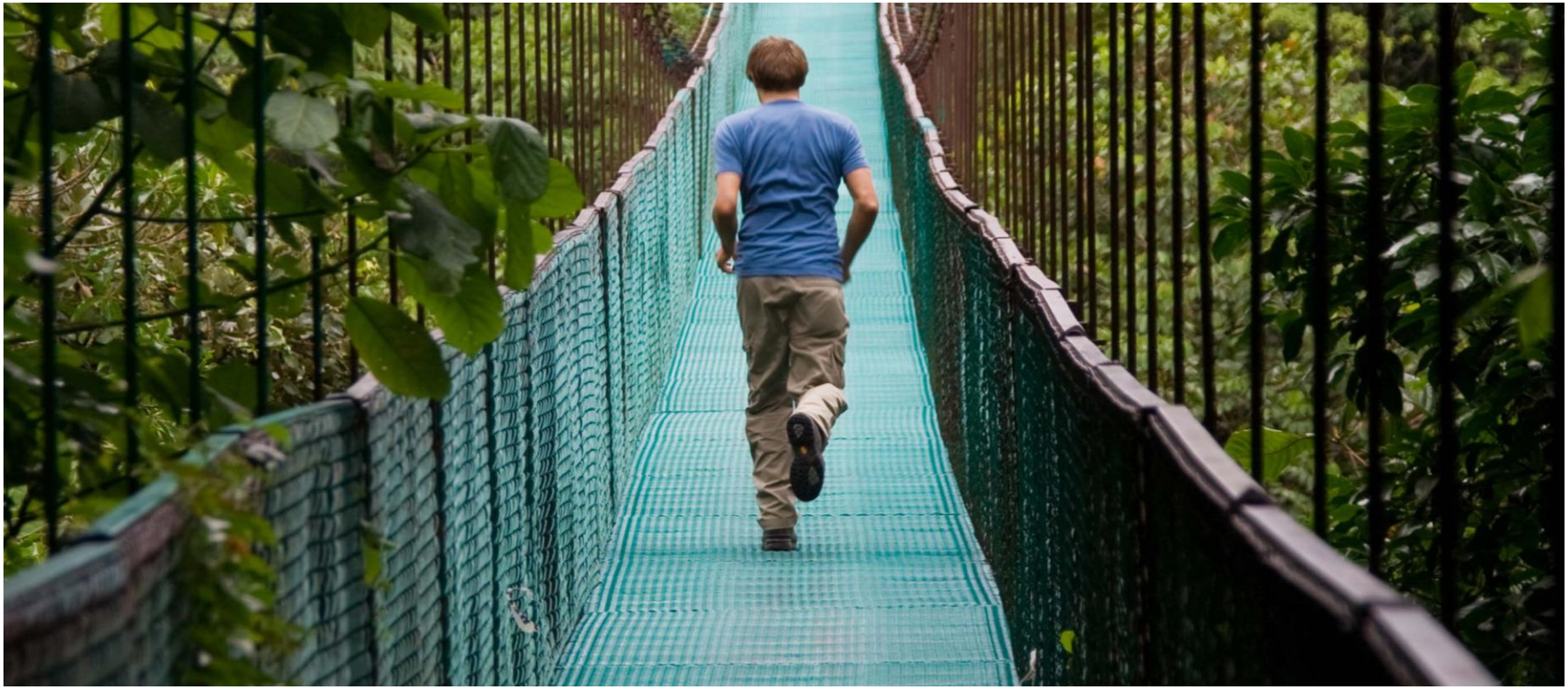

FLEXIBLE INTERFACES IN TRANSPORT NETWORKS

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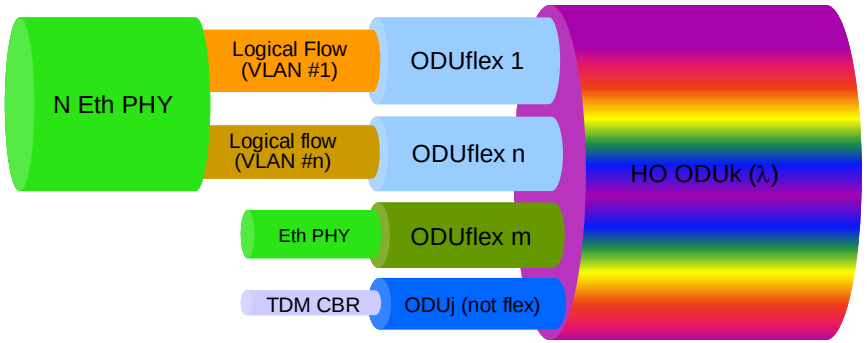
OPTICAL TRANSPORT NETWORK CHARACTERISTICS

- Tend to have large geographic scope – beyond the LAN. >>10km to worldwide, links as long as 12000km (trans-Pacific)
  - Optically Amplified Systems (often EDFA or RAMAN based) – longer reach links may be more amplifiers in the chain and not necessarily a different Tx/Rx. Signal impairment (e.g., Polarization Mode Dispersion) is more significant than attenuation.
  - Unlike client interfaces, generally NOT within the eye safety limit: different installation and maintenance practices, Automatic Laser Shutdown
  - Interoperable metro interfaces currently up to 10G (40G and 100G standardization underway). Long Haul interfaces, and today, 40G and 100G metro interfaces are SINGLE VENDOR. Modulation, amplification, dispersion accommodation, FEC, DSP algorithms are all "knobs" the vendor can work with to get a link to work.
  - Beyond certain metro interfaces, nearly everything is an engineered link.
  - Basic frame formats, client mappings are standardized so that vendors and operators can interconnect over shorter reach and client/inter-domain interfaces
- Multi-layer networking technology defined: not every network uses all of the tinker-toys in the box or does switching and grooming at every layer where switching and grooming is possible:
  - Some networks use TDM multiplexing and switching to carry multiple smaller-rate clients per wavelength
  - Some networks switch only at the optical layer (e.g., using ROADMs or other WSS)
  - Some networks don't switch at all – just point-to-point DWDM line systems

CURRENT FLEXIBLE RATE MECHANISMS IN OPTICAL TRANSPORT NETWORKS

"Sub-rate" mechanisms with OTN TDM multiplexing

VLAN or LSP depending on client technology



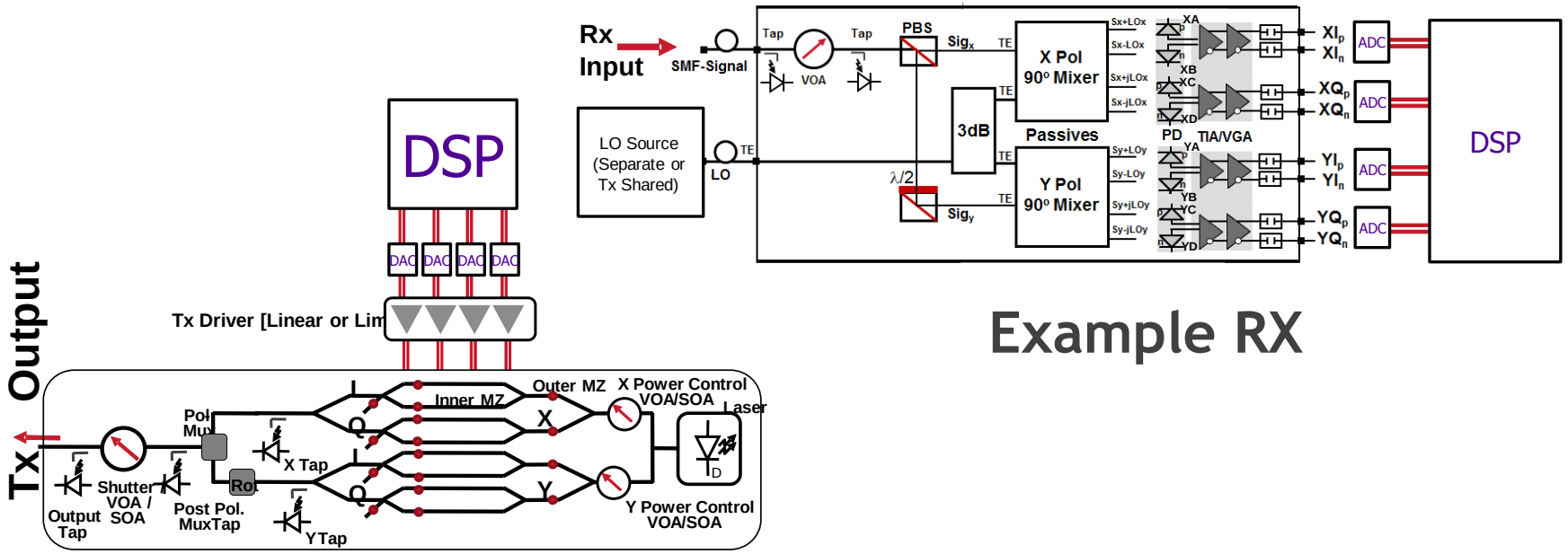
ODUflex Re-sizable in service

"Super-rate" mechanisms – Ethernet LAG (or ECMP)

- Transport network doesn't see this – LAG distributor and aggregator are in the Ethernet Endpoints
- LAG is good for large aggregates of small flows. Sub-optimal when some flows are large, and doesn't work at all with a flow that exceeds the capacity of a LAG group member

“FLEXIBLE” RATE LINE INTERFACES – WHAT’S UP WITH THAT??

- Most 40G, and virtually all 100G (and above) line interfaces use complex modulation formats (not NRZ, multiple bits per symbol)
- Many common modulations are in a family of dual-polarization coherent optical signaling which creates symbol “constellations” through polarization multiplexing, phase modulation, and (with linear drivers) amplitude. As these are DSP-driven, some hardware can produce and detect multiple different modulation formats

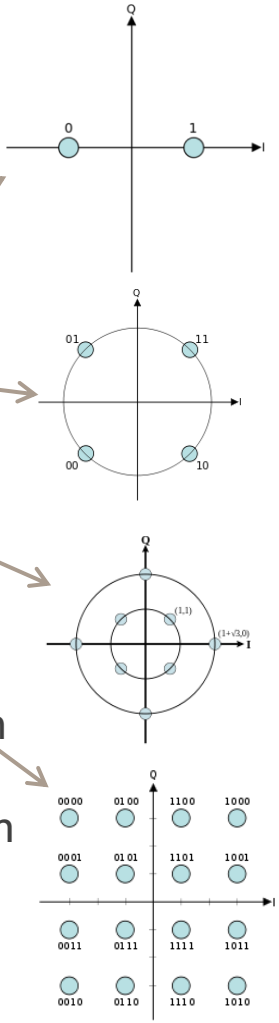


Example RX

EXAMPLE MODULATION FORMATS – PER LAMBDA

Modulation	Bits/Symbol	Baud Rate*	Bit-rate per lambda	Approximate Reach
DP-BPSK	2	25Gbaud	50 Gb/s	12000 km
DP-QPSK	4	25Gbaud	100 Gb/s	4000 km
DP-8QAM	6	25Gbaud	150 Gb/s	
DP-8QAM	6	33.3Gbaud	200 Gb/s	
DP-16QAM	8	25Gbaud	200 Gb/s	1000 km

* Not including FEC – typically 7-20% depending on reach



- The modulation format is selected during link engineering, primarily based on the reach required.
- Not “dial-a-rate”: you can’t “turn up” your San Francisco to Chicago link from 100G DP-QPSK to 200G DP-16QAM because you can’t move San Francisco and Chicago closer together!
- Digital clients don’t necessarily match lambda rate: 200G DP-16QAM might carry two OTU4 each carrying 100GbE, or one OTU4 might be carried over two sub-carriers of DP-BPSK
- Key advantage that it allows common spares for a variety of link distances: not that the rates of existing links are changing
- As these are single-vendor interfaces, the modulation formats and bit-rates supported by any given vendor may not be the same (a few rates may be common)

KEY QUESTION:

- Can flexible rates of Ethernet be used to efficiently fill the variety of lambda rates that are available in single-vendor interfaces on the line side?

THANKS!