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The bridge to possible

Lessons Learned from Designing Routed Optical Networks

... or how to embrace tradeoffs for fun and profit

Emerson Moura, Distinguished Solutions Engineer

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BRKOPT-2015

Acknowledgements

- Authors:
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Agenda

- The bare minimum of analog domain
- Lesson 1: Optical Performance
- Lesson 2: Build on IP traffic demands, not capacities
- Lesson 3: Topologies & architectures matter, but constraints even more so
- Lesson 4: IP services are protected and restored using IP
- Summary

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"If you haven't found the tradeoffs, you haven't looked hard enough.

Russ White's Rule #1

Mr. EIGRP

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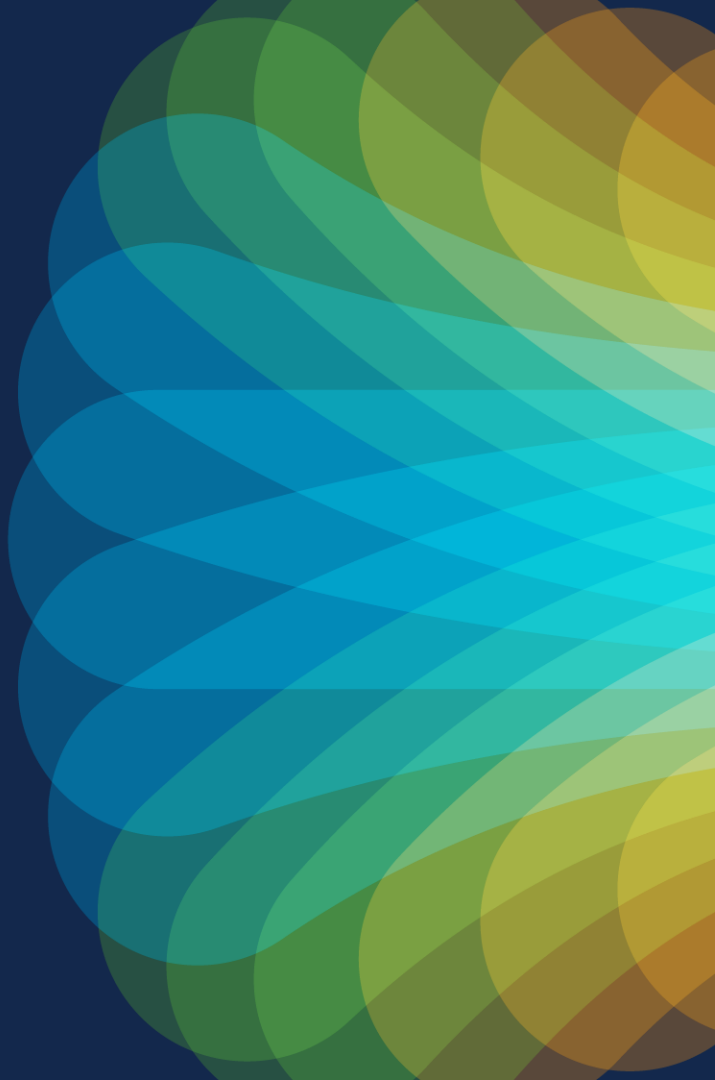
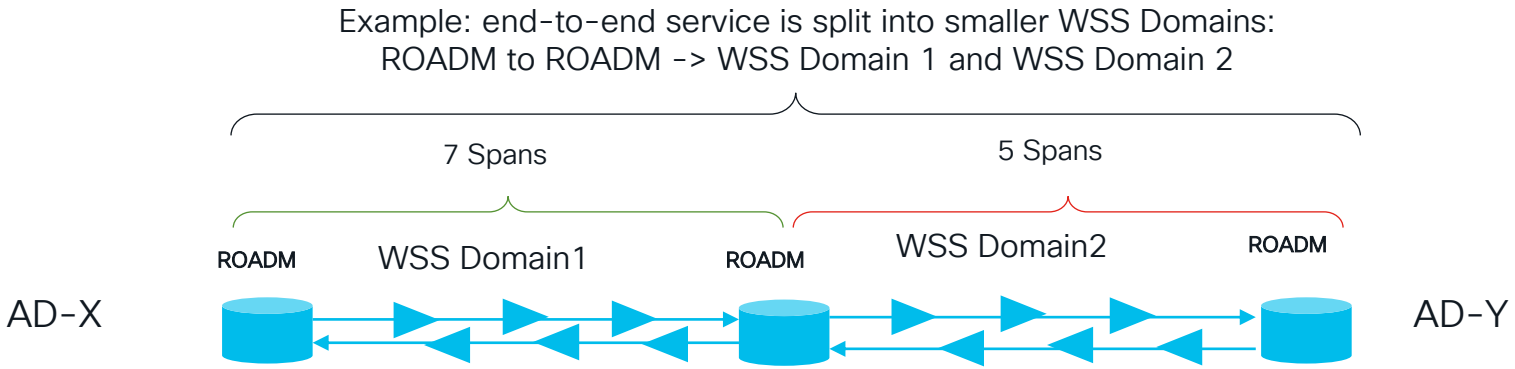
The bare minimum on the analog domain



DWDM transport is analog technology

In order to deal with intrinsic modeling complexity, we split the problem in smaller pieces.



Acronyms:
- WSS: Wavelength selective switch
- ROADM: Reconfigurable Optical Add/Drop Multiplexer

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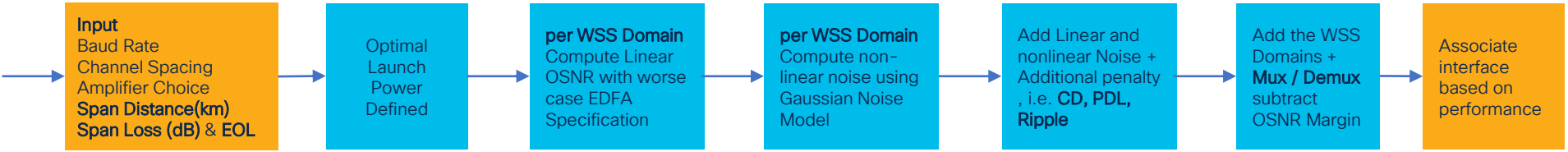
DWDM transport is analog technology (Cont'd)

Typical flow for optical analisys:



Required input:

- Topology (span length & attenuation), EOL margins

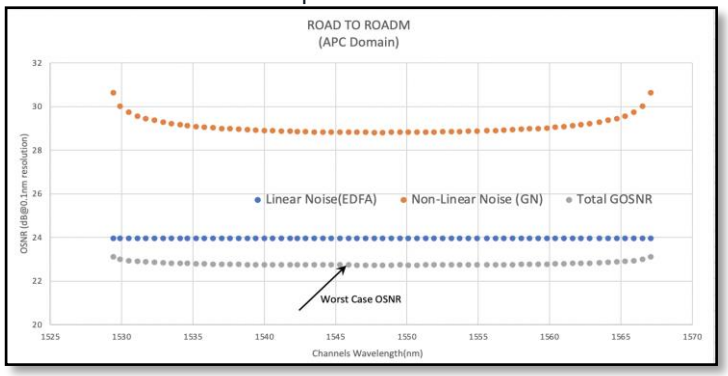
Method:

- Gaussian Noise simulation

Interesting:

- How we build the Add/Drop structure for the ROADM

Gaussian Optical Noise Model



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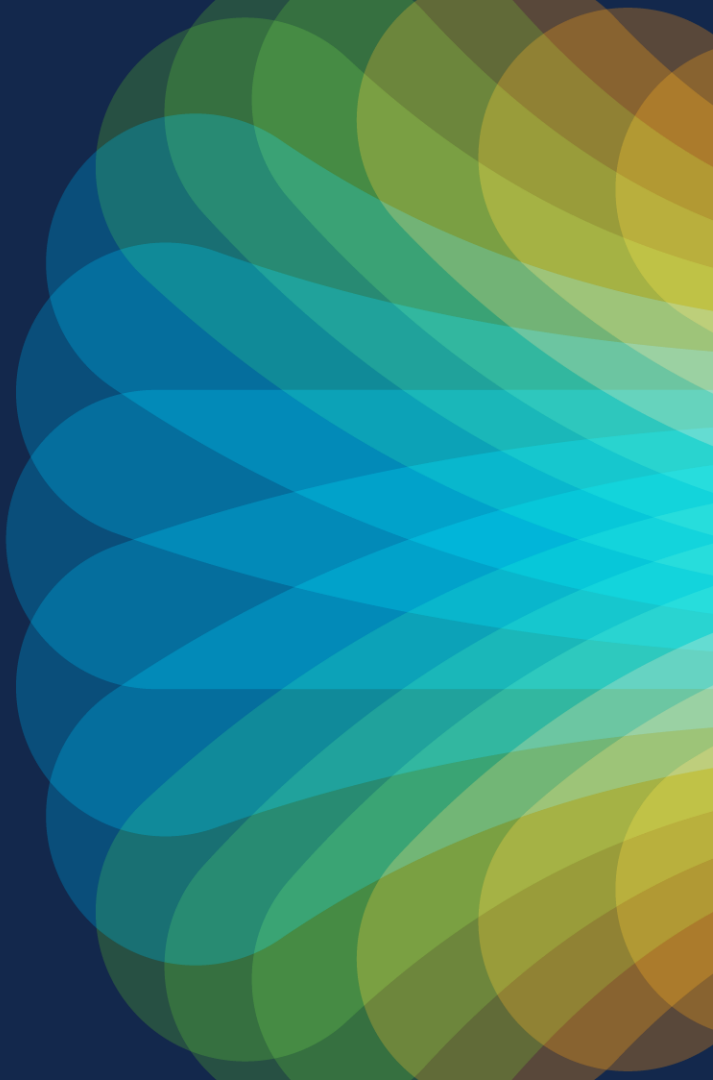
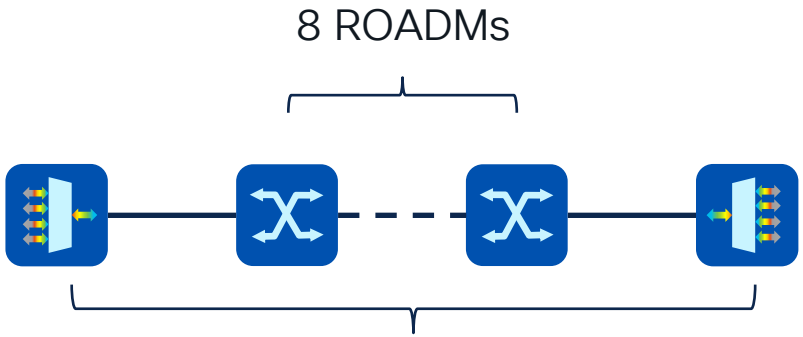
Lesson 1: Optical Performance



ZR+ and Transponder performance – comparable



Example from latest customer
Cisco OpenZR+ test
over 3rd party DWDM

400 Gbps	OpenZR+ 	NCS 1002 
OSNR(dB) @ 0.1 nm RBw	23.1	22.6
Baudrate (GBd)	60.14	69
# Channels per “Band”	**64**	**54**
Modulation	16-QAM	16-QAM

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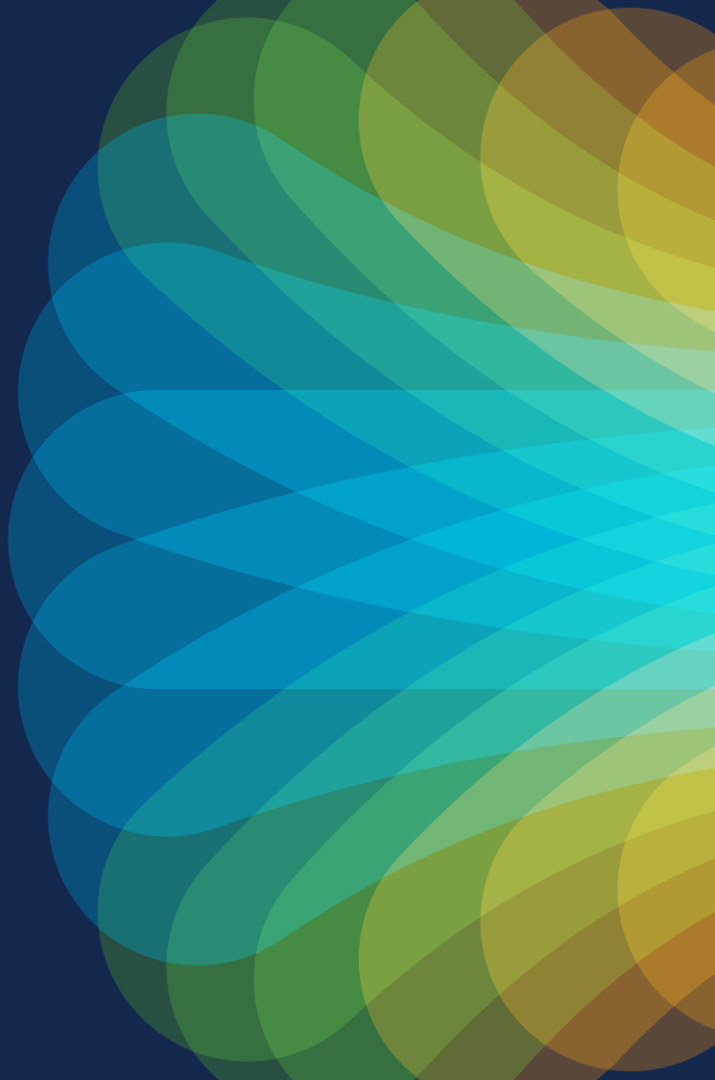
Lesson 2: Build on IP traffic demands, not capacities



US operator “metro” simulation results

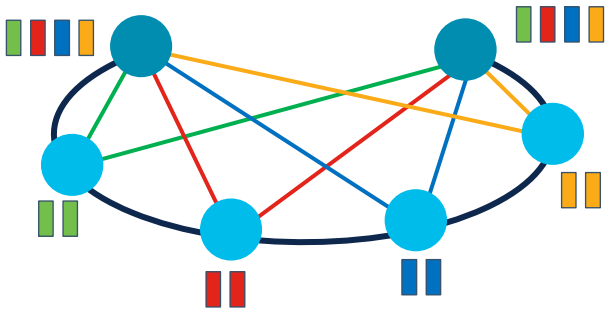
01 Simulation using **P95** of busy hour traffic

02 **X** Tb/s busy hour traffic.

03 **8 X** Tb/s installed capacity

04 **Single** wavelength on aggregation rings

Original design – dual-homed



34.1 Gb/s

29.3 Gb/s
Median site traffic

Routed Optical Networking benefits

-97%
Wavelength usage

-95%
Energy usage

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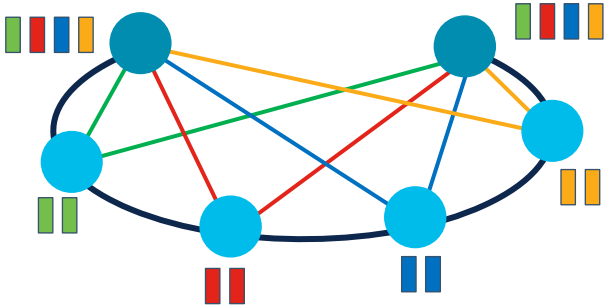
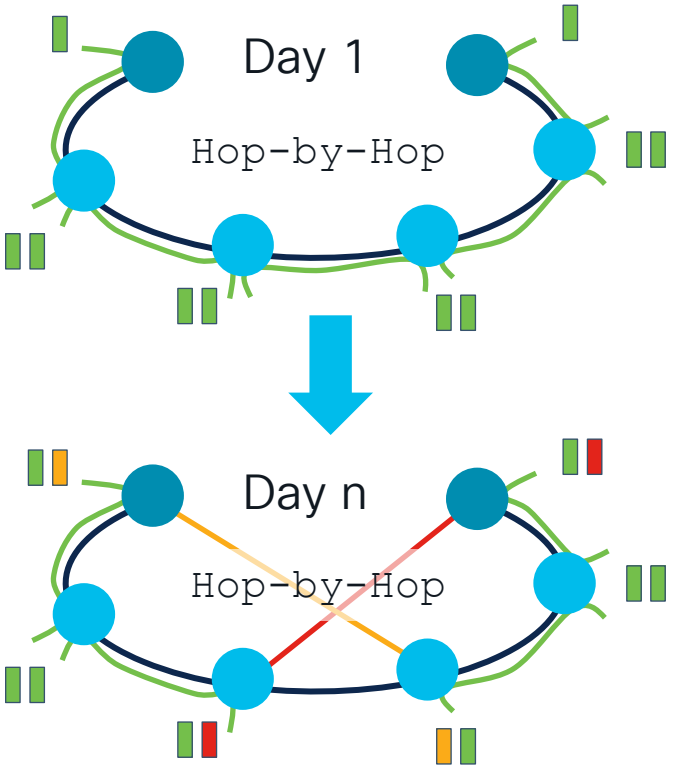
Transforming Hub & Spoke to Hop-by-Hop

Original design – dual-homed



Customer reported being short on wavelengths



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Simulation Results

	PMO at 40% max installed capacity	P95 busy hour traffic
Sum inter-site demands	**6.408 Tb**	**1.976 Tb**
Inter-site installed capacity	38.7 Tb	30.3 Tb
Intra-site installed capacity	67.26 Tb	62.8 Tb
ZR/ZR+ pluggables	**194**	**152**
Grey pluggables	334	314
Maximum λ used between hubs	4	2
Maximum λ used on rings	2	1
WC link utilization	100 %	70.69 %

Power savings from TXP elimination alone: 55.000 kWh p.a.

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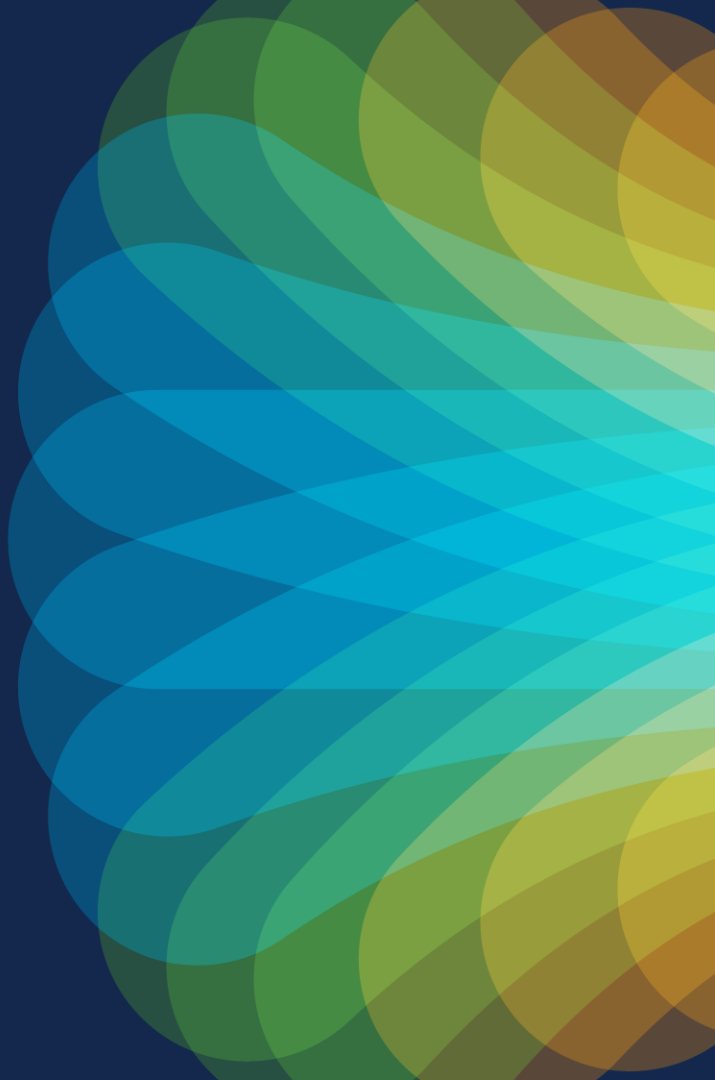
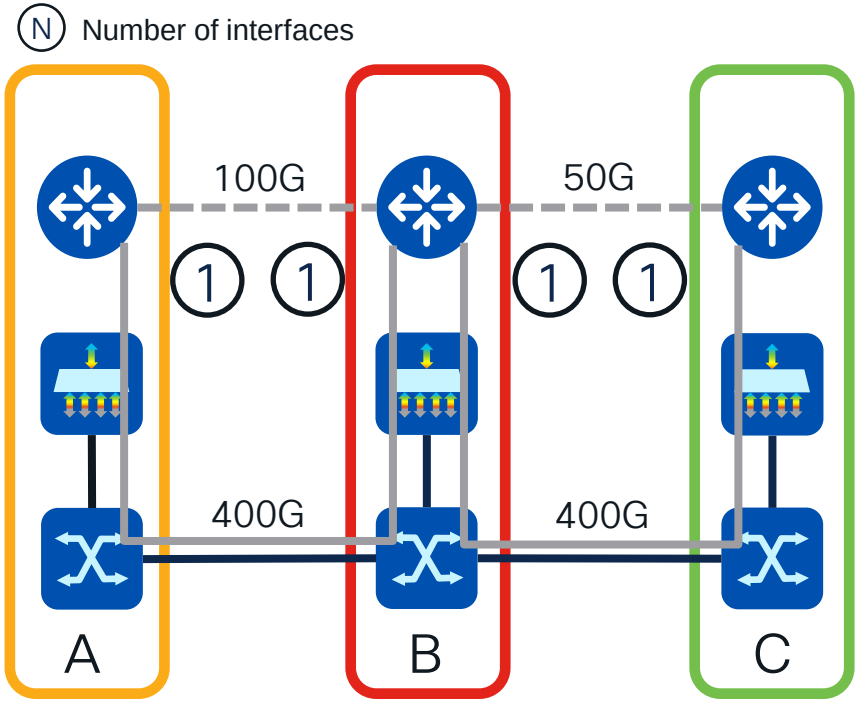
Lesson 3: Topologies & architectures matter, but *constraints* even more so.



A toy network showing the concept ...



- Not “one size fits all”
- Consider:
  - Fiber cost / availability
  - Relative importance of sites
  - Achievable bitrates
  - Impact on resiliency
  - Physics
- Both approaches have their place in designs.

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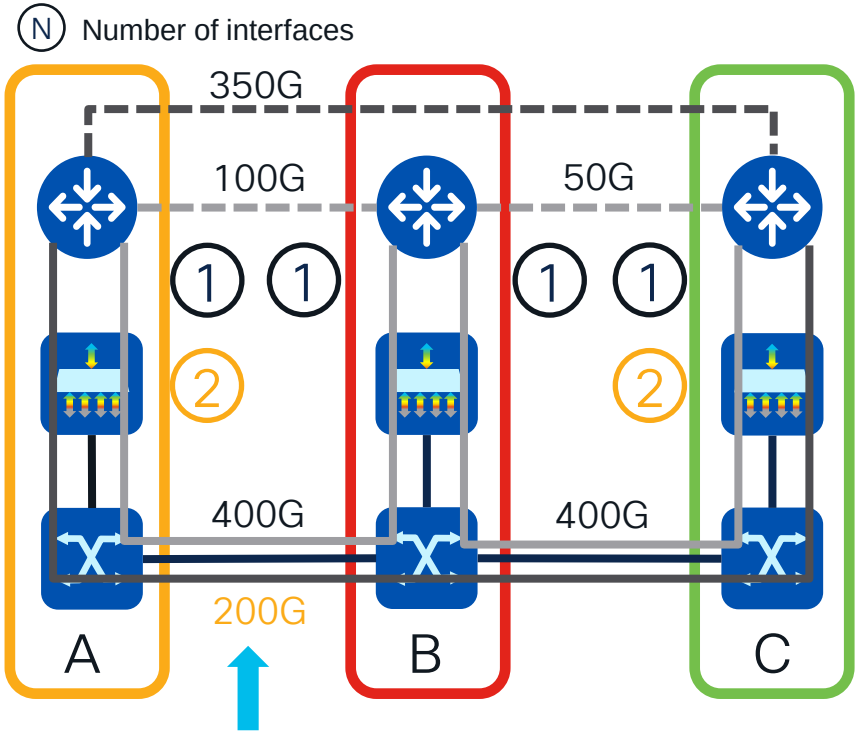

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  - Achievable bitrates
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Limitted by physics to 200G – 8 interfaces in total

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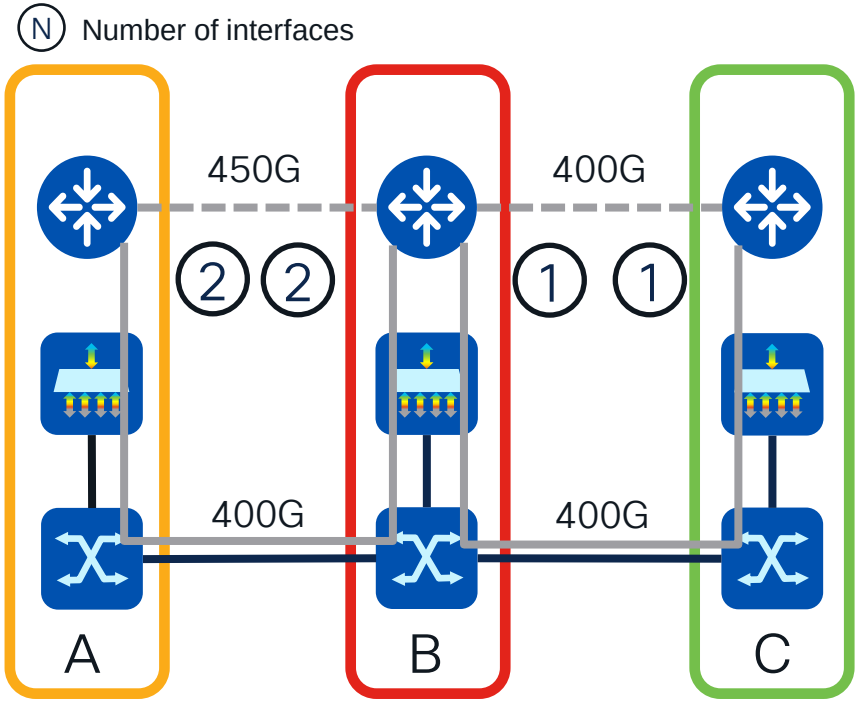
A toy network showing the concept ...



Same demand, 6 interfaces instead of 8

- Not “one size fits all”
- Consider:
  - Fiber cost / availability
  - Relative importance of sites
  - Achievable bitrates
  - Impact on resiliency
  - Physics
- Both approaches have their place in designs.

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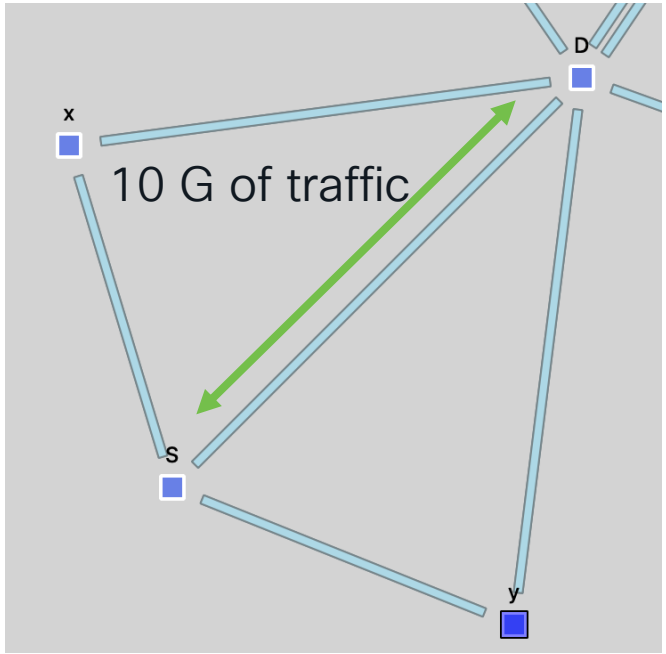
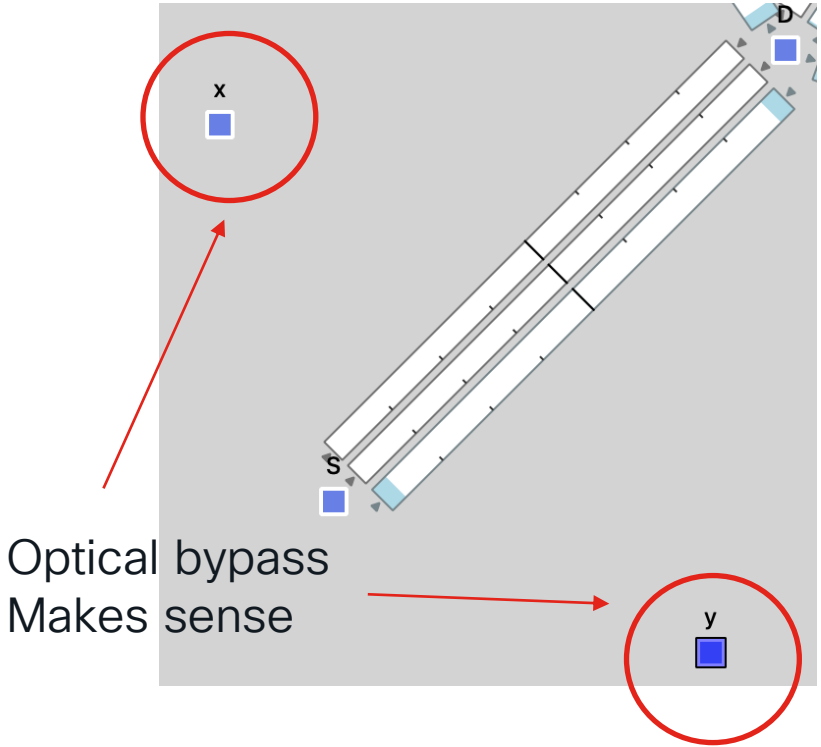
Real example 1





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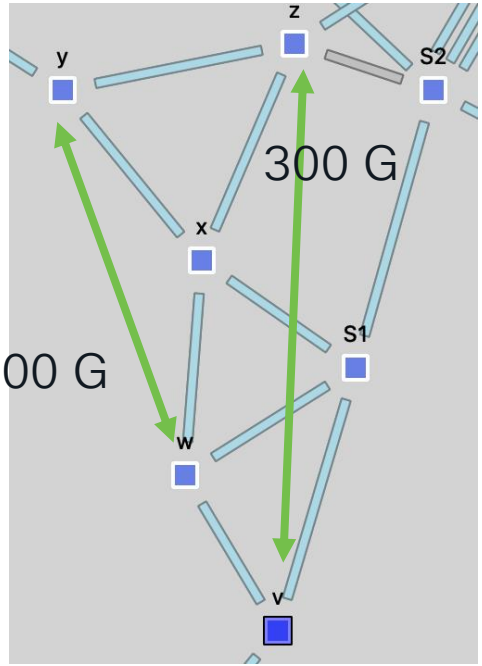
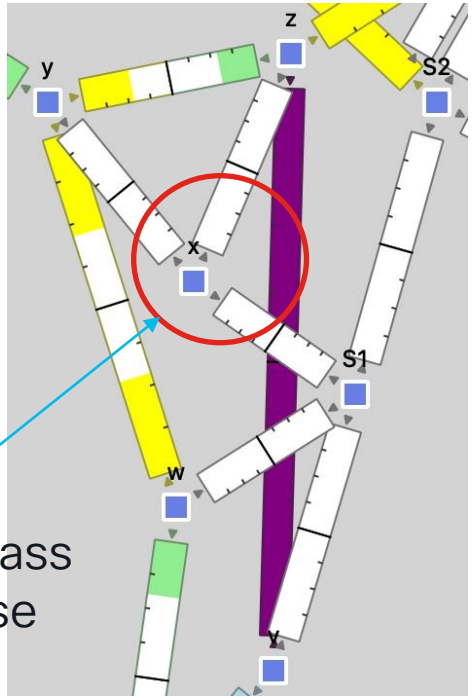
Real example 2





Optical bypass makes sense

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Key takeaways

- Be pragmatic.
  - Optical bypass is a valid design choice as seen in previous examples
  - Use hop–by-hop and optical bypass – the combination will likely provide the best result.

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Reasons to do it

Price to pay (trade-offs)

Physics forcing architectures

What can you do in order to increase fiber capacity?

Wider channel	Better FEC	Higher modulation	Better spectral efficiency	Use L-Band
"Easily" done	Increased reach	More bits per symbol -> Higher capacity	More b/s/Hz	"Easily" done
Increased capacity per channel	Higher overhead eats into usable capacity	Reach: ~ 1/(constellation size)	Dispersion coefficient β	Doubles # channels
Fewer channels	Power, real estate, cost	X km @ 16QAM -> X/4 km @ 64QAM	Nonlinear coefficient γ	Increases attenuation
Increased blocking probability	No "dramatically better" FEC on horizon		Reduce attenuation	Negatively impacts spectral efficiency
			Reduce reach	Not well suited for some fiber types (ex. low dispersion fibers)

Reality check

Requires drastically different fiber to to have big effect

Not a question of "if" but "when" physics mandates shorter paths

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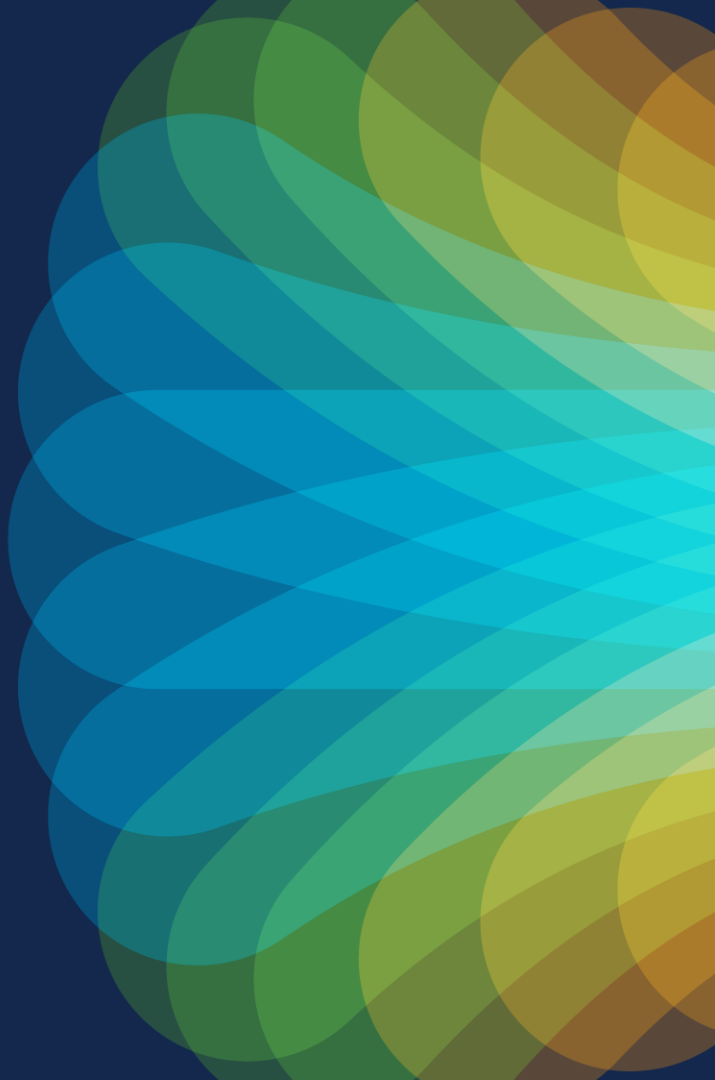
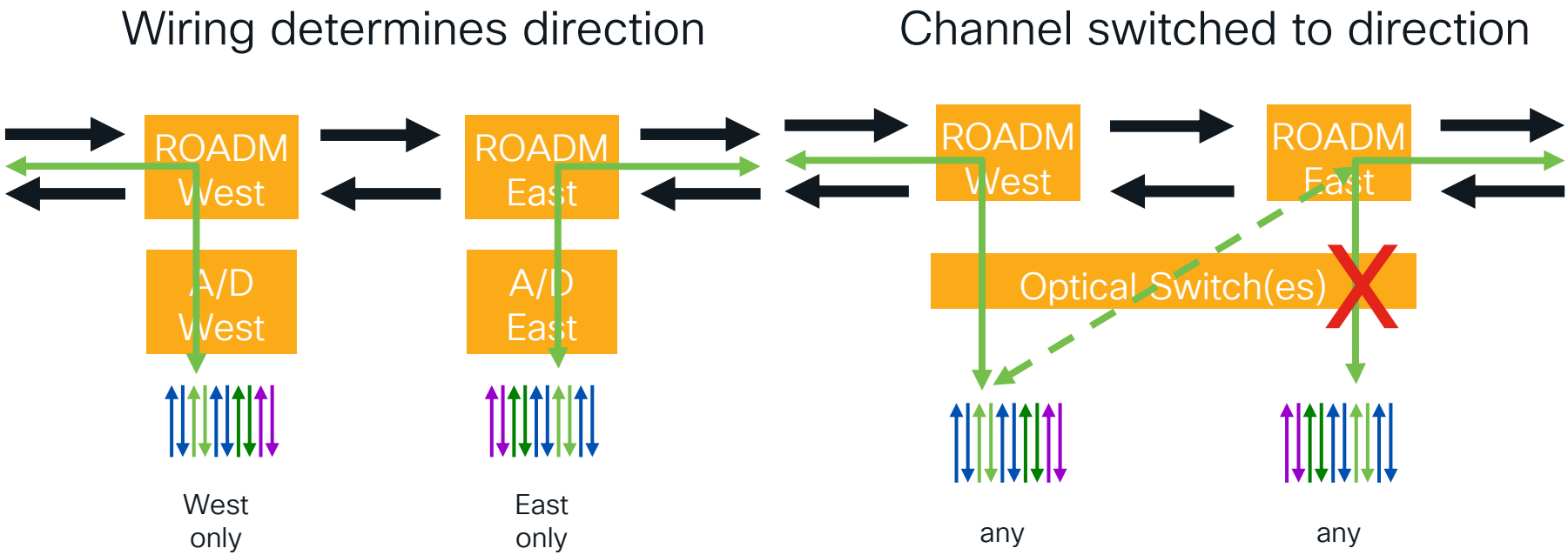
Lesson 4: IP services are protected and restored using IP



Omnidirectional Add/Drop



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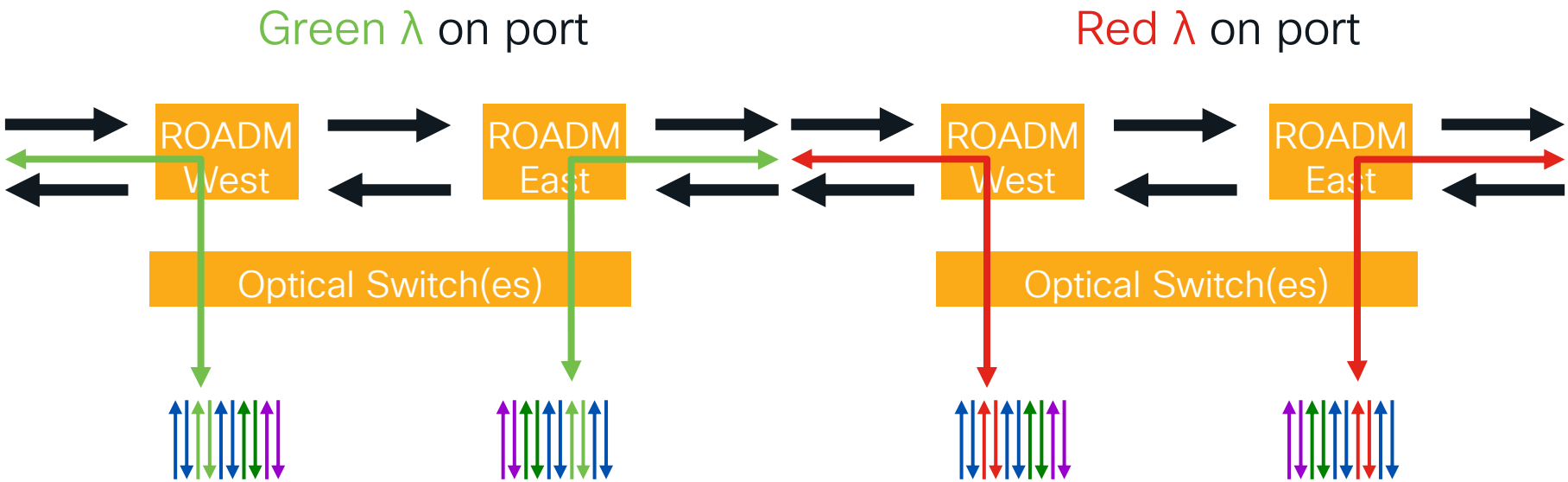
Colorless Add/Drop



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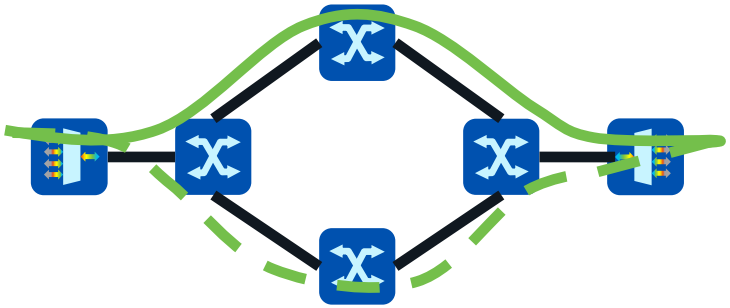
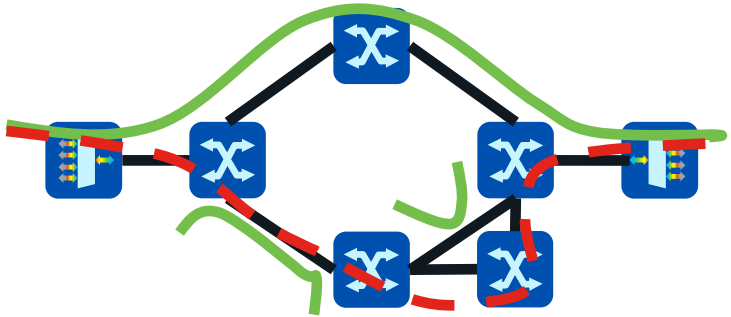
OK, so what is the use case ?

Optical Protection



Bridge green λ to lower part of network – same patch panel port

Optical Restoration with recoloring



Compute new path (optical control plane) and change to red λ – same port

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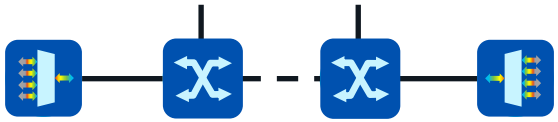
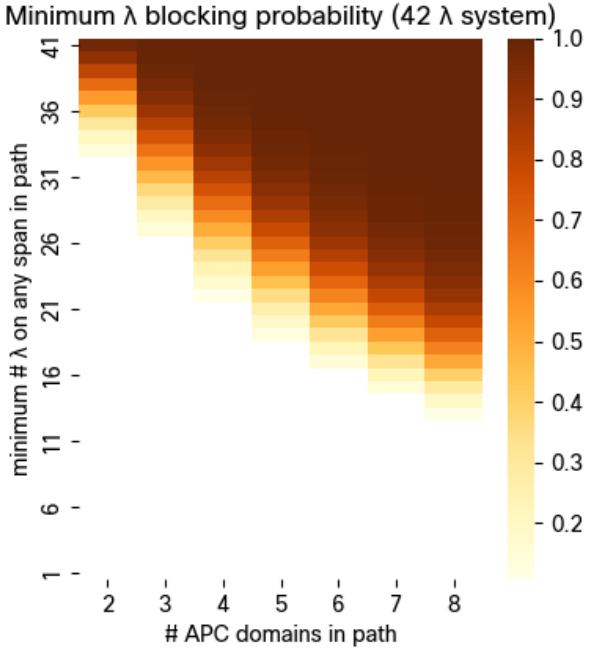
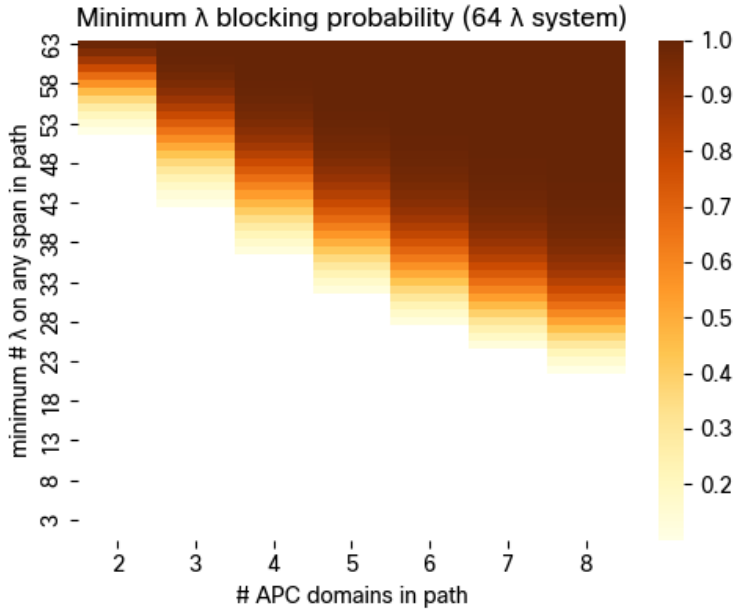
Is λ blocking really an issue ?







It can be – especially in meshed networks ! (Only probabilities >= 10 % shown)

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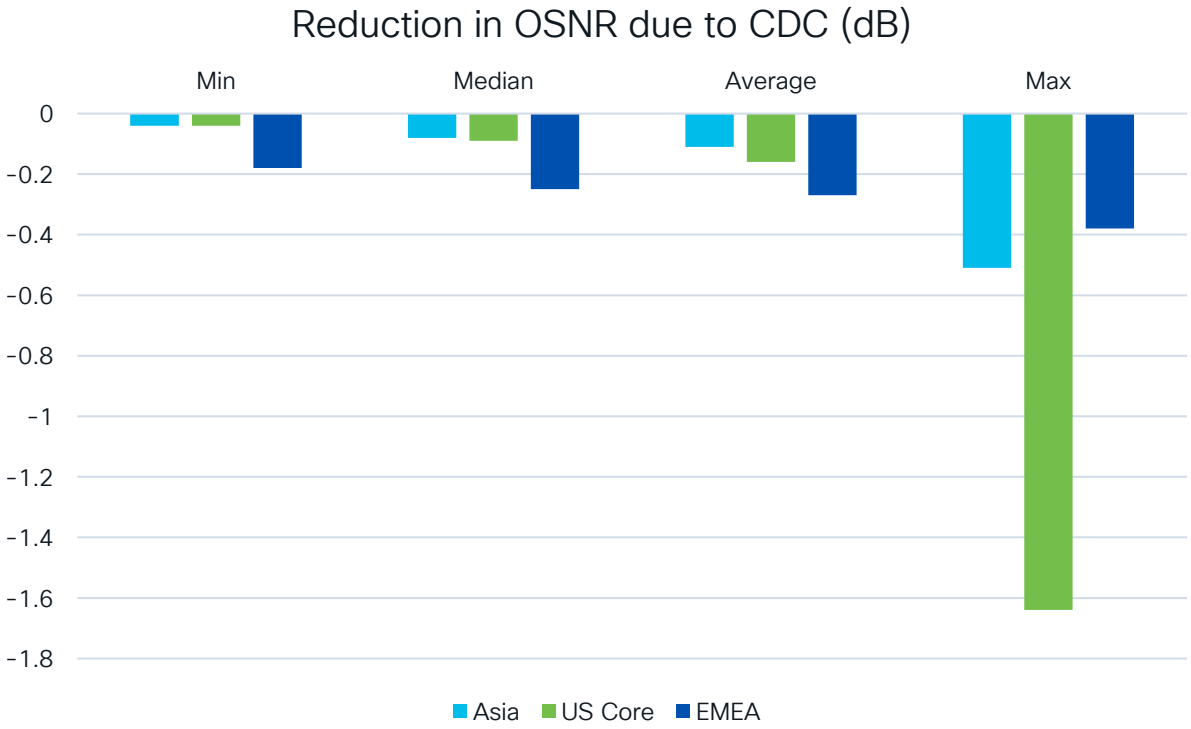
Negative effect on OSNR & bitrate due to CDC



	Decreased Bitrate (% of non-regen circuits)
Asia	3 %
US Core	4 %
EMEA	0 %

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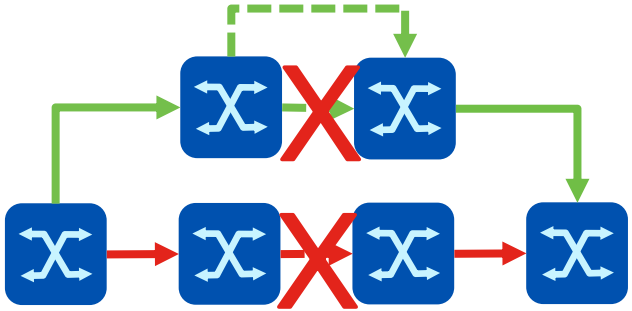
Does optical restoration work for the Asia net ?

Relations	157
Relations w/o regenerators	121
Relations >= 2 spans	117
Restorable *on same bitrate*	82
Requires regenerators standing-by on the restoration paths	35



Optical restoration is (by design) not fast – think minute(s)

Of the three networks, Asia network was specifically set up for DWDM restoration

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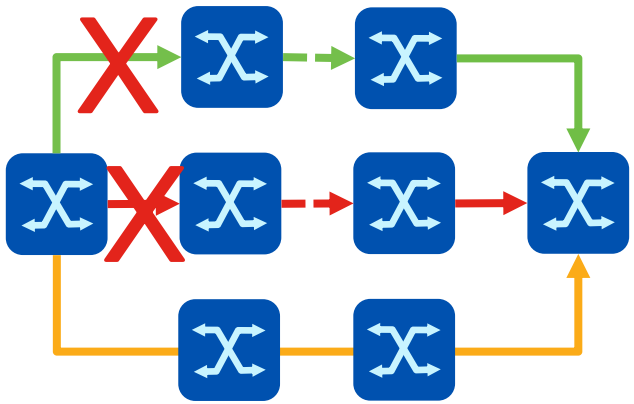

Relations	157
Relations w/o regenerators	121
Relations > 2 spans	N/A
Restorable on same bitrate	72
Requires regenerator	49

Optical restoration is (by design) not fast – think minute(s)

Of the three networks, Asia network was specifically set up for DWDM restoration

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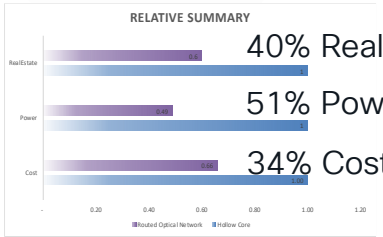
Actual Network Results

Reduced TCO with enhanced availability vs. Present mode of Operation

>80,000km Long Haul

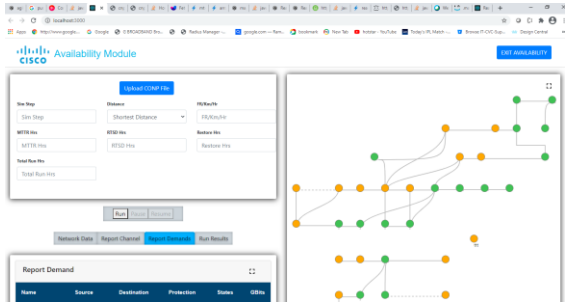


40% Real Estate

51% Power

34% Cost

What about Reliability?



PMO = 50% additional cost for equivalent availability to the Routed Optical Network

Present Mode of Operation	Routed Optical Networking
~ 45 Tbps traffic demands	All IP Protection/Restoration
Optical Restoration used	Saved **12000 km** of fiber (3 x LA -> NYC)

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“Design is an iterative process. You probably need one more iteration than you’ve done to get it right.

Russ White’s Rule #2

Mr. EIGRP

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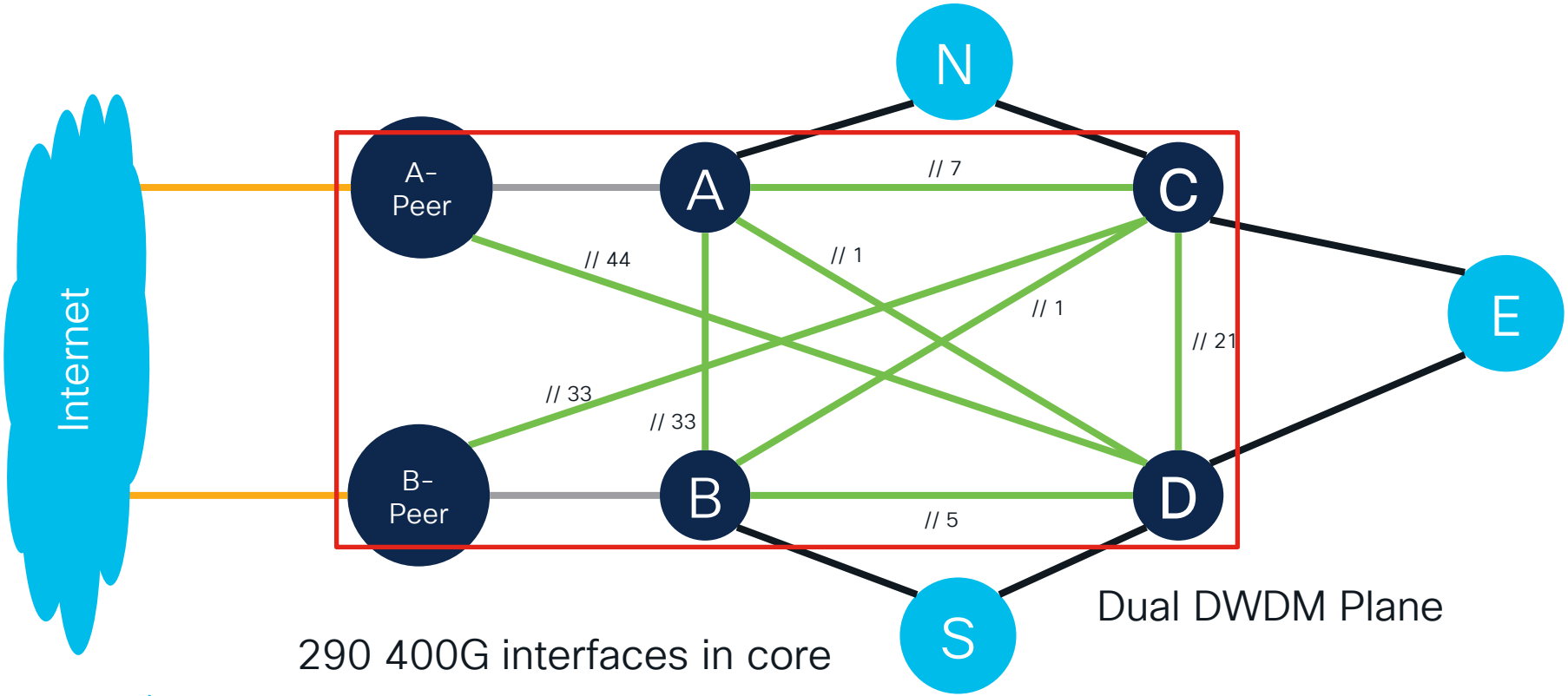
That EMEA network – customer view



290 400G interfaces in core

Dual DWDM Plane

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Switching to single plane

Customer Ask

400G IFs	290
Wavelengths	580
# DWDM systems	2

Final Solution

400G IFs	292
Wavelengths	292
# DWDM systems	1

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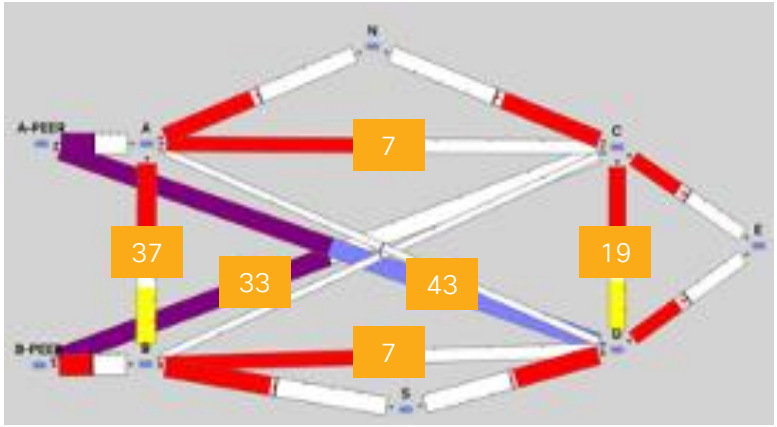
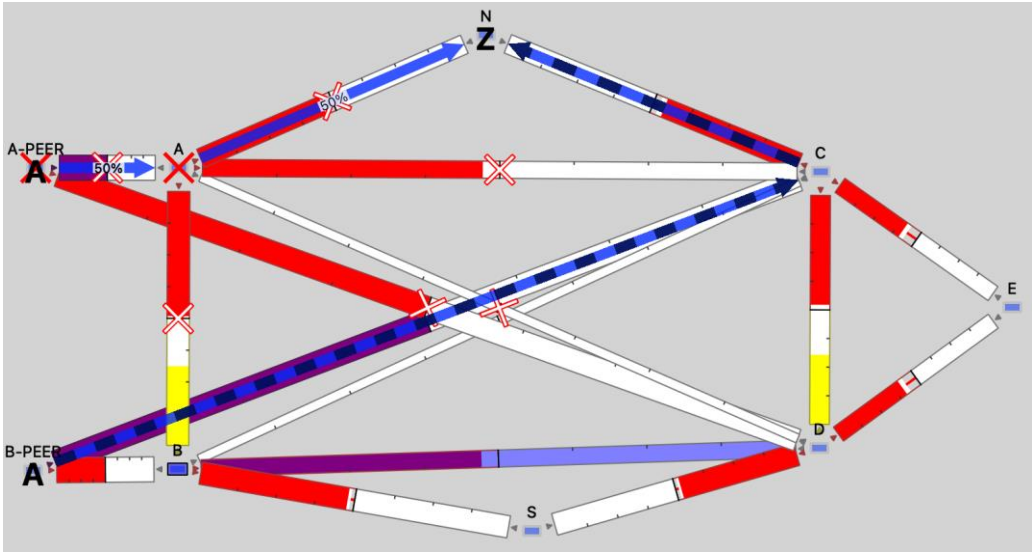
… still survives complete failure at A, B





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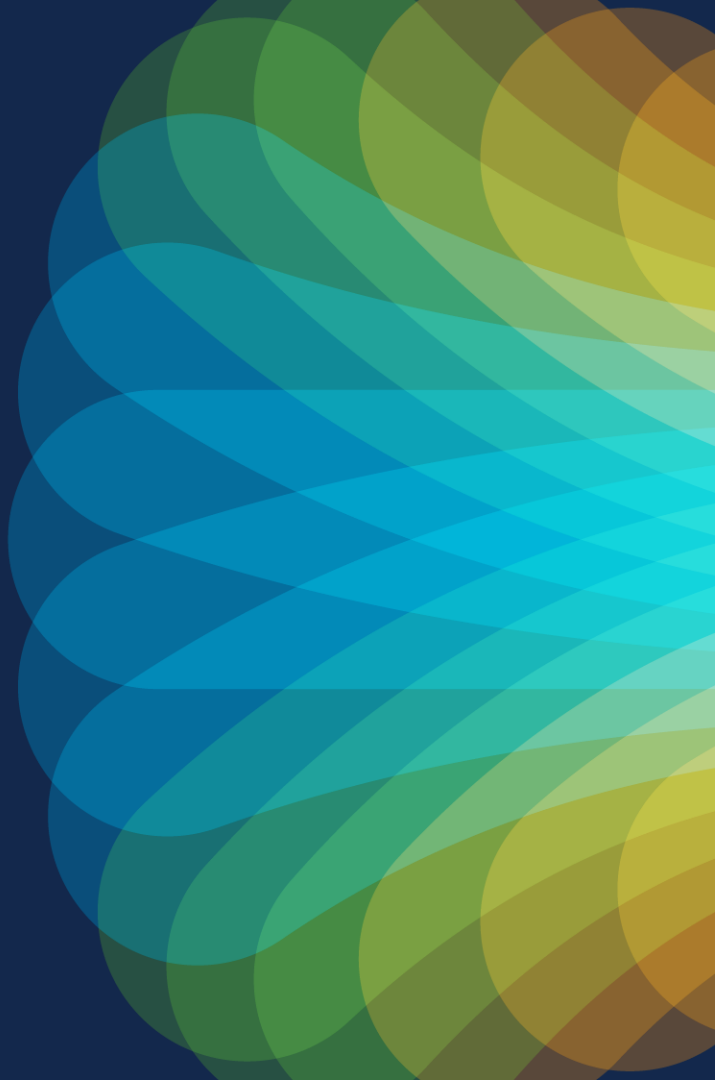
Summary



Conclusion

- It is all about tradeoffs
- Design from IP layer down
- Physics determine trade-offs…
- Know your IP demands
- Simplify DWDM network
  - Add/Drop structures
  - IP “restoration”
- Design tools

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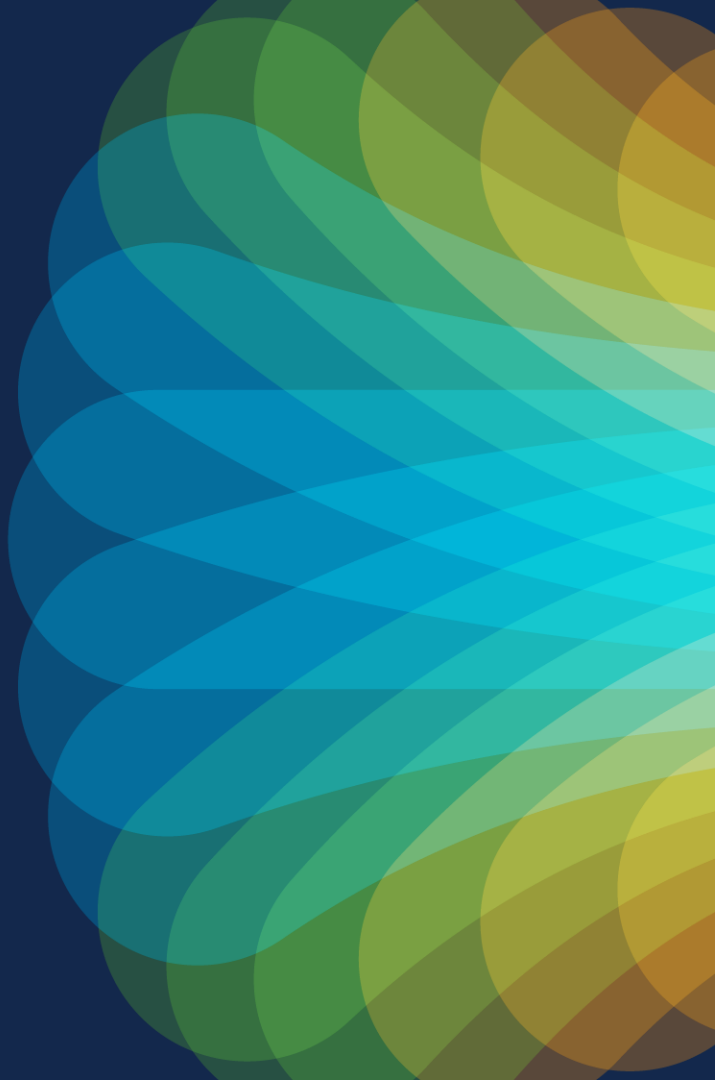
The bridge to possible

Thank you



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