Optical (Long-Haul) Transport of 100 Gigabit Ethernet

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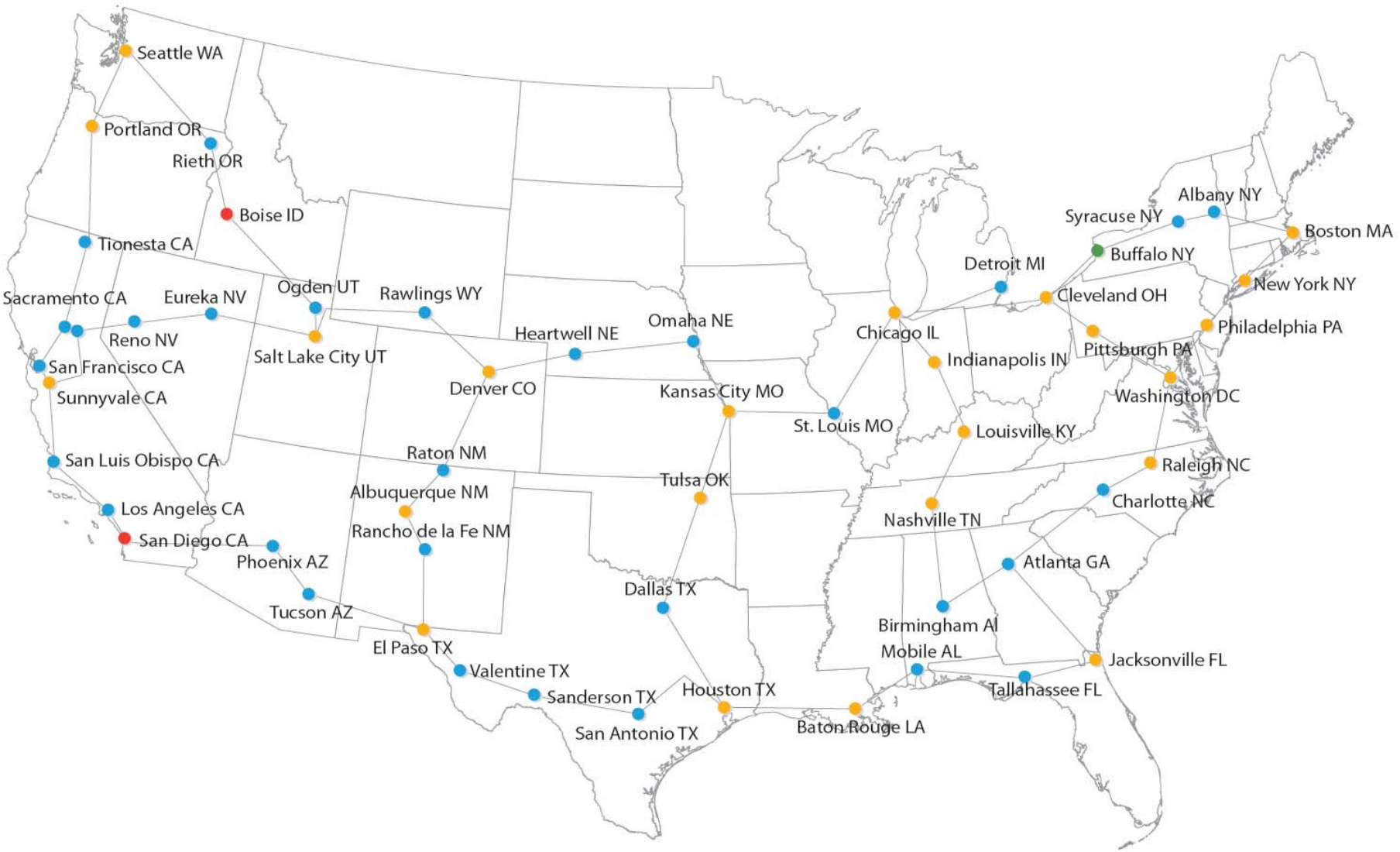
Example: The Internet2 Network



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Remote Locations with Routers that have 100 GbE Interfaces

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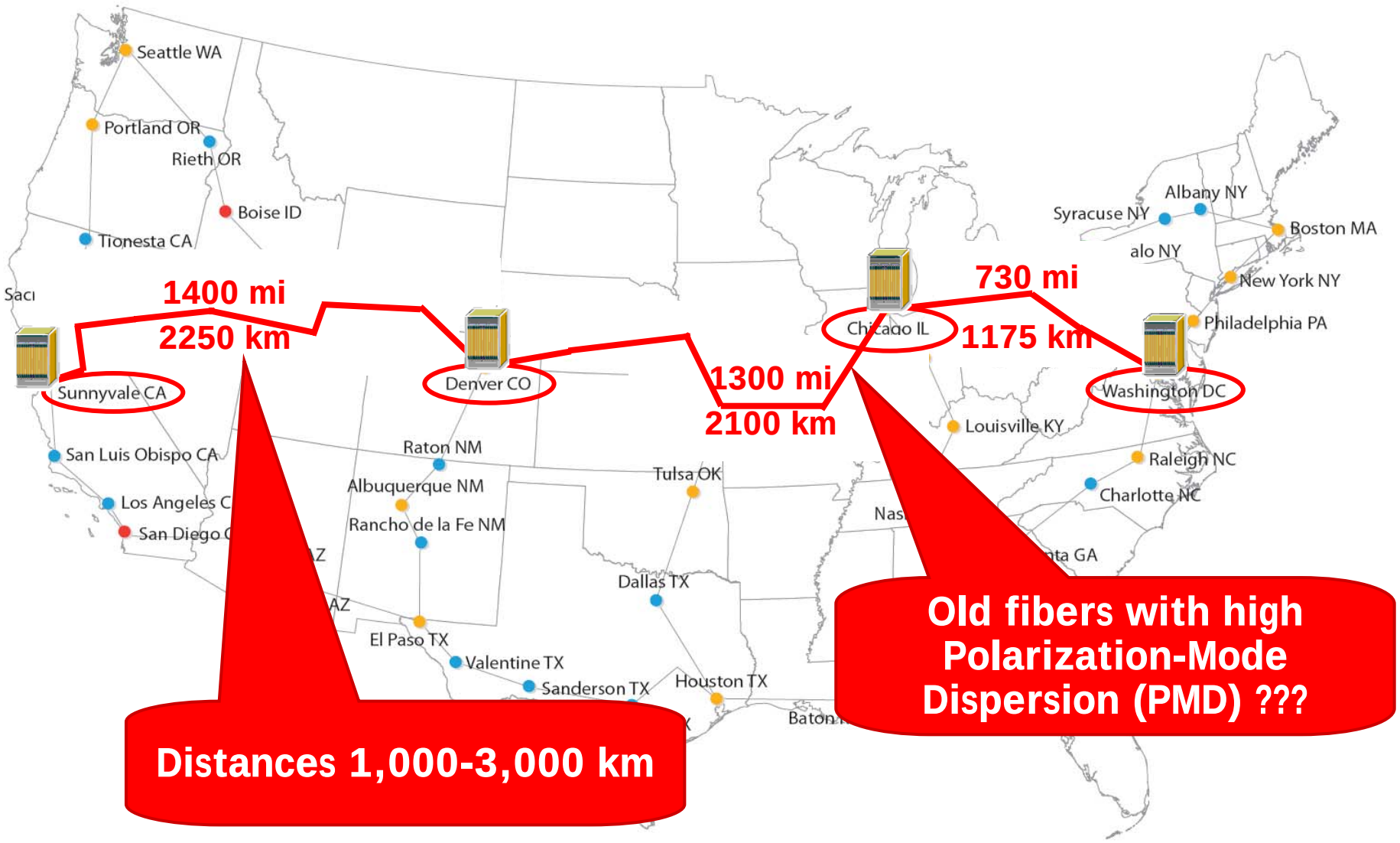
How to Transport 100 GbE between Routers ?



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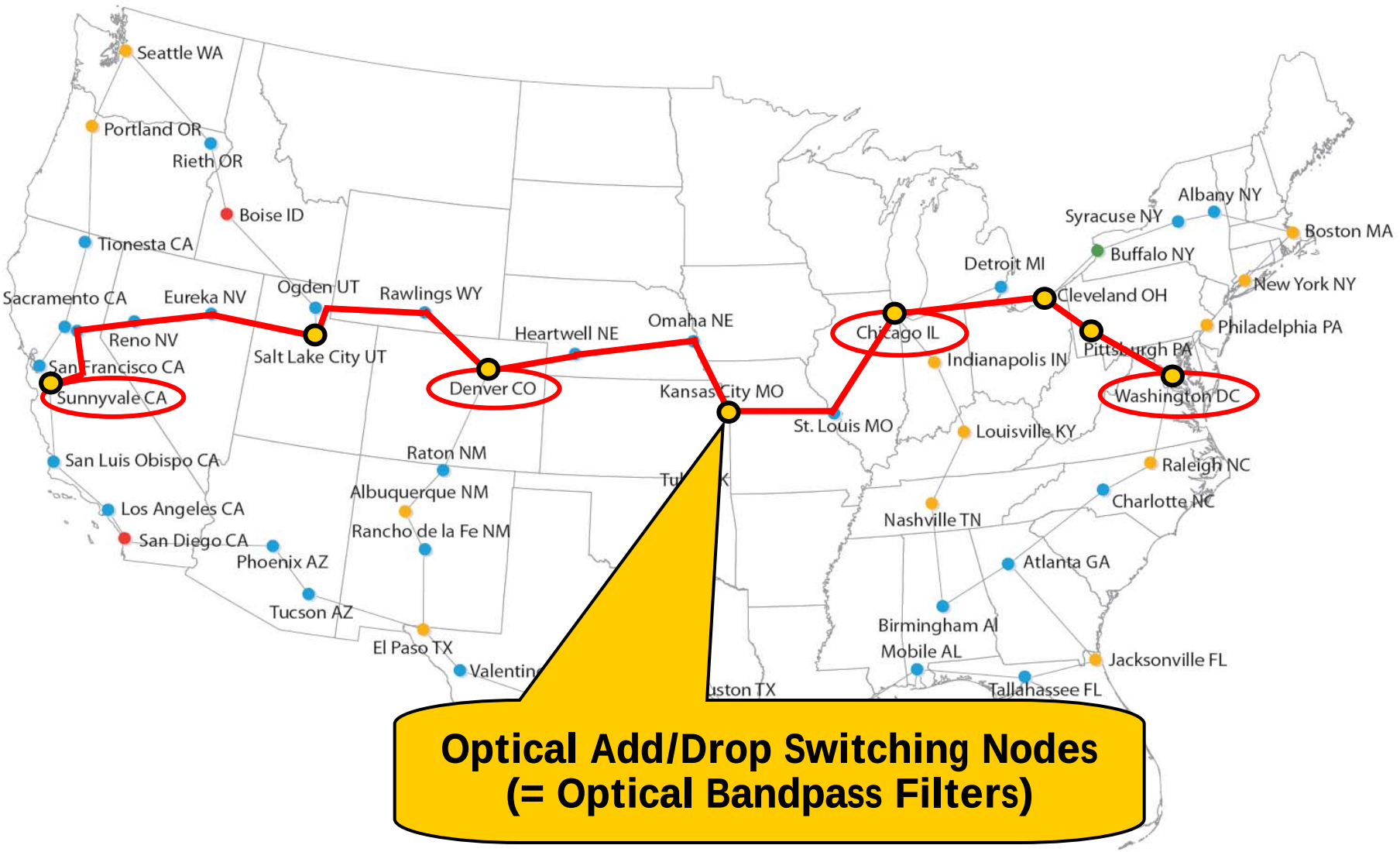

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Serial vs Parallel Transport

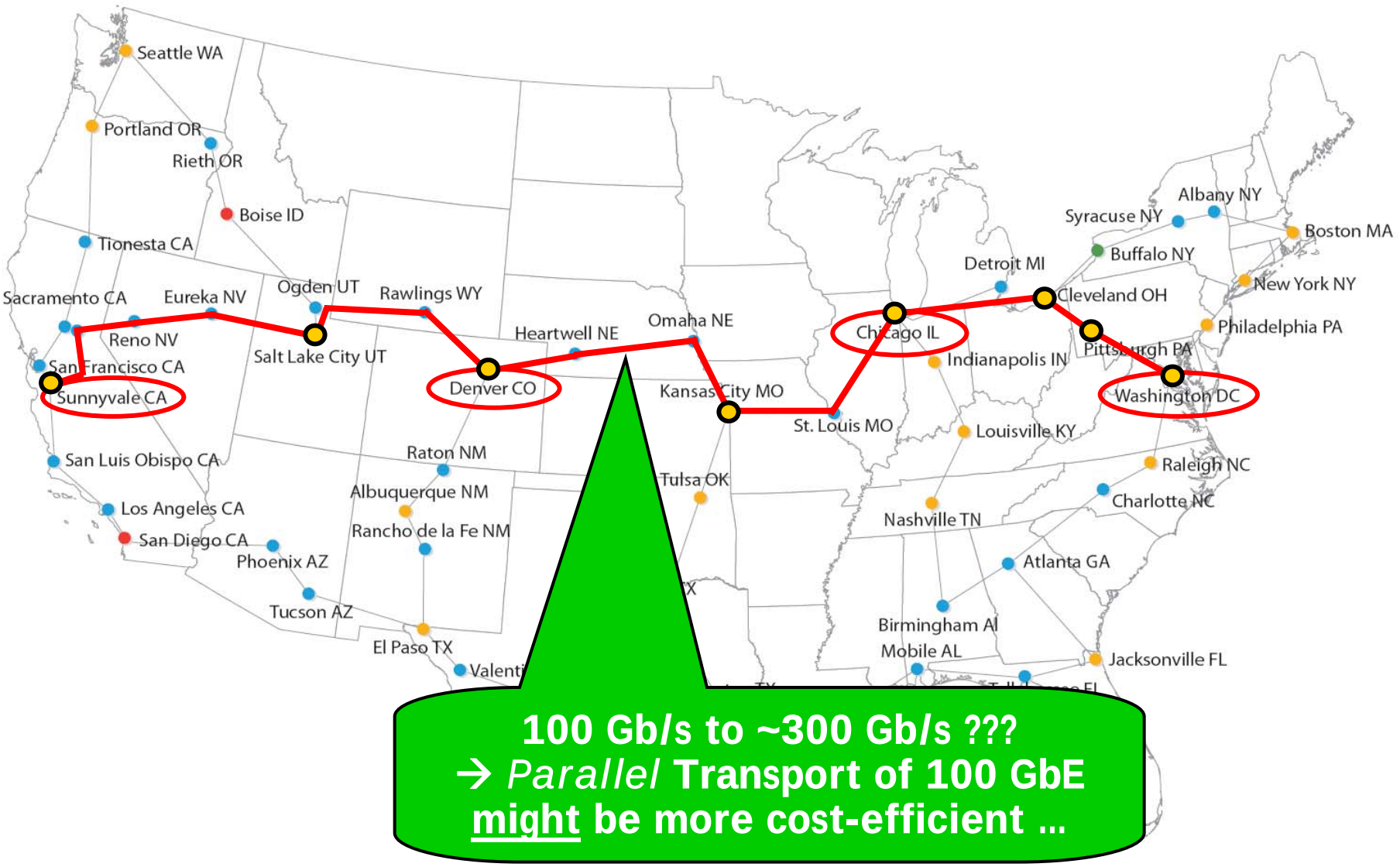
Serial PHY

- All information transported on one wavelength
- Higher spectral efficiency
- Higher total transport capacity in a WDM system, resulting in lower $$$/bit
- Complexity in high-speed transponder implementation
- Physical transmission constraints depending on symbol rate
- Could use multi-level modulation formats and/or both polarizations of light to reduce baud rate

Parallel PHY

- All information transported over multiple lanes (fibers, wavelengths, etc.)
- Lower baud rate per lane
- Fewer transmission constraints on physical layer
- Complexity in multi-lane implementation & management (e.g., Virtual Concatentation VCAT, Link Capacity Adjustment Scheme LCAS, etc.)

What is the Total Capacity per Fiber Link ?



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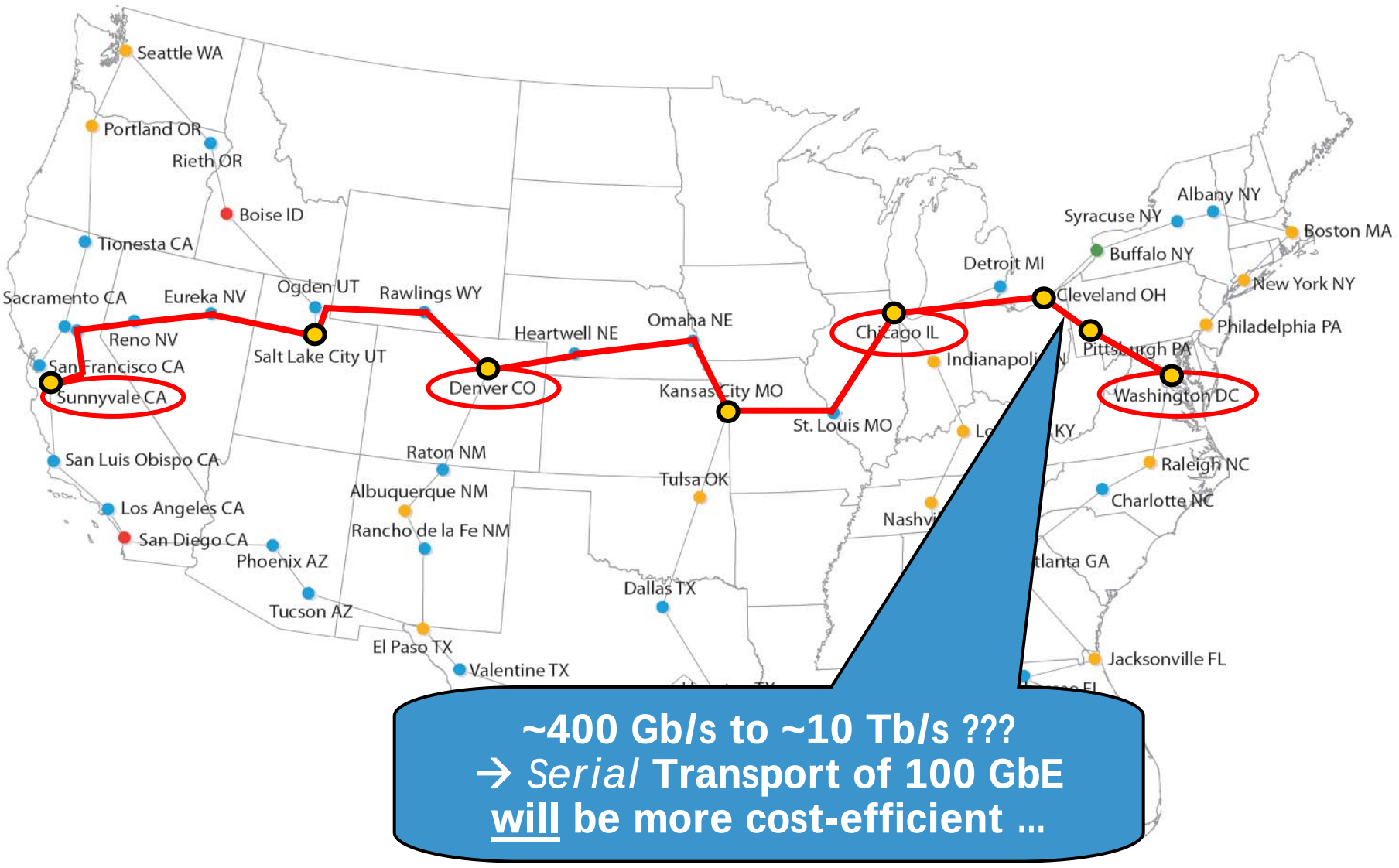

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What are the (Likely) Bit Rates ?

100 Gigabit Ethernet

- IEEE 802.3ba standard
- MAC rate = 100.000 Gb/s
- 3.125% overhead due to 64B/66B PCS encoding
- PCS-encoded line rate = 103.125 Gb/s

- Single-mode fiber PHY = parallel = 4 wavelengths @ 25.78 Gb/s
- Max. 40-km reach, single-channel fiber links, no optical amplification (OEO)

"100 Gigabit OTN"

- ITU-T G.709 standard (OTN = Optical Transport Network)
- OPU4 payload rate ~104 Gb/s
- 7% overhead due to framing and Forward Error Correction (FEC)
- OTU4 line rate ~112 Gb/s

- Single-mode fiber PHY = serial = 1 wavelength @ 112 Gb/s but at lower baud rate …
- Longer spans, multi-channel fiber links (WDM), optical amplification, etc.

What are the Promising Options for ~112 Gb/s Serial Transport ?

56 Gbaud per wavelength

- 2 bits per symbol
- Single polarization
- Advanced phase modulation format (Differential Quadrature Phase-Shift Keying, DQPSK)

- "Advanced 40G technology"
- Technology & components available today !

- Lower tolerance to chromatic dispersion, PMD, optical filtering … (similar to today's 40G systems)

28 Gbaud per wavelength

- 4 bits per symbol
- Dual polarization
- DQPSK/QPSK with polarization-multiplexing & coherent detection

- Coherent receiver main challenge, first introduction of 40G coherent Rx expected in 2008, not yet ready for 100G (very fast A/D converters & DSP with 1 Tb/s throughput required) !

- Higher tolerance to chromatic dispersion, PMD, optical filtering …

100G Hero Experiments

When	Experiment	Reach	Author
ECOC 2005	107-Gb/s binary ETDM Tx & OTDM Rx	—	Alcatel-Lucent
OFC 2006	10x107-Gb/s NRZ transmission **(0.7 b/s/Hz)**	400 km	Alcatel-Lucent
	100-Gb/s DQPSK generation	—	KDDI+NICT+Sumitomo
	100-Gb/s binary ETDM Rx	—	HHI+Siemens+Micram
ECOC 2006	100-Gb/s binary OOK ETDM Tx and ETDM Rx	—	Alcatel-Lucent
	10x107-Gb/s RZ-DQPSK transmission **(0.7 b/s/Hz)**	2,000 km	Alcatel-Lucent
	140x111-Gb/s PDM-CSRZ-DQPSK transmission **(2.0 b/s/Hz)**	160 km	NTT
OFC 2007	10x107-Gb/s NRZ-DQPSK transmission + ROADMs **(1.0 b/s/Hz)**	1,200 km	Alcatel-Lucent
	10x107-Gb/s NRZ transmission **(0.5 b/s/Hz)**	480 km	Alcatel-Lucent
	10x111-Gb/s PDM-RZ-DQPSK transmission **(2.0 b/s/Hz)**	2,375 km	CoreOptics+Siemens
	204x111-Gb/s PDM-CSRZ-DQPSK transmission **(2.0 b/s/Hz)**	240 km	NTT
	107-Gb/s O/E Rx (photodetector & electrical demux)	—	Alcatel-Lucent
ECOC 2007	80x107-Gb/s NRZ-VSB transmission **(1.0 b/s/Hz)**	510 km	Alcatel-Lucent
	8x107-Gb/s PDM-RZ-DQPSK transmission + ROADMs **(2.0 b/s/Hz)**	1,280 km	Alcatel-Lucent
	30x100-Gb/s OFDM transmission + ROADMs **(1.0 b/s/Hz)**	1,300 km	NTT

- **Spectral efficiency @ 10 Gb/s = 0.1 or 0.2 b/s/Hz**
- **Spectral efficiency @ 40 Gb/s = 0.4 (or 0.8) b/s/Hz**

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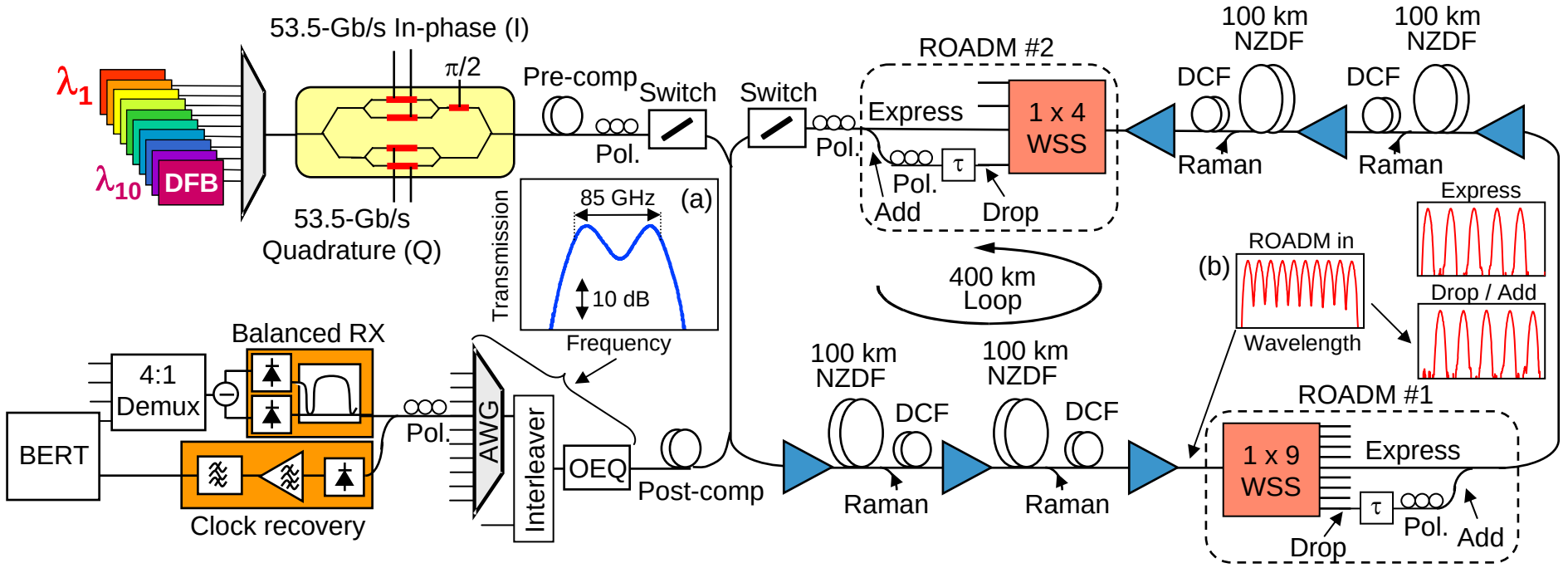
107 Gb/s NRZ-DQPSK on 100-GHz grid over 1,200 km and 6 ROADMs



- High spectral efficiency, 1 bit/s/Hz, (100-GHz channel spacing)
- No polarization multiplexing, full ETDM
- Reconfigurable optical add/drop multiplexers (ROADMs)
  - Placed every 200 km, adjacent channels dropped and re-inserted
- 1,200-km reach with six ROADMs
- 2,000-km reach without ROADMs

P.J. Winzer et al.,
OFC 2007 PD paper
ECOC 2006 PD paper

www.alcatel-lucent.com