RAIL: A Case for Redundant Arrays of Inexpensive Links in Data Center Networks

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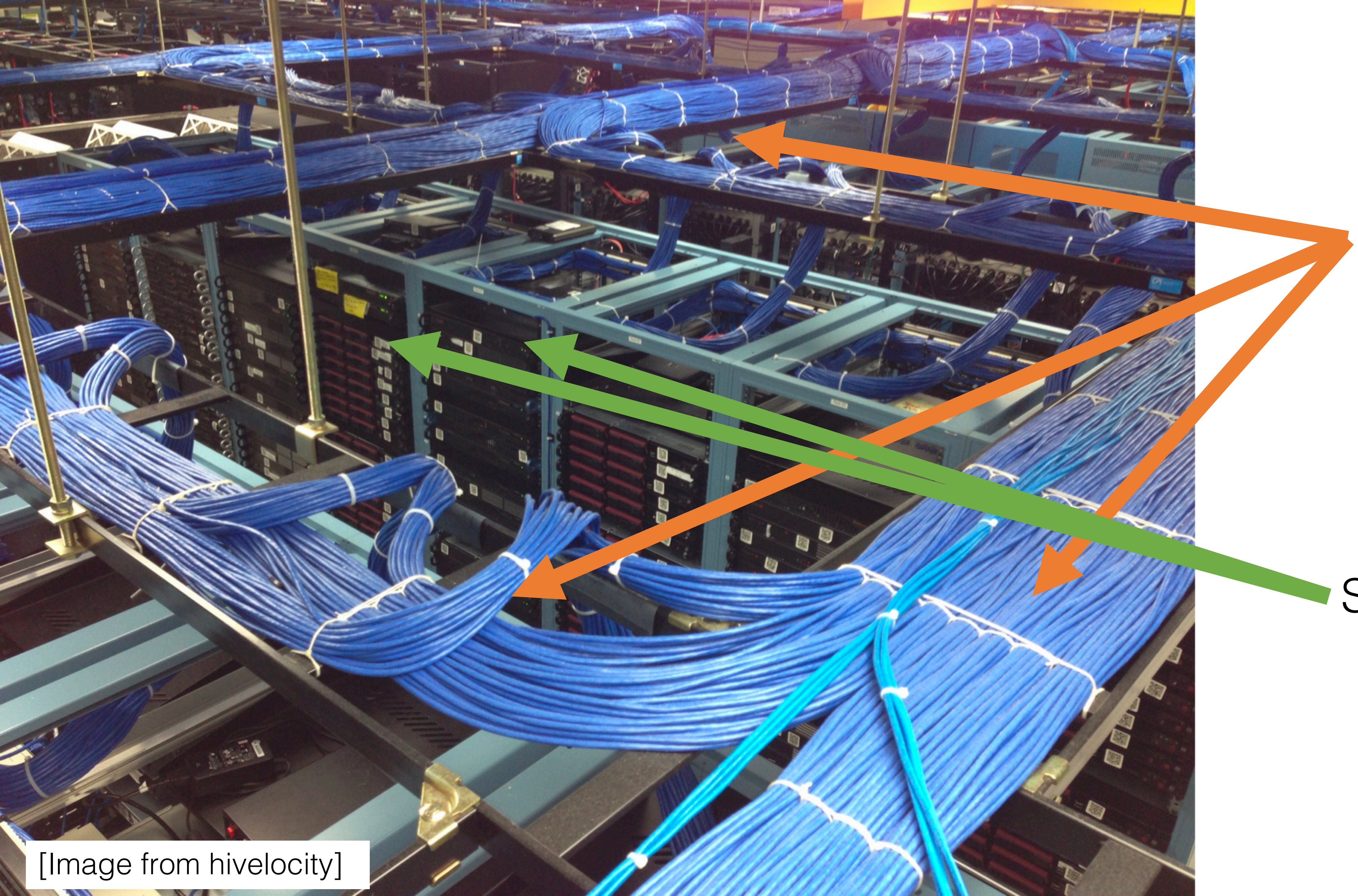


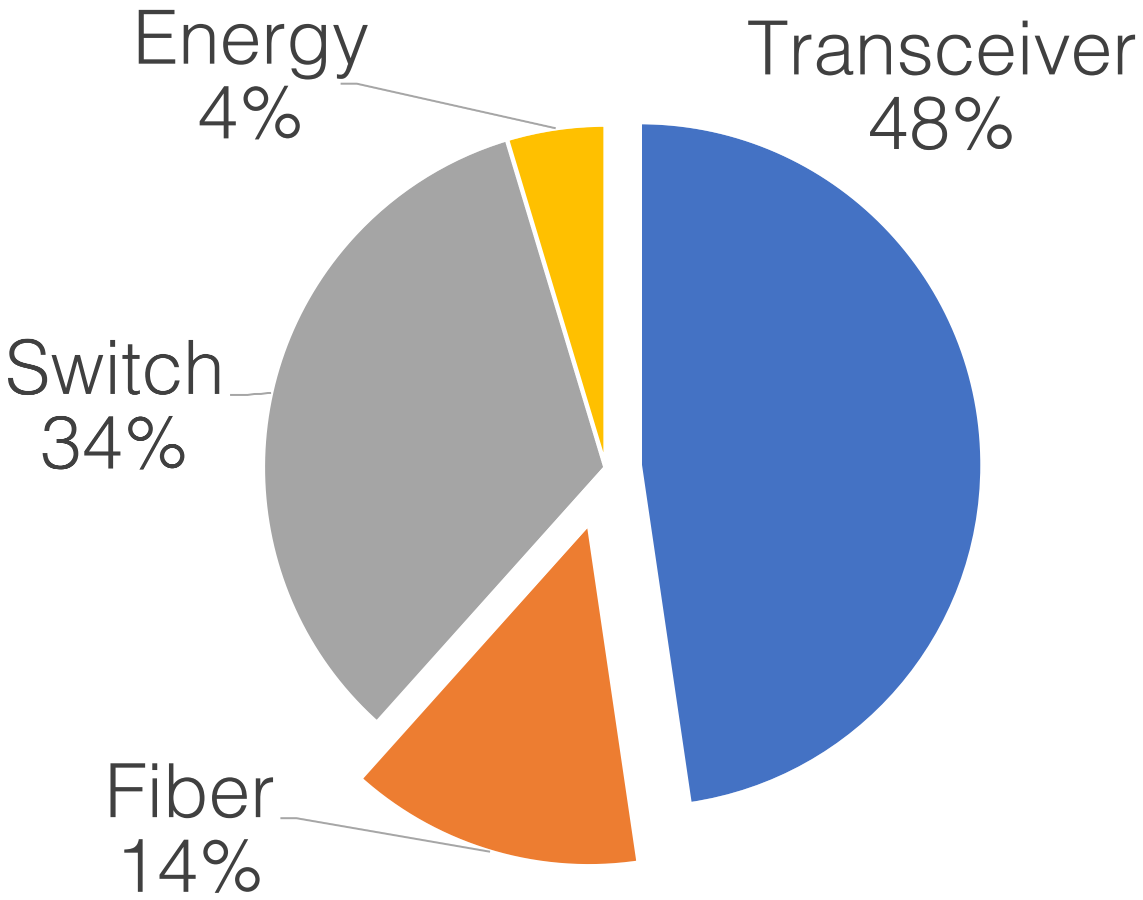
Fiber

Switch

[Image from hivelocity]

Optical Links are Expensive

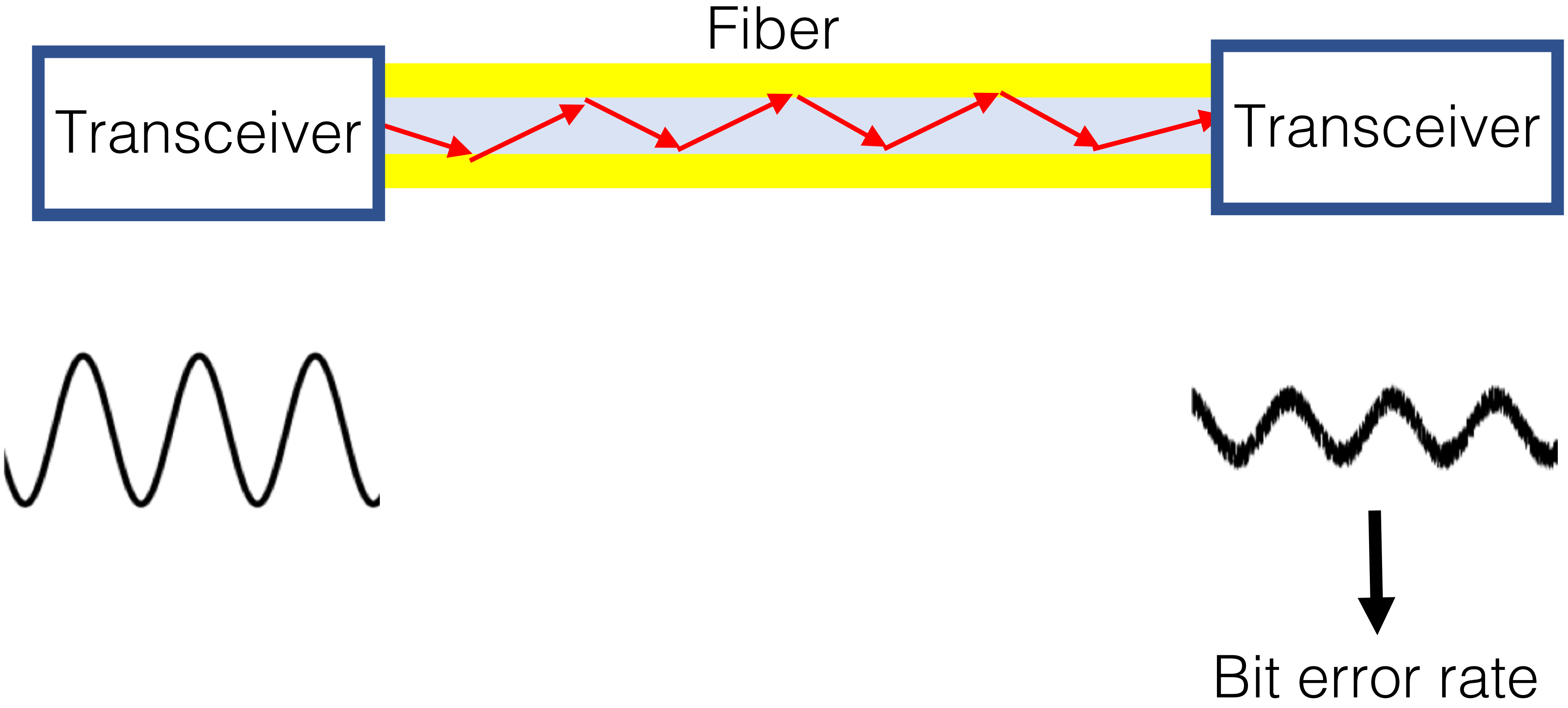
Transceiver



In this talk..

- First large-scale measurement of optical links in DCN
  - Significant over-engineering in optics
- Reduce over-engineering by using transceivers beyond design reach limit
  - Cost saving up to 40% of DCN
- Challenge: Packet loss on a small fraction of links
  - RAIL protects loss sensitive applications from this packet loss

Signal Strength and Bit Error Rate



Fiber

Transceiver

Transceiver

Bit error rate

Transceiver Classification

→	10G-SR	10G-LR	40G-SR4	40G-LR4
→	300m	10km	100m	10km
→	$45	$111	$165	$1249

SR 300m multi-mode 10G rate SFP+ 850nm

$45.00

LR 10Km single-mode 10G rate SFP+ 1310nm

$111.00

SR4 100m multi-mode 40G rate QSFP+ MPO connector 850nm

$165.00

LR4 10Km single-mode 40G rate QSFP+ LC connector CWDM

$1,249.00

[Image from robofiber]

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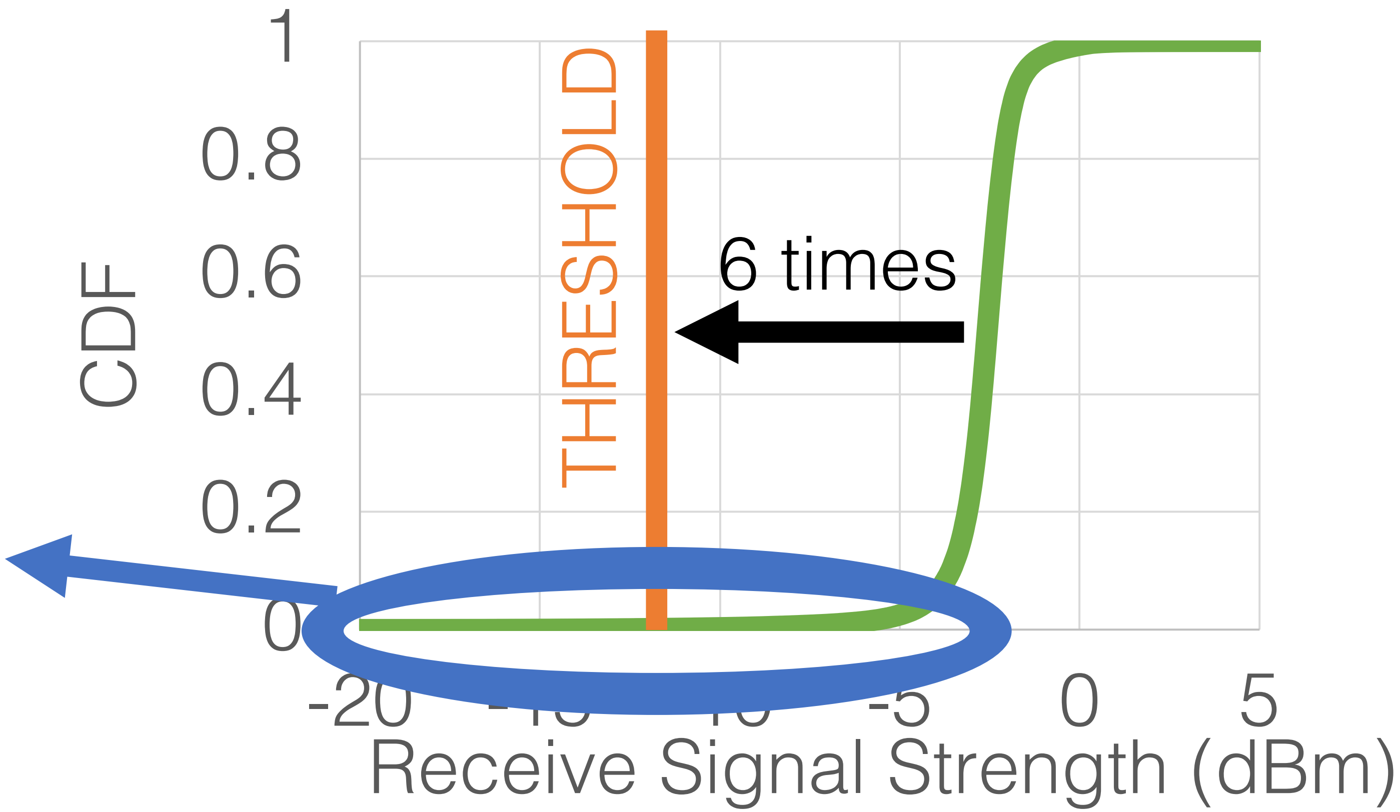
Over-engineering in Optics

300K links

10G-SR



Uniform randomly distributed

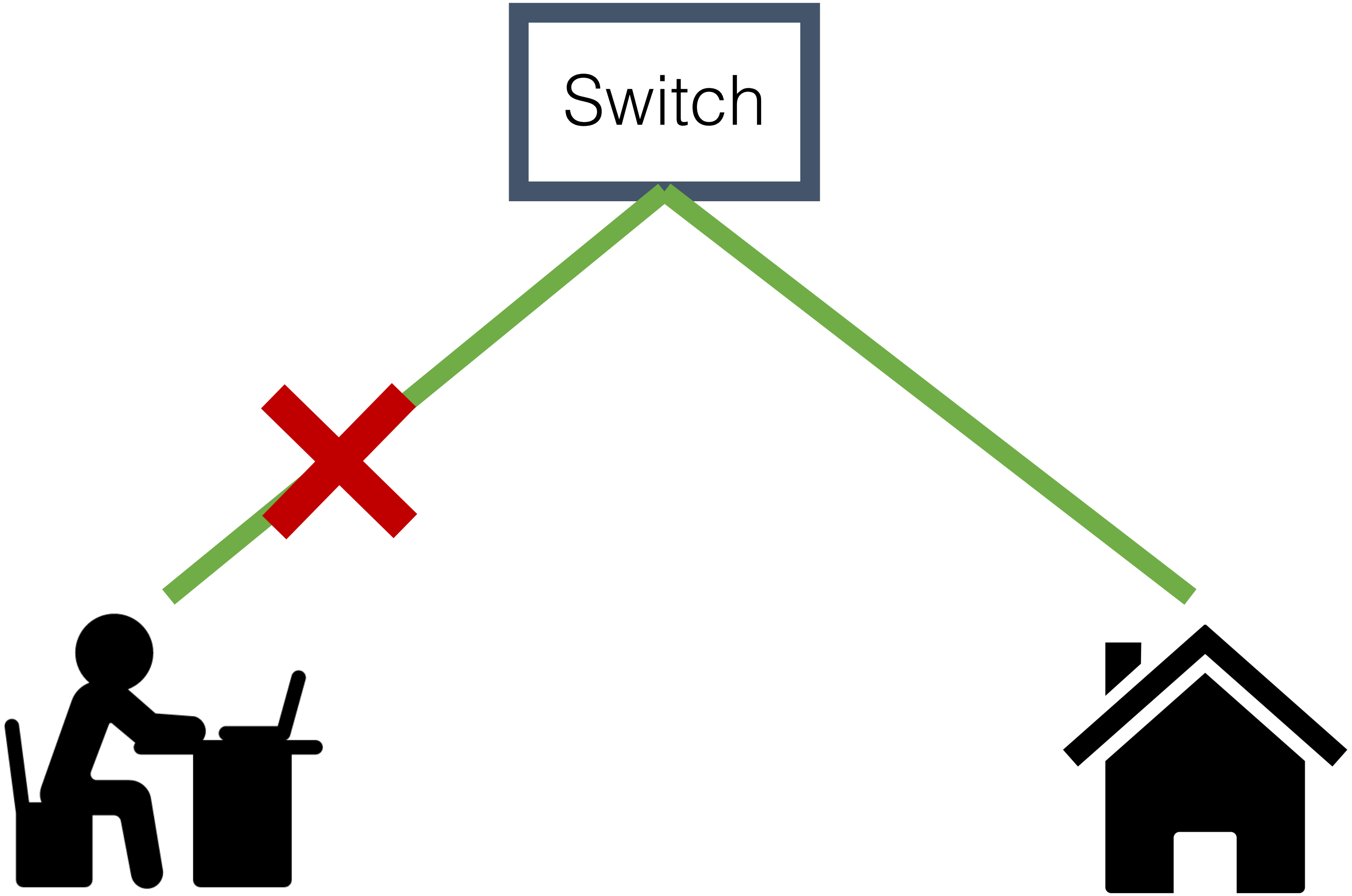
Pervasive across: technology types (10G, 40G, 100G), 20 data centers, 5 major transceiver manufacturers, 10 months

Why so much over-engineering?

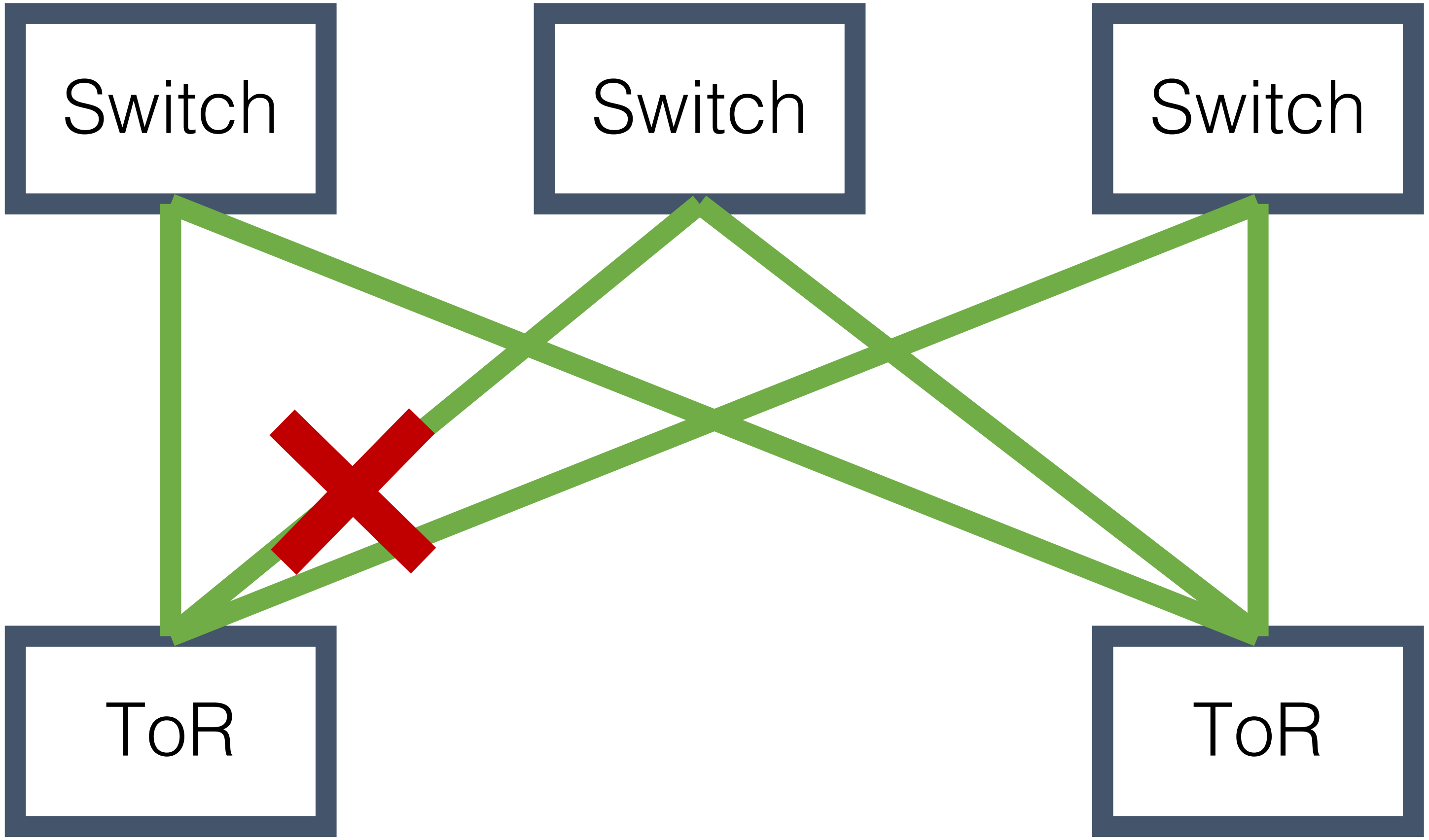
IEEE 802.3 Standards

- Ensure every link is reliable under worst-case assumption
  - Fiber quality
  - Connector loss
  - Dispersion
- Derive reach limit based on worst-case assumption

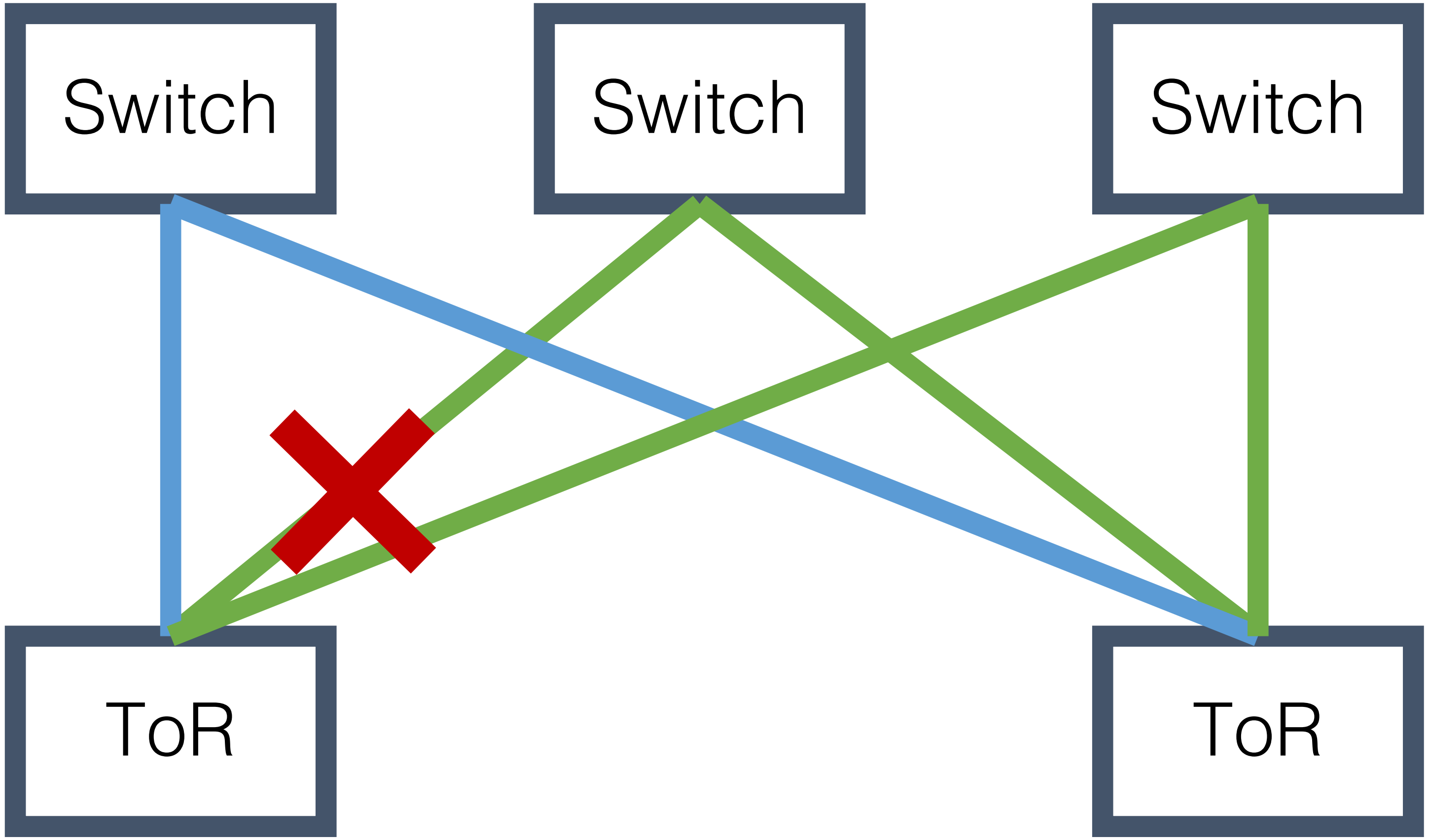
IEEE 802.3 Standards



IEEE 802.3 Standards

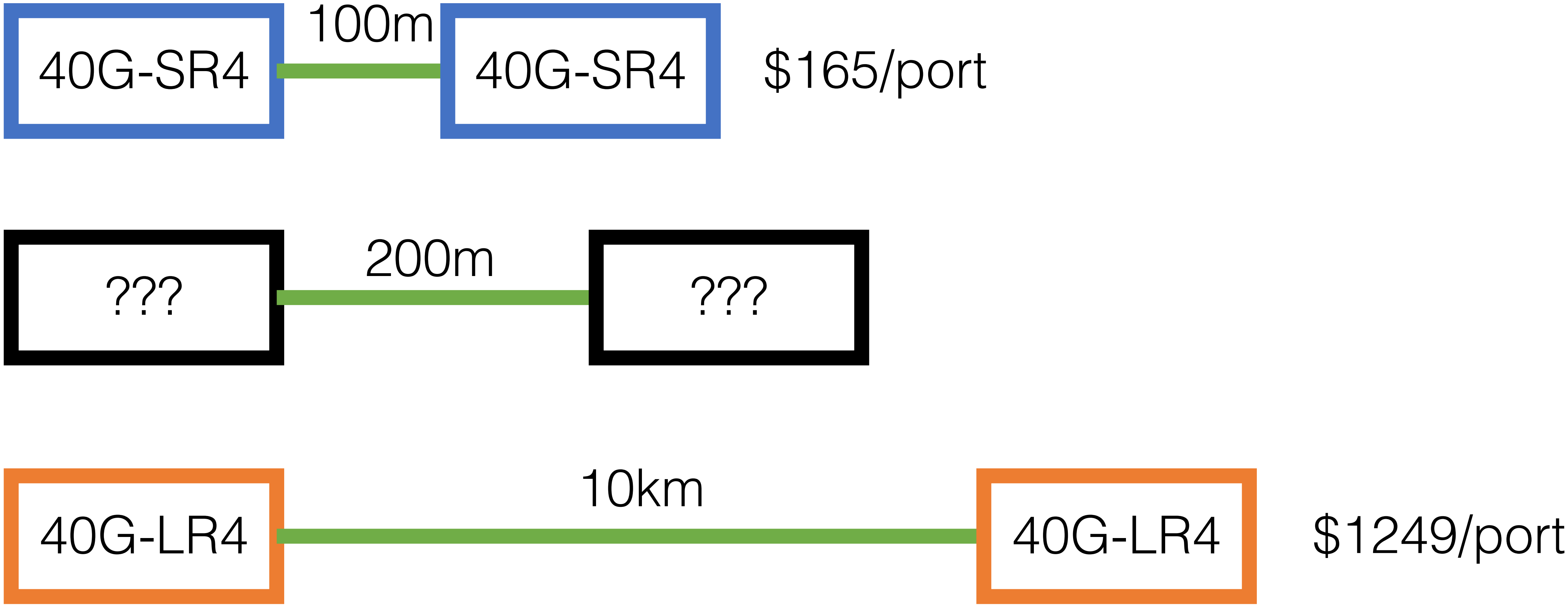


IEEE 802.3 Standards



How to reduce over-engineering?

Use Transceivers beyond Design Reach Limit

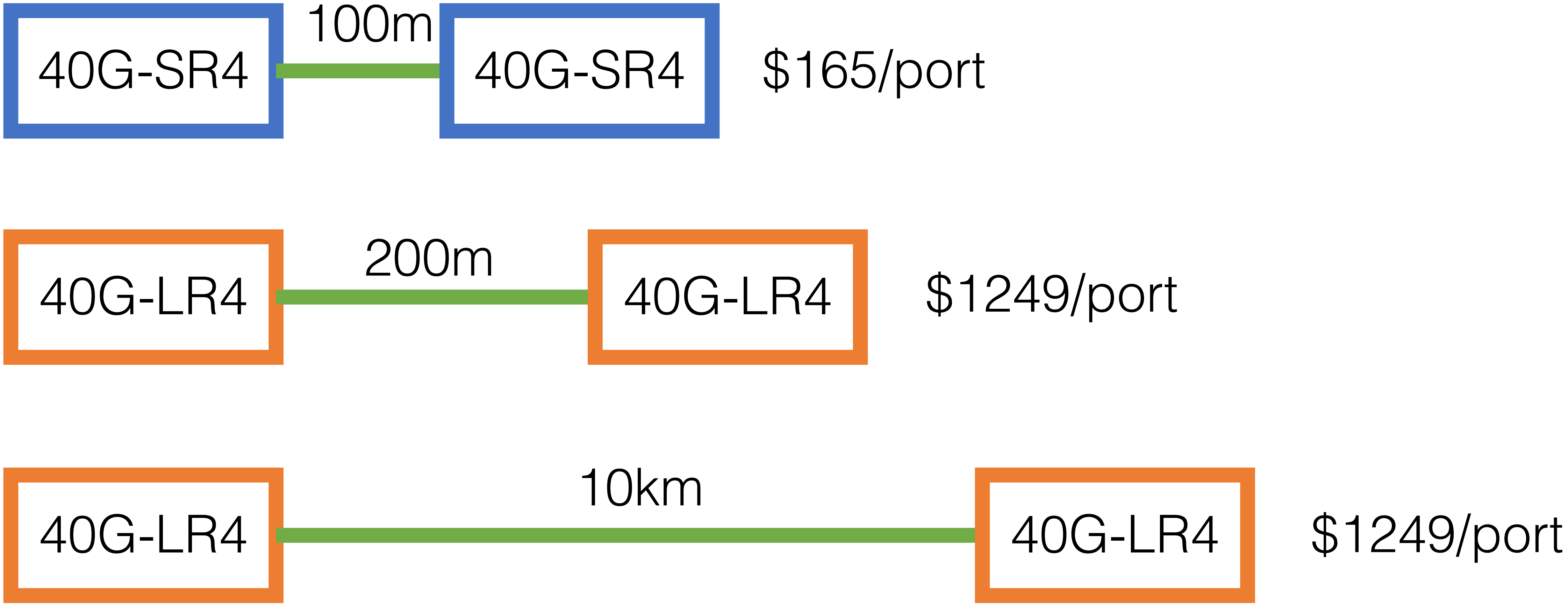


40G-SR4 100m 40G-SR4 $165/port

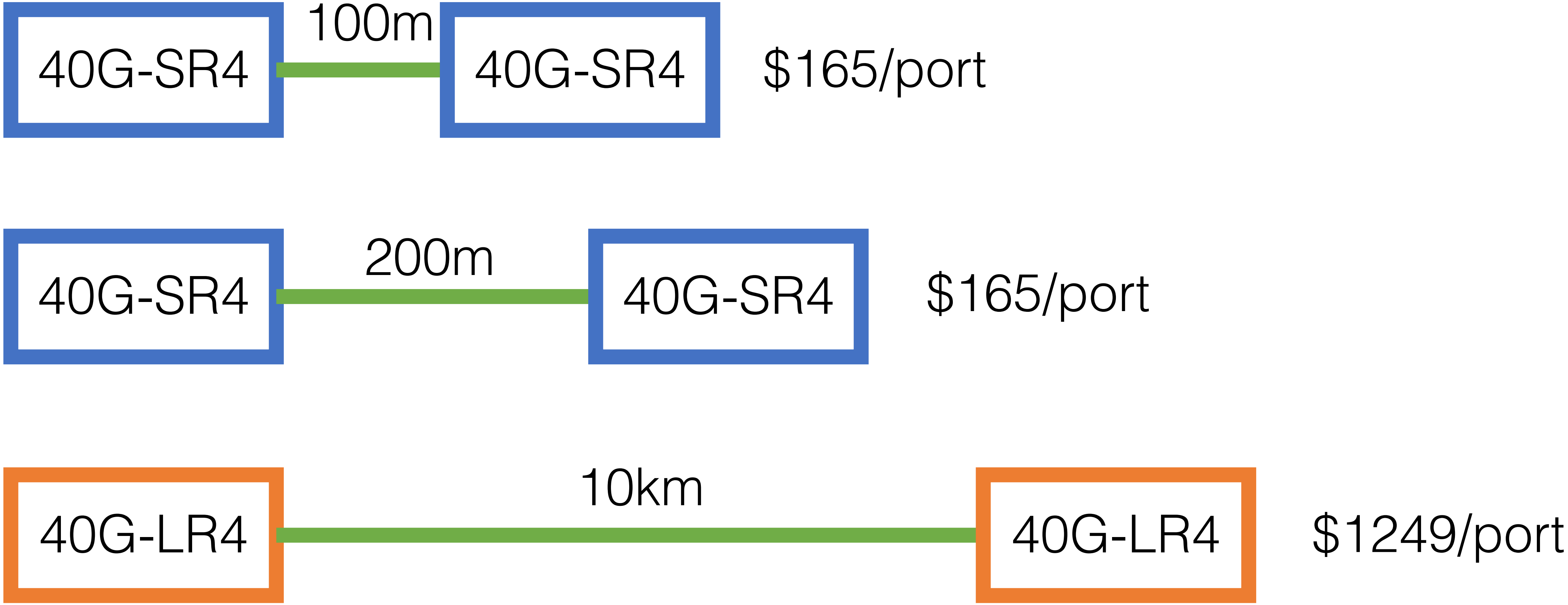
??? 200m ???

40G-LR4 10km 40G-LR4 $1249/port

Use Transceivers beyond Design Reach Limit



Use Transceivers beyond Design Reach Limit



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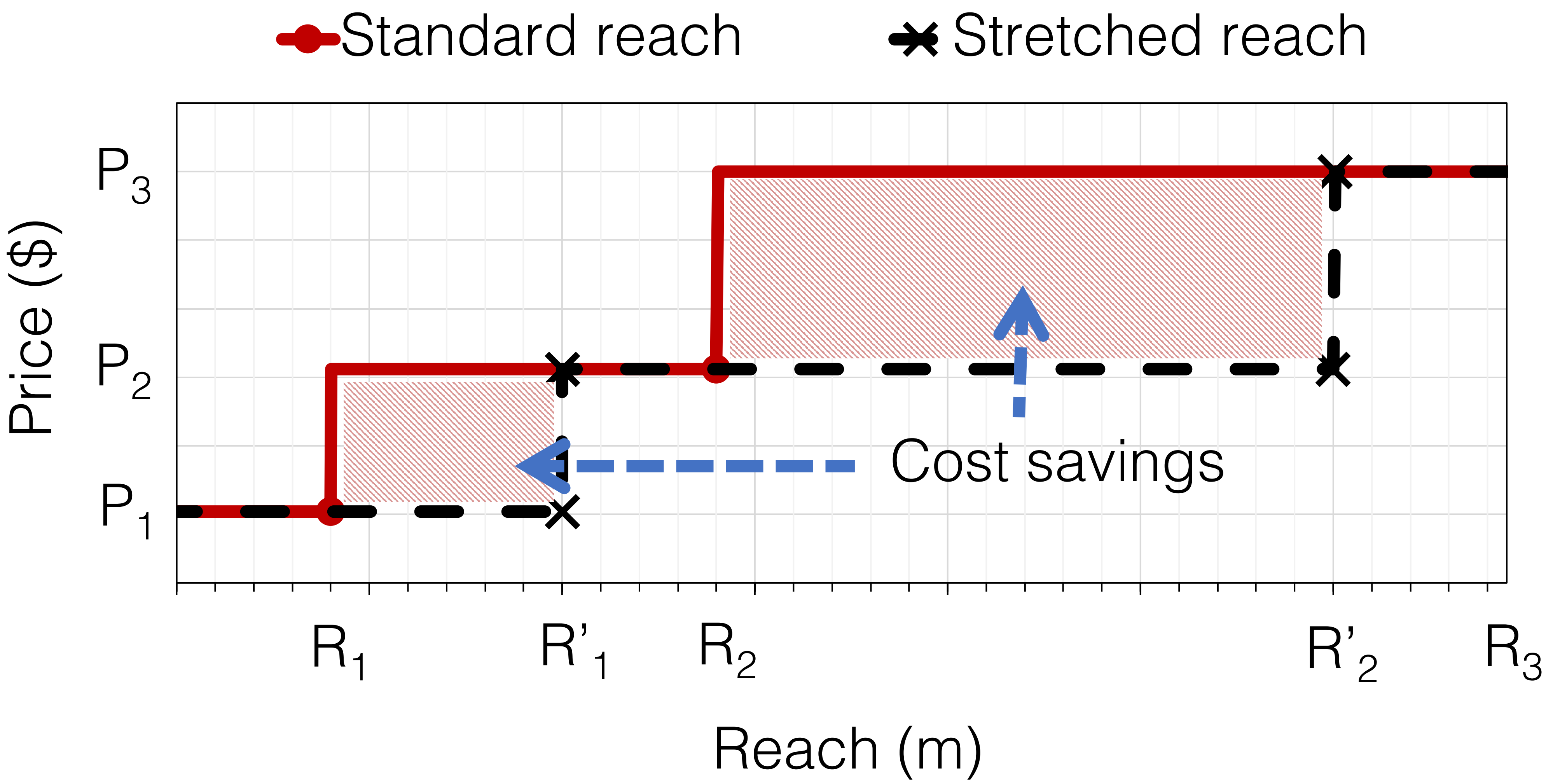
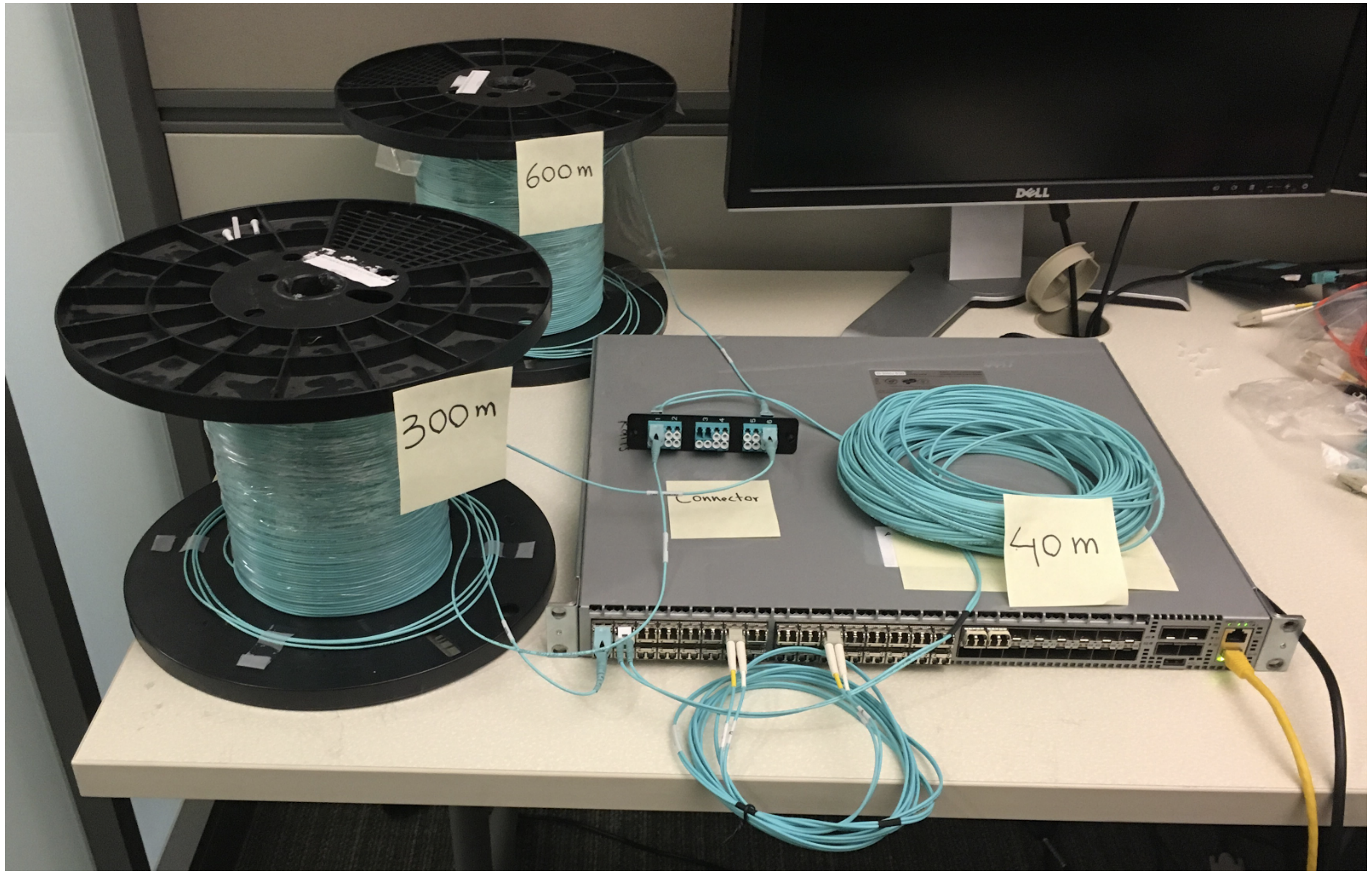
Reducing DCN Cost



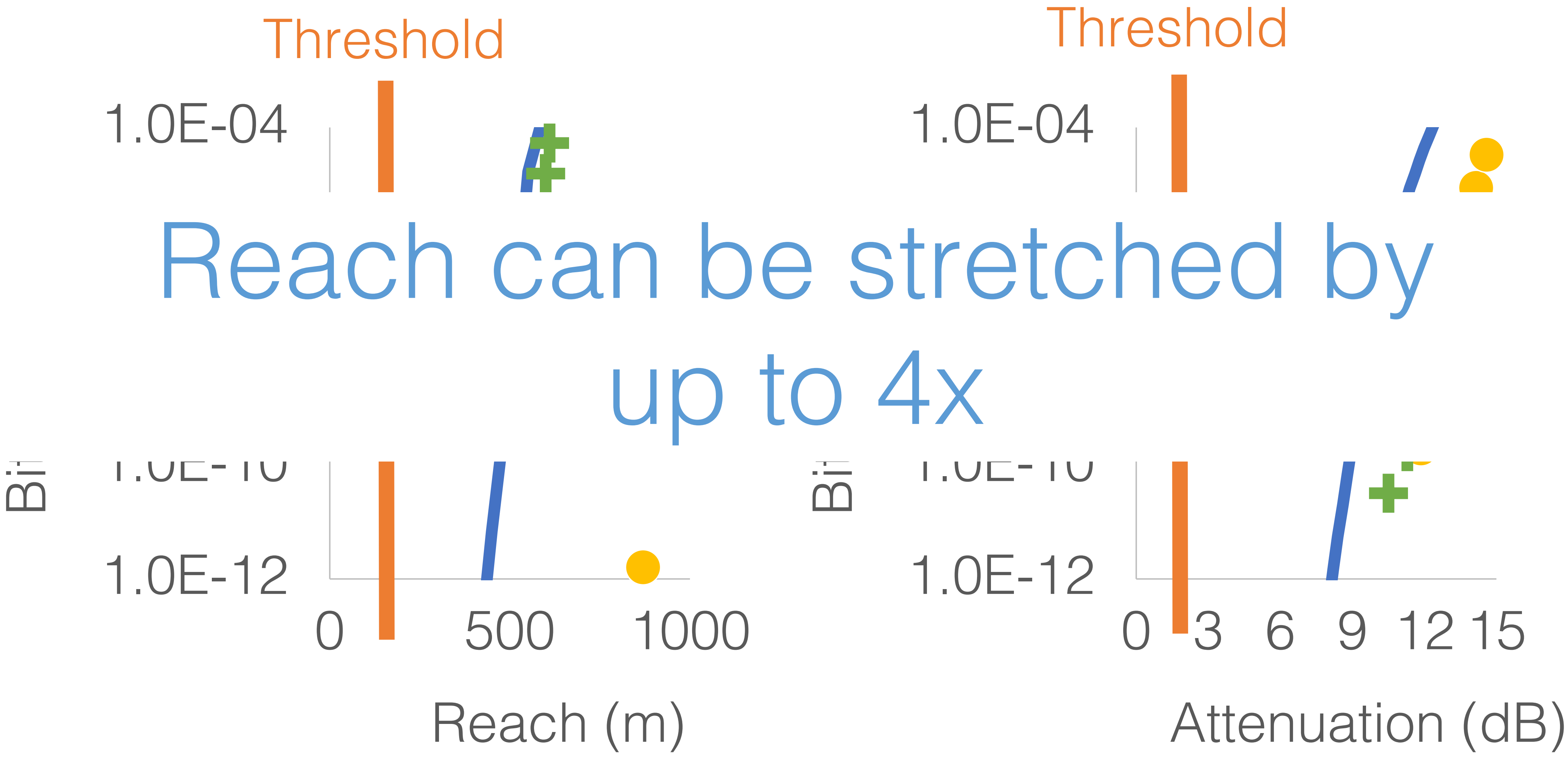
Quantifying Stretch Limit



- Concatenate short fibers to emulate a long fiber.
- Use optical attenuator to emulate dirty on optical connectors.
- Test packet error rate and convert it to bit-error rate (BER).
- Modeling effect of stretching on BER.

Quantifying Stretch Limit

40G-SR4



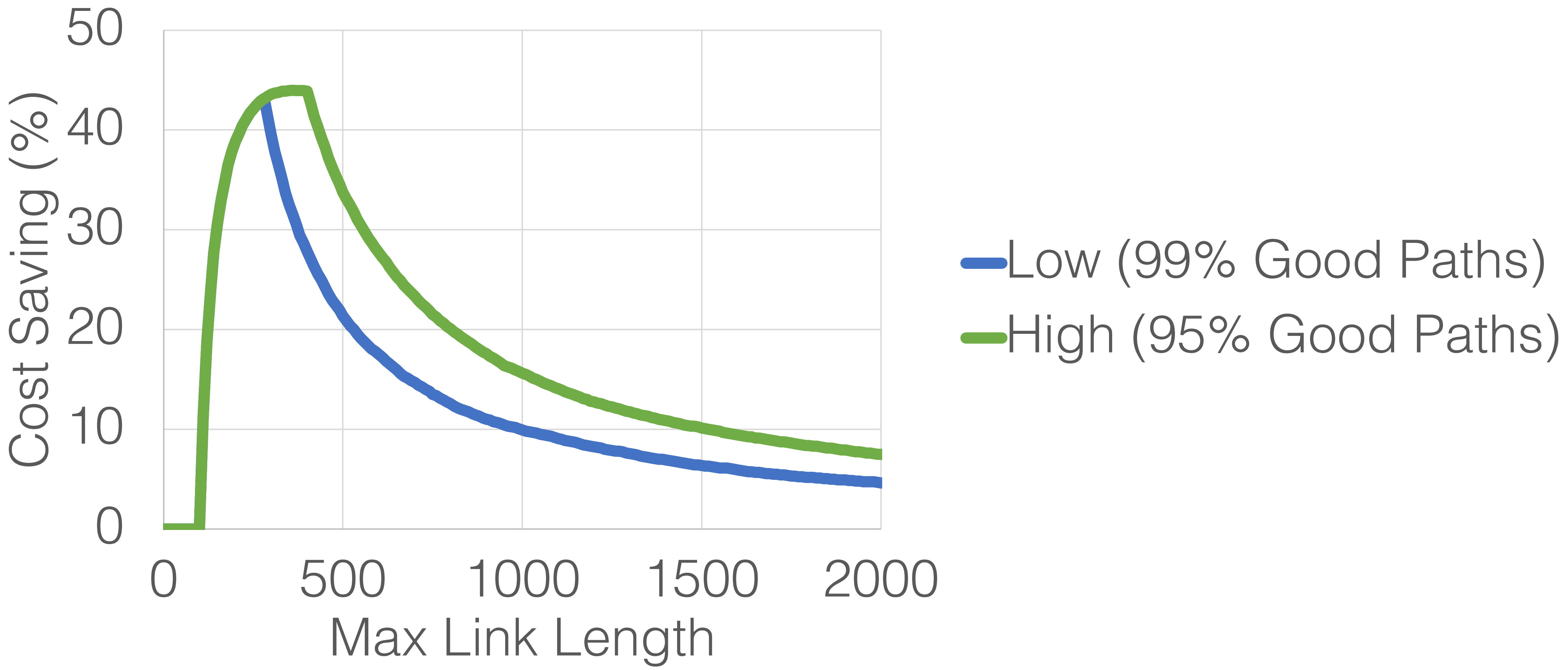
Reach can be stretched by up to 4x

Modeling Network Cost

- 3-stage Clos network (512 ToRs, 512 Aggs, 256 Cores)
- Uniform link length distribution (max length = 10m – 2 km)
    - Pick cheapest optical technology for each link ← Stretch
- Calculate the total DCN cost by summing up:
    - Fiber cost
    - Transceiver cost
    - Switch cost
    - Energy cost

Cost Saving after Stretch

100m 40G-SR4
10km 40G-LR4



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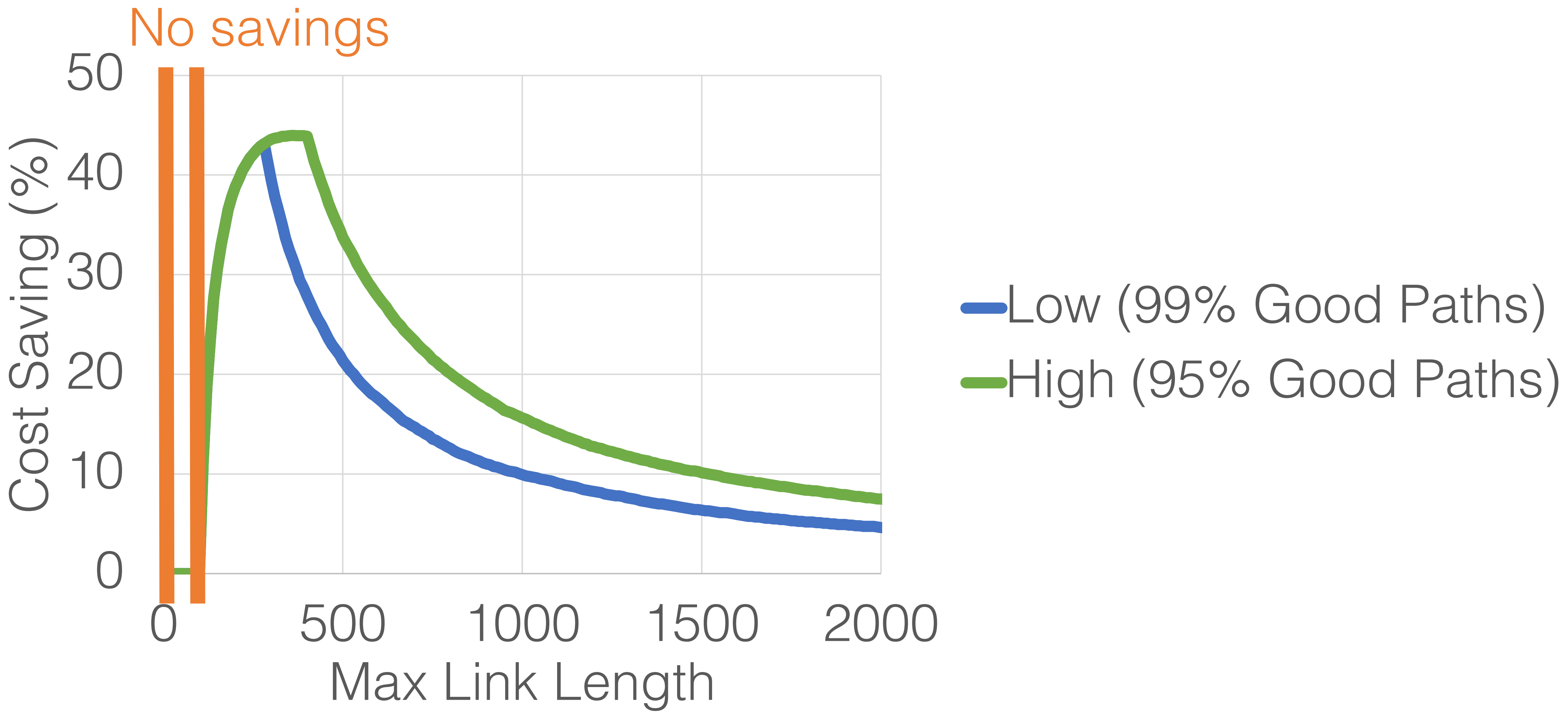

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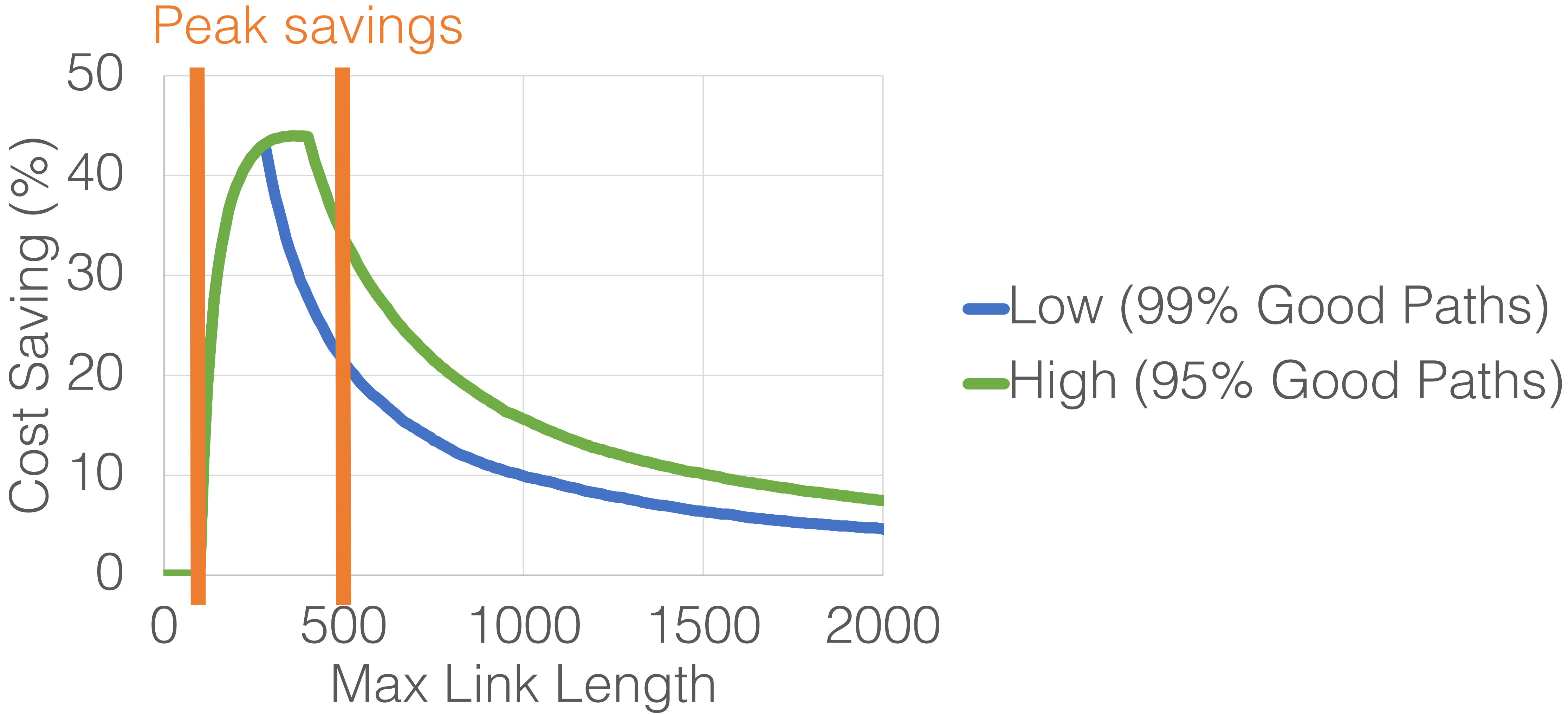

Cost Saving after Stretch

100m 40G-SR4
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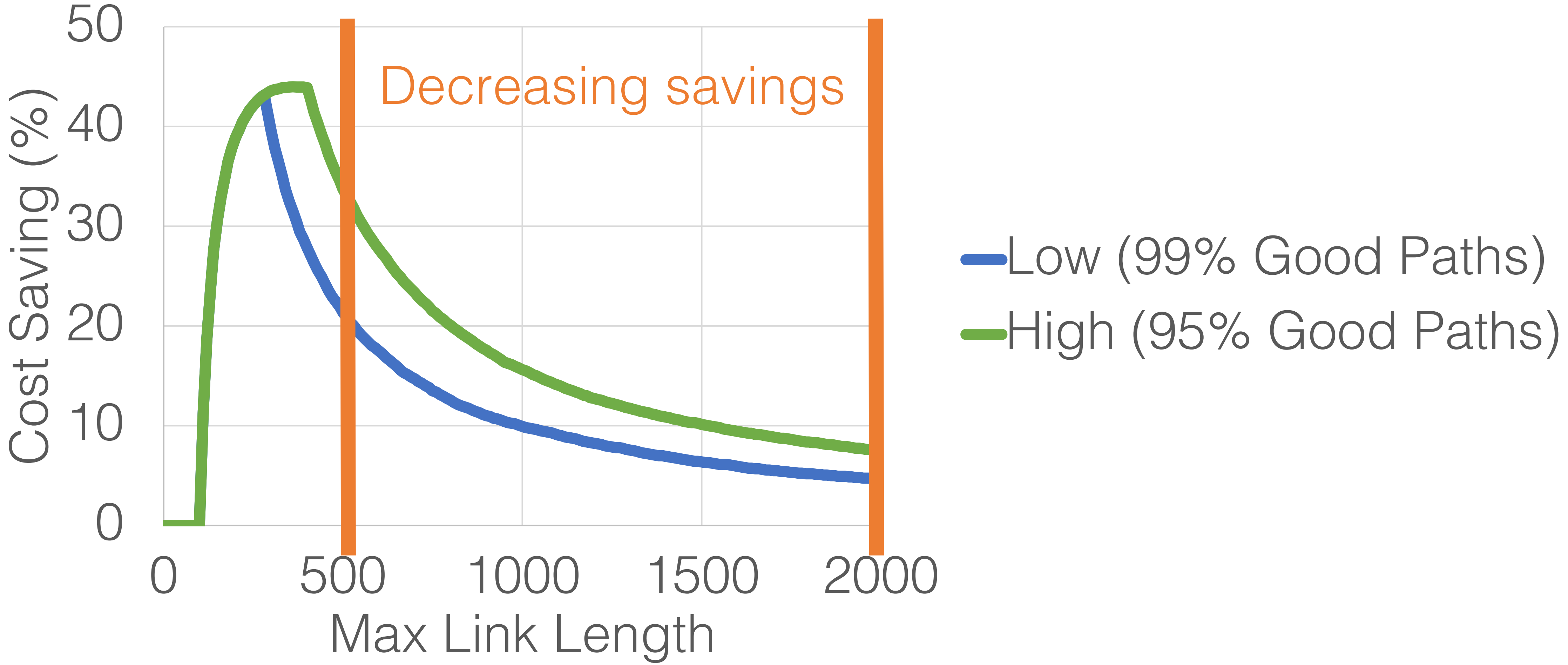
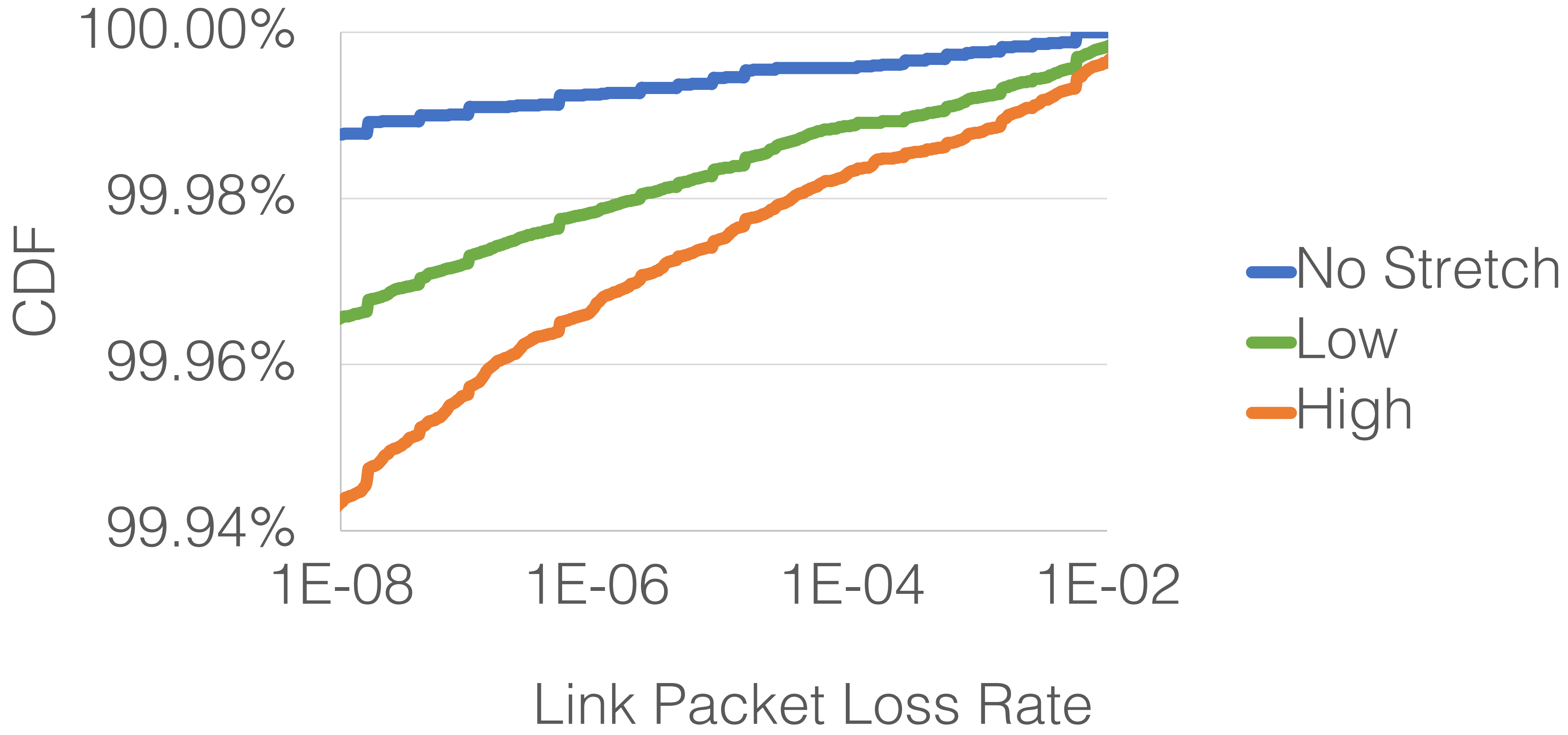


Impact on Packet Loss

0-500m, 40G



How to protect loss-sensitive applications from a small number of low loss links?

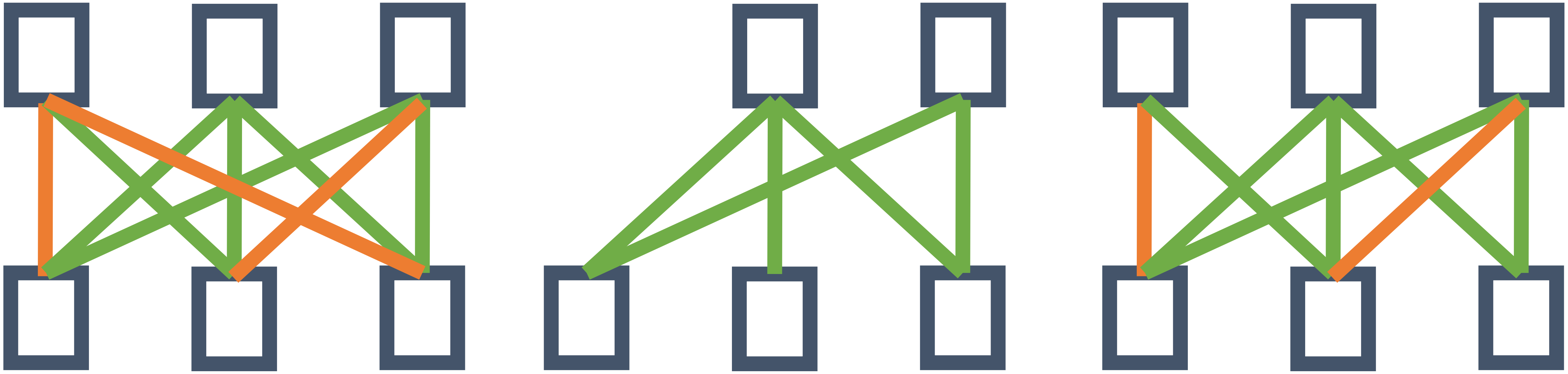
Possible Solutions

- Strawman: Source-routing
  - Source server picks a path that meets application requirement
  - Hard to scale
- Strawman: Error-correction code
  - Need to encode with per-path error rate to avoid bandwidth overhead
  - Latency of error correction for short flows

RAIL’s Approach

- Virtual Topology
    - Ensures a maximum end-to-end path packet error rate
    - Higher class virtual topology has higher loss rate
    - Applications choose virtual topology
- Error correction for higher class
    - Route with error-correction appropriate for path

Virtual Topologies



Physical Topology

0% path loss rate

0.1% path loss rate

🟩 0% link loss rate

🟧 0.1% link loss rate

Support Unmodified Applications

- Server exposes multiple virtual NICs where each virtual NIC corresponds to a path loss rate guarantee
- Applications simply choose a virtual NIC to bind
  - Flow is transparently error-encoded when traversing high loss path
  - Loss rate is queried from centralized controller

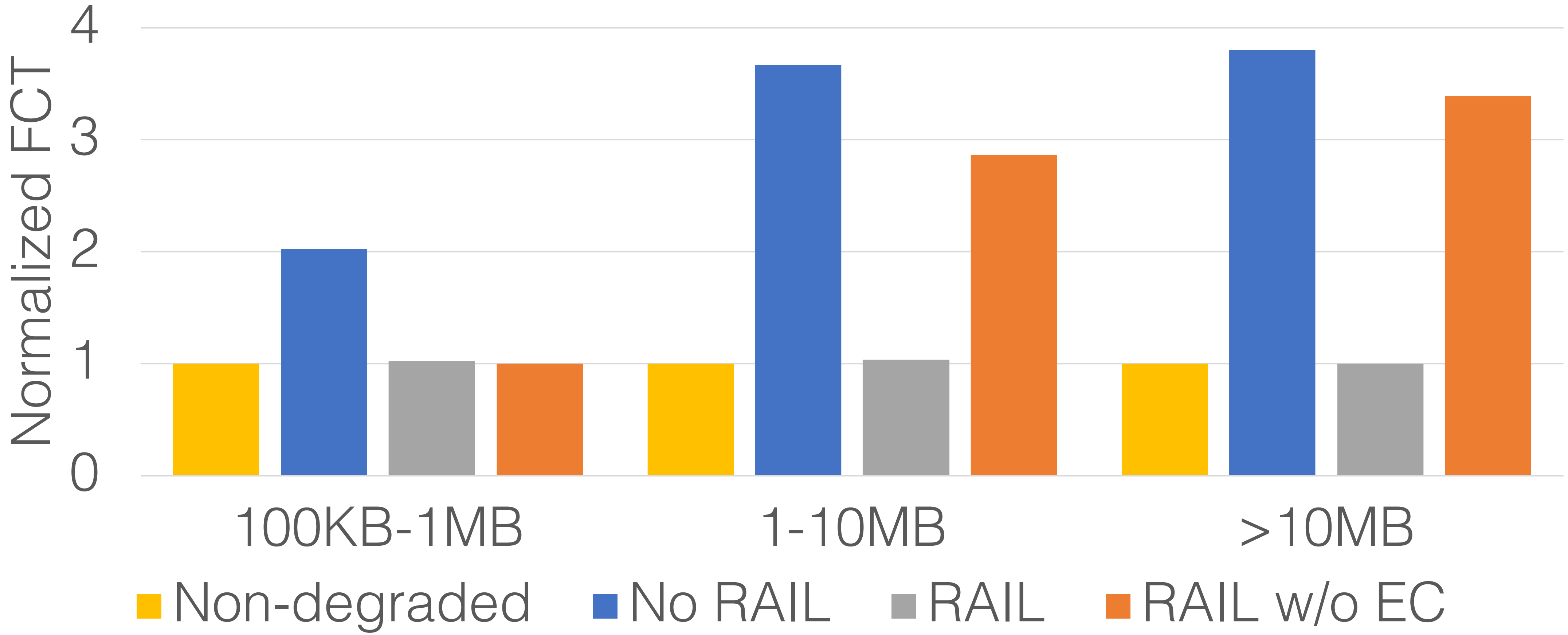
Testbed Experiments

- 3-stage Clos network (4 ToRs, 4 Aggs, 2 Cores)
  - 10G-SR optical technology
  - TCP CUBIC on Linux 3.19
- Use an optical attenuator to degrade the quality of a single link
- Two virtual topologies
  - Virtual topology #1: Without the degraded link
  - Virtual topology #2: With the degraded link

Evaluation Methodology

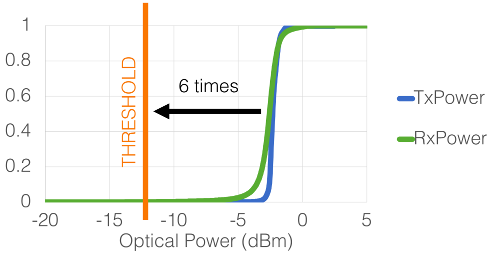
- Comparison
  - No RAIL
  - RAIL
  - RAIL w/o EC, use virtual topology #1 to protect flows less than 1MB
- Compute flow completion time normalized by performance on non-degraded network; Flow length distribution from pFabric.
  - Binned by flow sizes

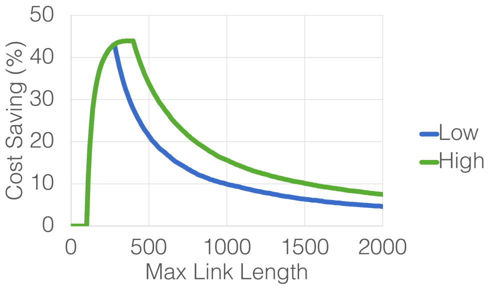
Evaluations

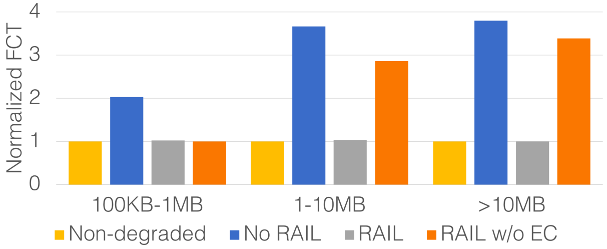


Summary

- Room for cost saving in optics used in DCN
- Reducing over-engineering
  - Stretching design reach limit for optical links can save up to 40%
- RAIL protects loss sensitive applications from packet loss due to reduction in over-engineering.


Optical Power (dBm)
THRESHOLD
6 times
TxPower
RxPower


Cost Saving (%)
Max Link Length
Low
High


Normalized FCT
100KB-1MB
1-10MB
>10MB
Non-degraded
No RAIL
RAIL
RAIL w/o EC