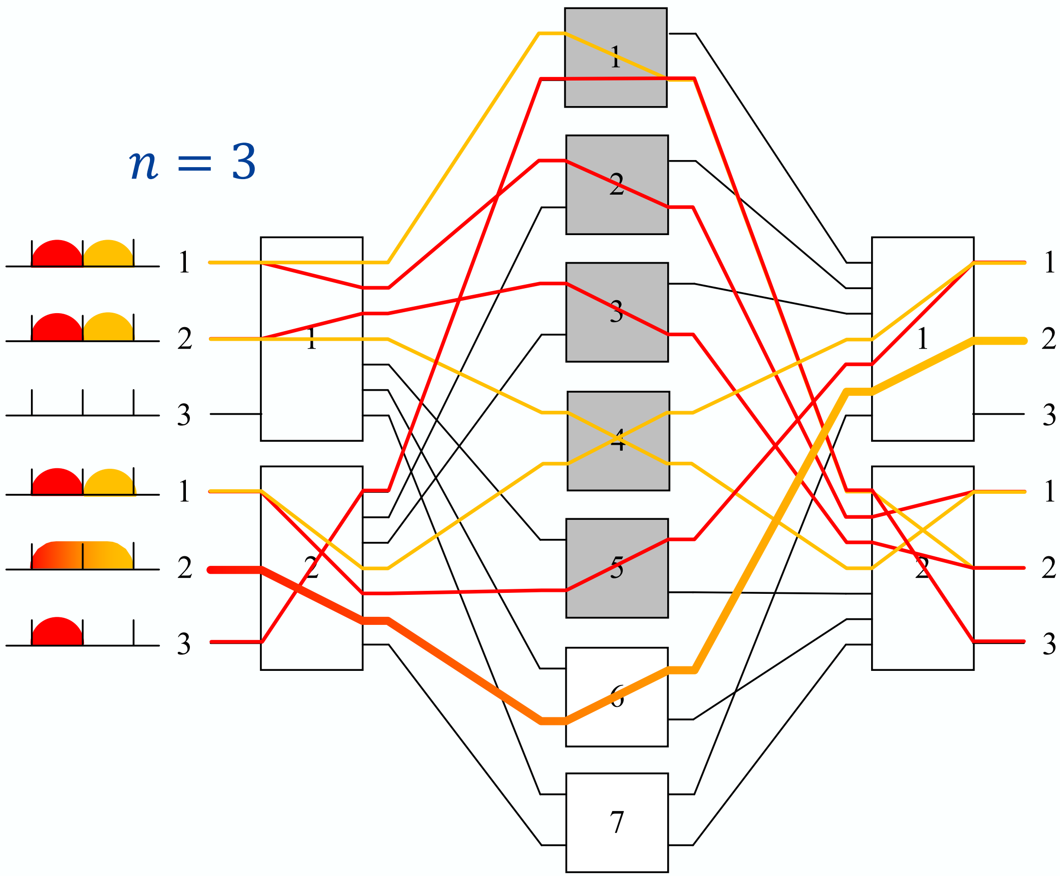


Wide-Sense NonBlocking for k-g LPs

- A Clos network is **WSNB** for k-g LPs, if a new k-g LP can always be set up without rearranging the existing LPs under a routing strategy
  - Note: "WSNB for k-g LPs" means WSNB for k'-g LPs is not guaranteed, if $k' \neq k$

Lemma 2

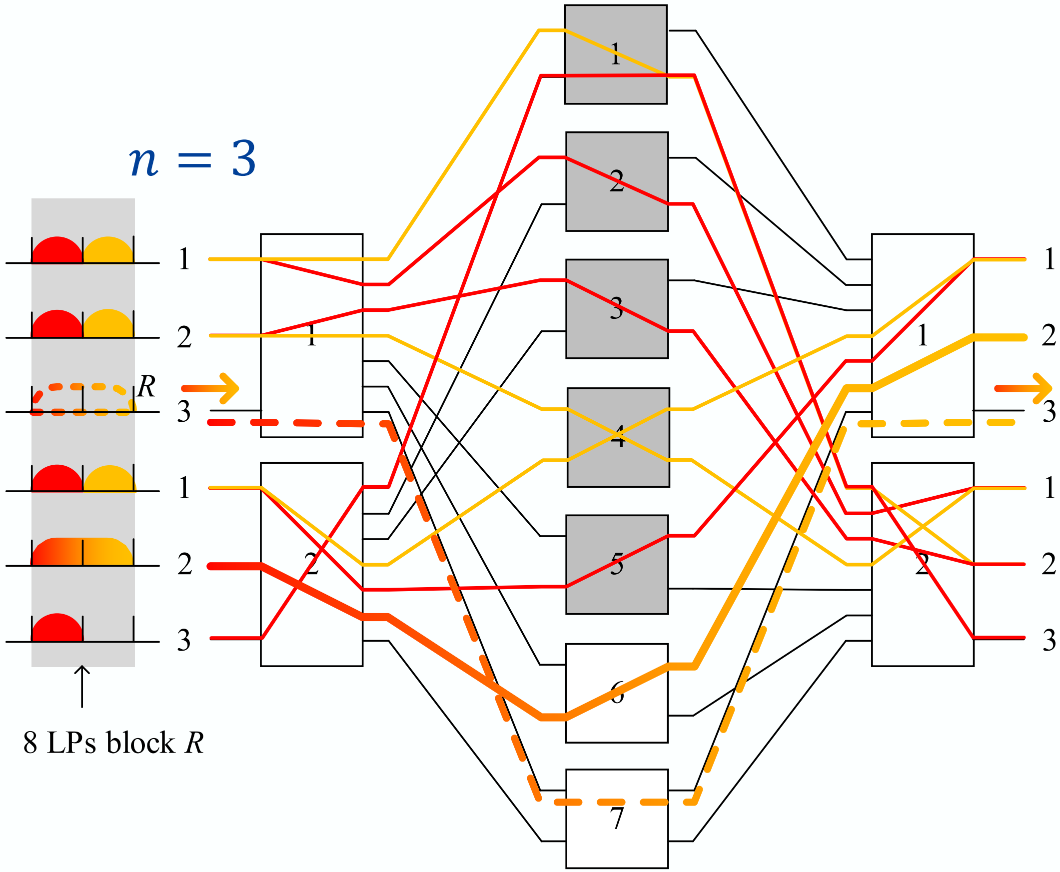
- Under the routing strategy for 1-g LPs, $\mathcal{C}$ is WSNB for 1&2-g LPs, iff $m \geq 2n - 1 + \boldsymbol{n - 1}$



$m \geq 2n - 1 + n - 1 = 7$

Lemma 2

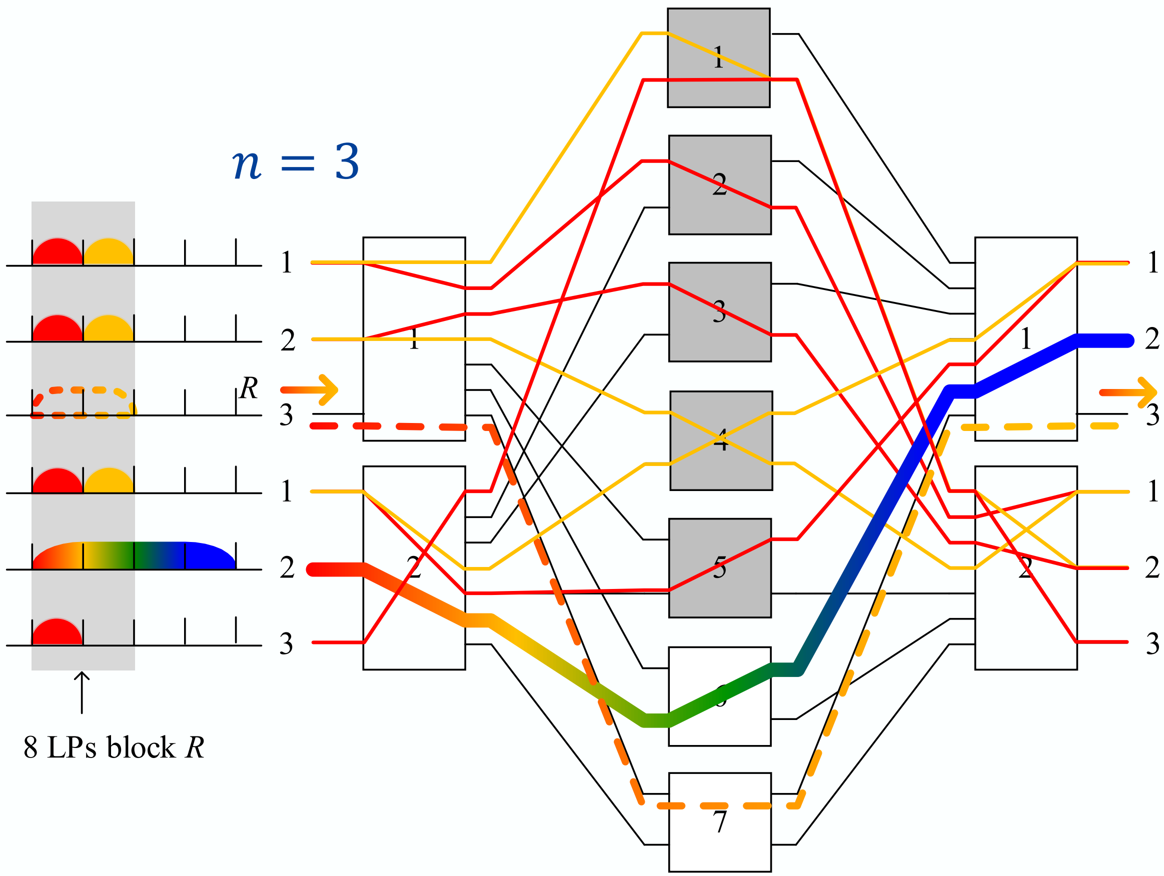
- Under the routing strategy for 1-g LPs, $\mathcal{C}$ is WSNB for 1&2-g LPs, iff $m \geq 2n - 1 + \boldsymbol{n - 1}$



$m \geq 2n - 1 + n - 1 = 7$

Lemma 2 holds even if 4-g LPs are present

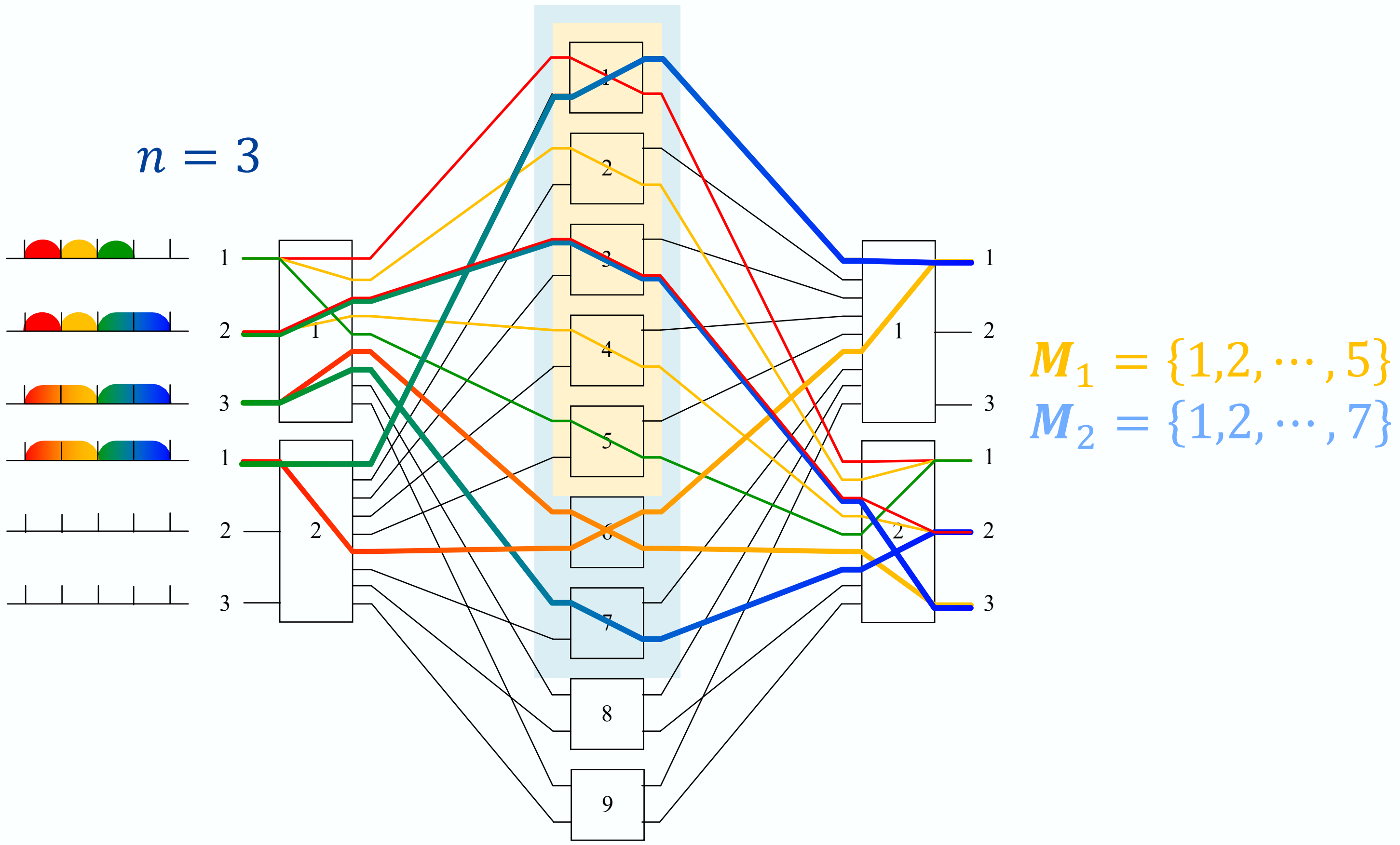
- Under the routing strategy for 1-g LPs, $\mathcal{C}$ is WSNB for 1&2-g LPs, iff $m \geq 2n - 1 + \boldsymbol{n - 1}$



$m \geq 2n - 1 + n - 1 = 7$

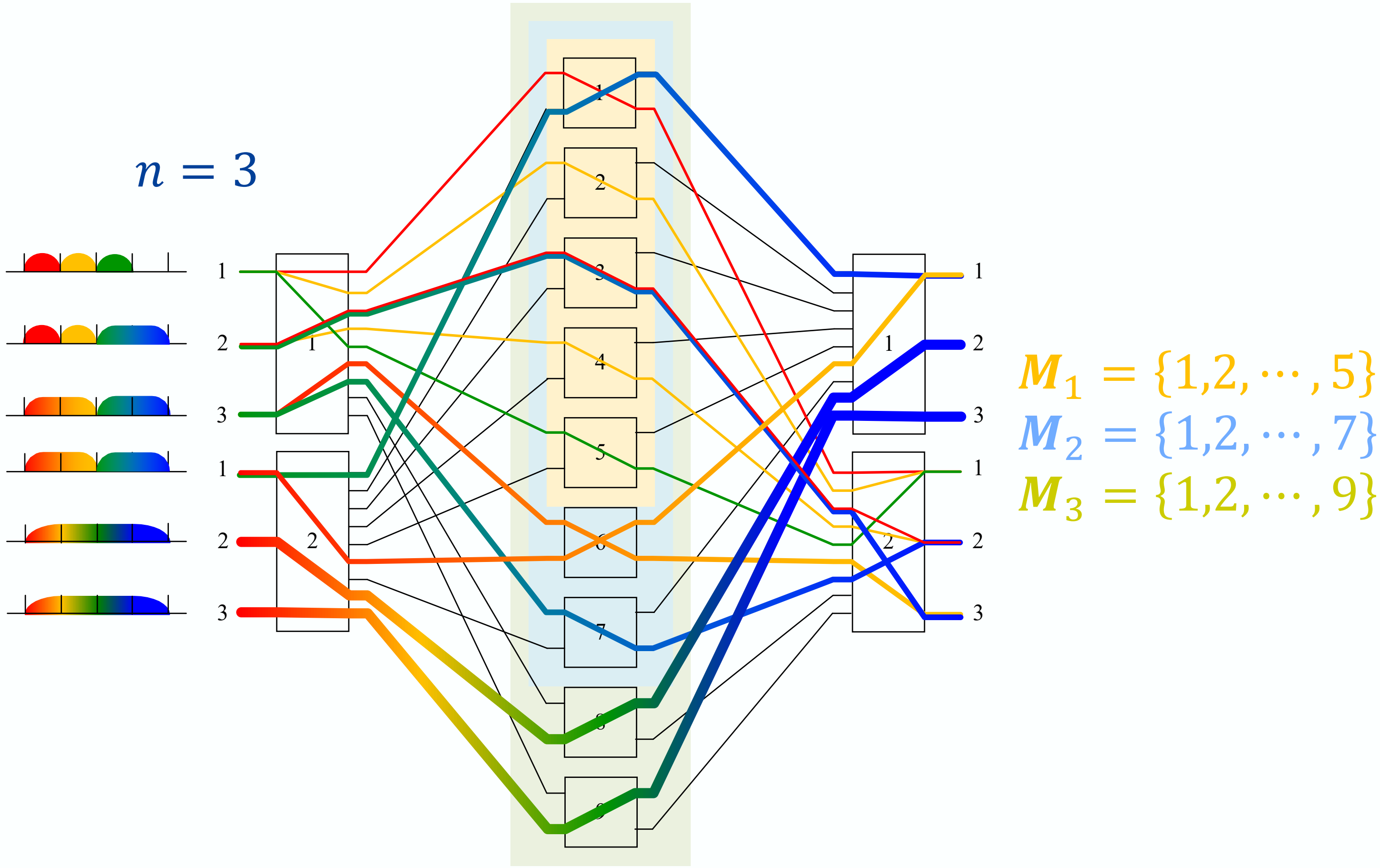
Routing Strategy for 1&2-g LPs

- Specify CMs $\boldsymbol{M}_1 = \{1,2,\cdots,2n-1\}$ for 1-g LPs and CMs $\boldsymbol{M}_2 = \{1,2,\cdots,3n-2\}$ for 2-g LPs



Granularity Differential Routing (GDR)

- Specify CMs $\boldsymbol{M}_i = \{1,2,\cdots,2n-1+i(n-1)\}$ for 2^i-g LPs, where $i = 1,2,\cdots,K-1$



Theorem 2

- $\mathcal{C}$ is WSNB for the 2^0-g, 2^1-g, $\cdots$, 2^k-g LPs, iff

$$m \geq 2n - 1 + k(n - 1)$$

where $k = 1,2,\cdots,K$.

Case 1: $n = 3, r = 100, K = 5$ ($m^* = 13$)		**Case 2:** $n = 4, r = 100, K = 4$ ($m^* = 16$)	
m	Blocking Rate	m	Blocking Rate
6	2.01×10^{-2}	**8**	1.27×10^{-2}
8	1.33×10^{-3}	**10**	7.44×10^{-4}
10	2.39×10^{-5}	**13**	1.17×10^{-6}
11	3.39×10^{-6}	**14**	9.68×10^{-8}
12	6.20×10^{-8}	**15**	3.52×10^{-9}
13	0	**16**	0

Conclusions

- Derive SNB and WSNB conditions for flex-grid OXC-Clos networks for the first time
- Propose a GDR strategy
  - remarkably reduce # of needed CMs

$$2^K(n-1)+1 \Rightarrow 2n-1+K(n-1)$$

  - have no computation and operation overheads

Thanks!