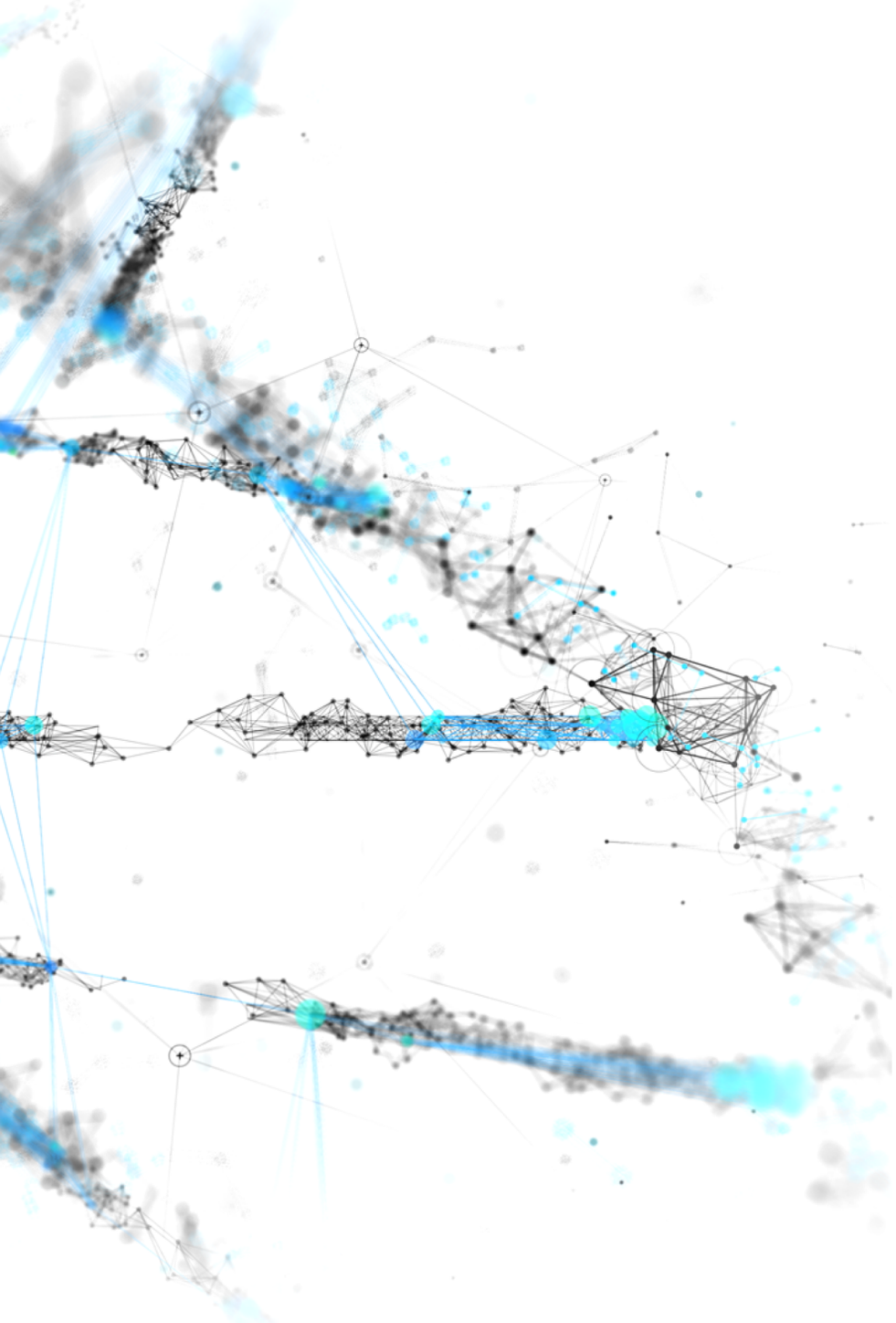

Flexible Transport Network Architectures

No Crystal Ball Needed

Chad Lamb

XKL

PACIFIC TELECOMMUNICATIONS COUNCIL

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Building a Flexible Network

- Take advantage of new technologies
- Want next-generation network today
- Green-field deployment?

- Future proofing requires deeper understanding

Talking Points

- Elements of an Optical Network
- Aggregation Techniques
- Applications
- Summary

Talking Points

- **Elements of an Optical Network**
- Aggregation Techniques
- Applications
- Summary

Elements of an Optical Network

- DWDM Transceivers
  - 10G OOK
  - 100G DP-QPSK
  - 200G 16QAM
  - 400G 64QAM
- Optical Amplification
  - EDFA – Erbium Doped Fiber Amp
  - Raman
  - SOA – Semiconductor Optical Amp
  - ROPA – Remote Optical Pumping Amp
- Optical Filters
  - Channel Filters
  - Dispersion Compensators
  - ROADMs
- Optical Fiber Types
  - SMF28 (G.652)
  - LEAF (G.655)

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Elements – DWDM Transceivers

- 10G Solutions use OOK (On/Off Keying)
- 100G/200G/400G Solutions use Coherent DP-QPSK/16QAM/64QAM

- Forward Error Correction (FEC)
- FEC increases power, cooling, and latency
- All 100G+ line-side modulation approaches leverage FEC

Elements – DWDM Transceivers

- Modulation Techniques
  - OOK, PSK, QAM, OFDM
  - Probabilistic
  - Flexible
- Baud Rates/Symbol Rates
- Sampling Rates
- Spectral Efficiency

Elements – Spectral Efficiency

- Maximize (bits/sec)/Hertz
- Problems trying to improve Spectral Efficiency (SE)
  - If you have 10G (OOK), adding 100G/200G Coherent can be a problem
    - Need guard band between OOK signal and Coherent signal
    - Wastes spectrum
  - Filters narrow a channel's bandwidth
    - Limits adoption of next generation devices
  - Increased cost, must find a good balance
  - Reach/Distance inversely proportional to SE

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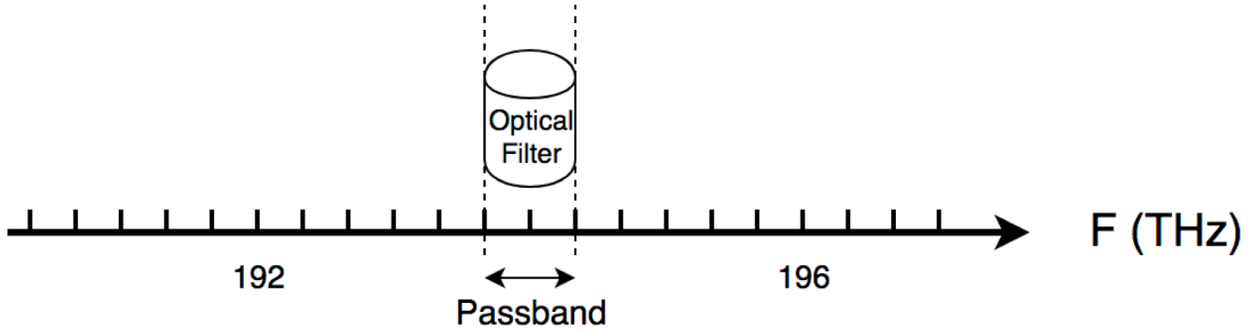
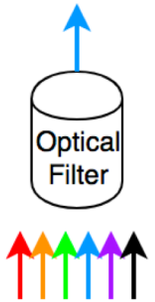
Elements – Optical Filters





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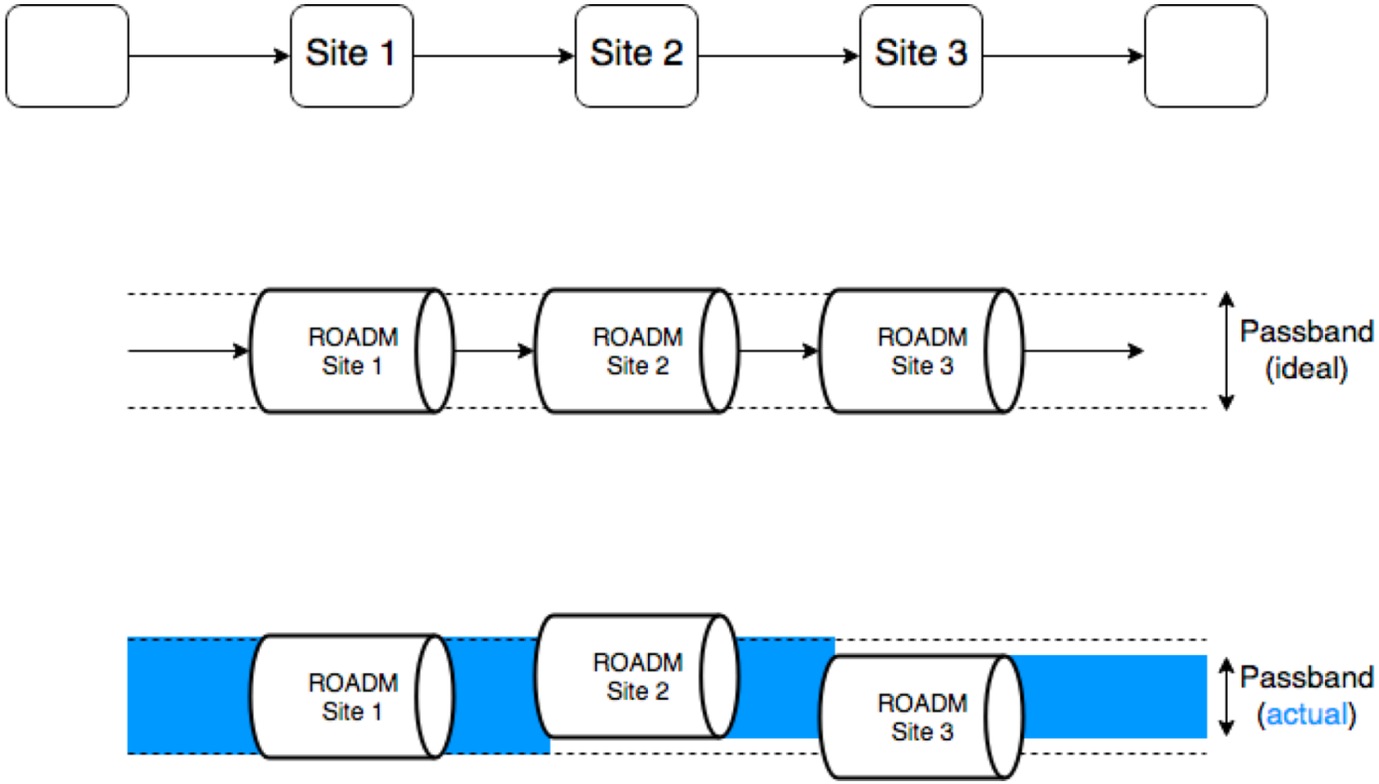

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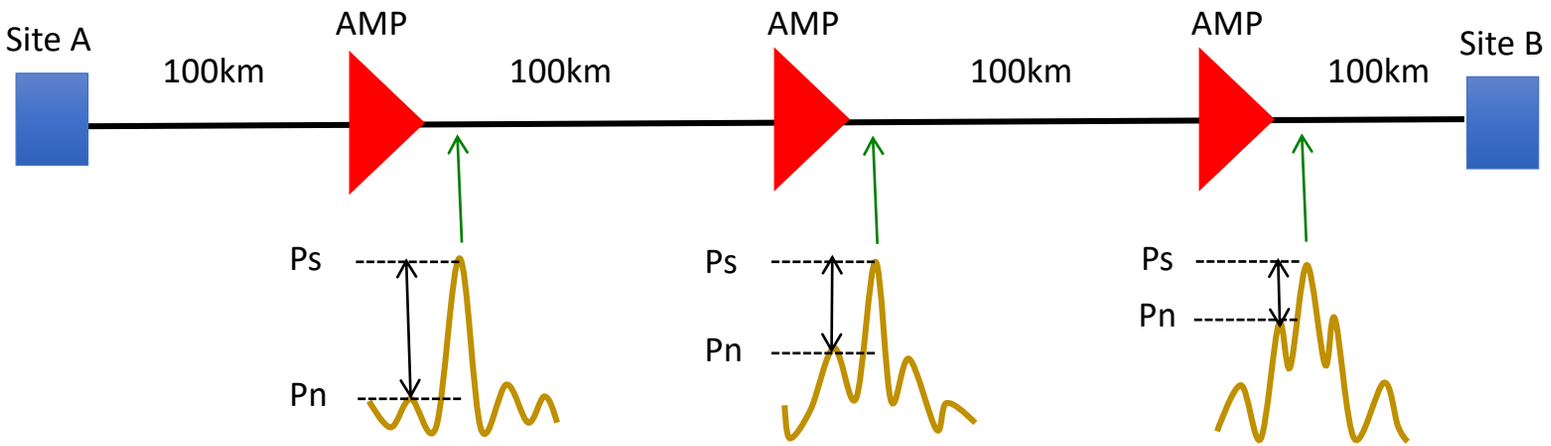
Elements – Optical Amplifiers

- EDFA – Erbium-Doped Fiber Amplifier
  - Most common, cost effective
  - Supports C Band spectrum
  - Devices exists for L Band: more expensive, higher noise
  - C+L Band solutions existing, 4-wave mixing problems, much more complicated

  - Ideal noise figure is 3dB. Good EDFAs have 4.5dB noise figure

Elements – Optical Amplifiers



OSNR = Ps / Pn

Ps = Signal Power
Pn = Noise Power

The noise power increases with each added amplifier stage, decreasing the OSNR.
If the OSNR gets too low, then the signal is not recoverable once it get to Site B.

Elements – Optical Amplifiers

- Raman Amplifier
  - Much less gain than EDFA, more expensive
  - Supports more spectrum than EDFAs
  - Lower noise contribution than EDFAs
  - Used when the limits of EDFAs have been reached

Elements – Optical Amplifiers

- SOA – Semiconductor Optical Amplifier
  - Less gain and output power than EDFA
  - Higher noise contribution than EDFAs
  - Smaller than EDFA
  - 4-wave mixing problems

Elements – Optical Amplifiers

- ROPA– Remote Optical Pumping Amplifier
  - Requires doped fiber 100km away from Amplifier
  - Less gain and output power than EDFA
  - Higher noise contribution than EDFAs
  - Used when EDFA + Raman is not enough

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Elements – Fiber Type

- Insertion Loss (IL) is key, reduces the number of amp stages
- Fewer Amps:
  - Reduces CapEx, OpEx
  - Increases OSNR, data rates, performance

Fiber Type	SMF28 ULL	Leaf
IL (dB/km)	0.17	0.22
Total IL for 500km Link (dB)	85	110
Number of Amp Stages	4	5

Talking Points

- Elements of an Optical Network
- **Aggregation Techniques**
- Applications
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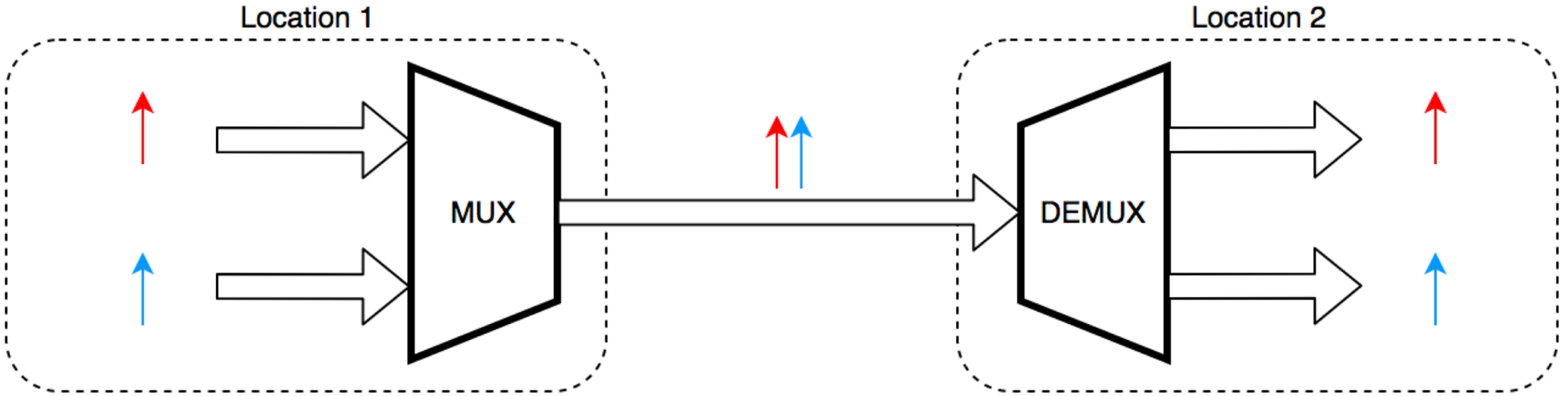
Aggregation Techniques - WDM

- C/DWDM – Course/Dense Wave Division Multiplex



Aggregation Techniques - DWDM

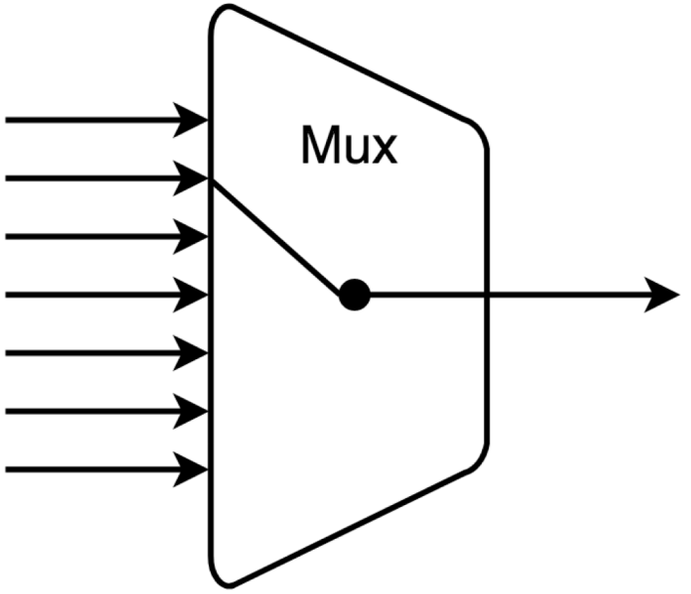
- Optical Power:
  - Power per channel is limited
  - Total power (sum of all channels) is limited
- Example of 96 channel DWDM solution:
  - Max Power/ch = 8dBm (try to increase OSNR by launching as high as possible)
  - 96 channels x 8dBm/ch = 28dBm
  - Need EDFAs that can provide 28dBm – not available!

Aggregation Techniques

- 1-to-1, i.e., no aggregation
  - 100G/200G router port -to- 100G/200G DWDM port
- Many-to-1
  - Nx10GE router ports -to- 1x100G DWDM Port
  - Mixed services -to- 1x100G DWDM Port
  - IP over DWDM
  - OTN – Optical Transport Network
- Services:
  - Ethernet: 1GE, 10GE, 25GE, 40GE, 50GE, 100GE, 200GE, 400GE, 1TE
  - Sonet: OC-48, OC-192, OC-768, OC-1920, OC-3840
  - Fiber Channel: 1G, 2G, 4G, 8G, 16G, 32G, 64G, 128G, 256G
  - Video

Aggregation Techniques

- TDM – Time Division Multiplexing



Aggregation Techniques

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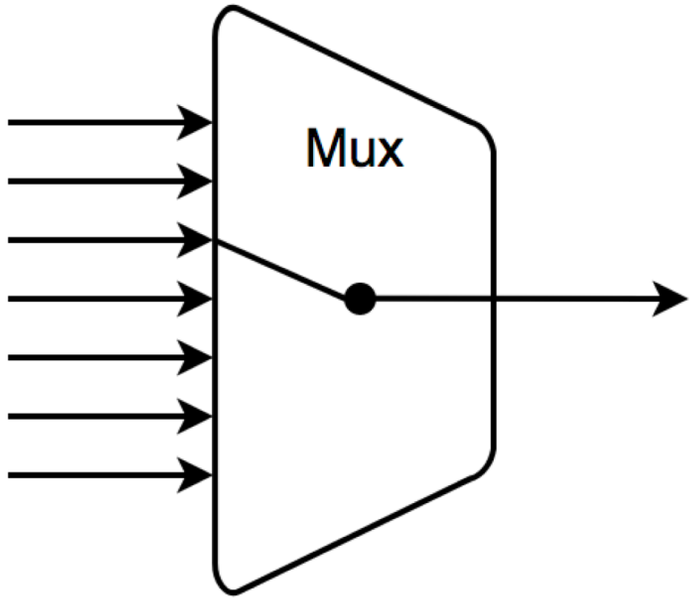
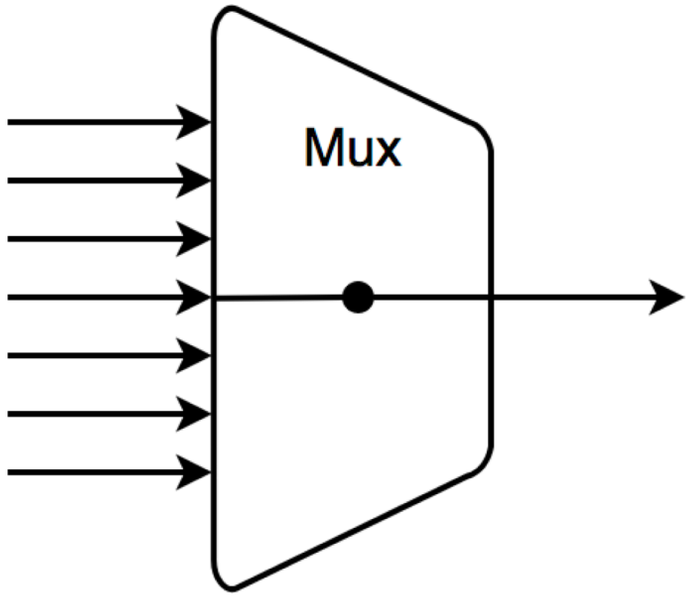


Aggregation Techniques

- TDM – Time Division Multiplexing



Aggregation Techniques

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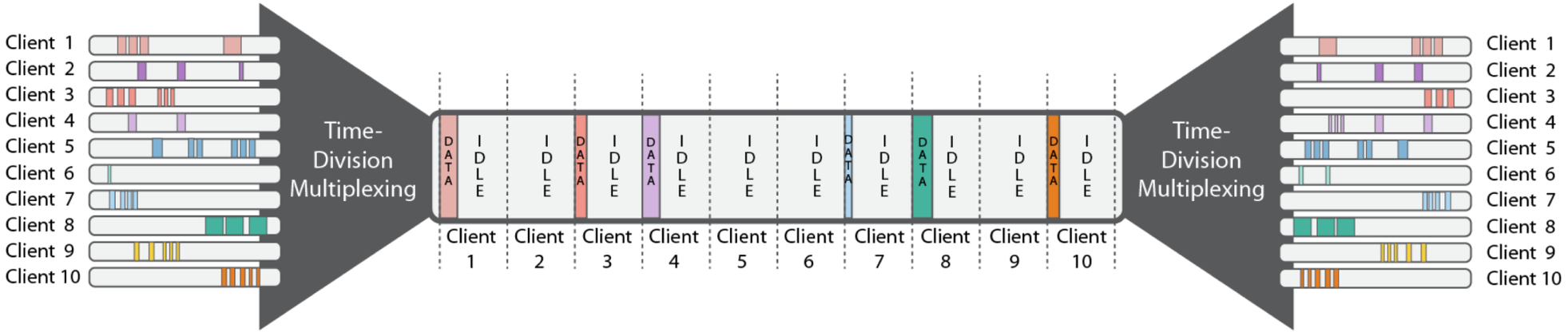

Aggregation Techniques

- Stat Mux – Statistical Multiplexing

Talking Points

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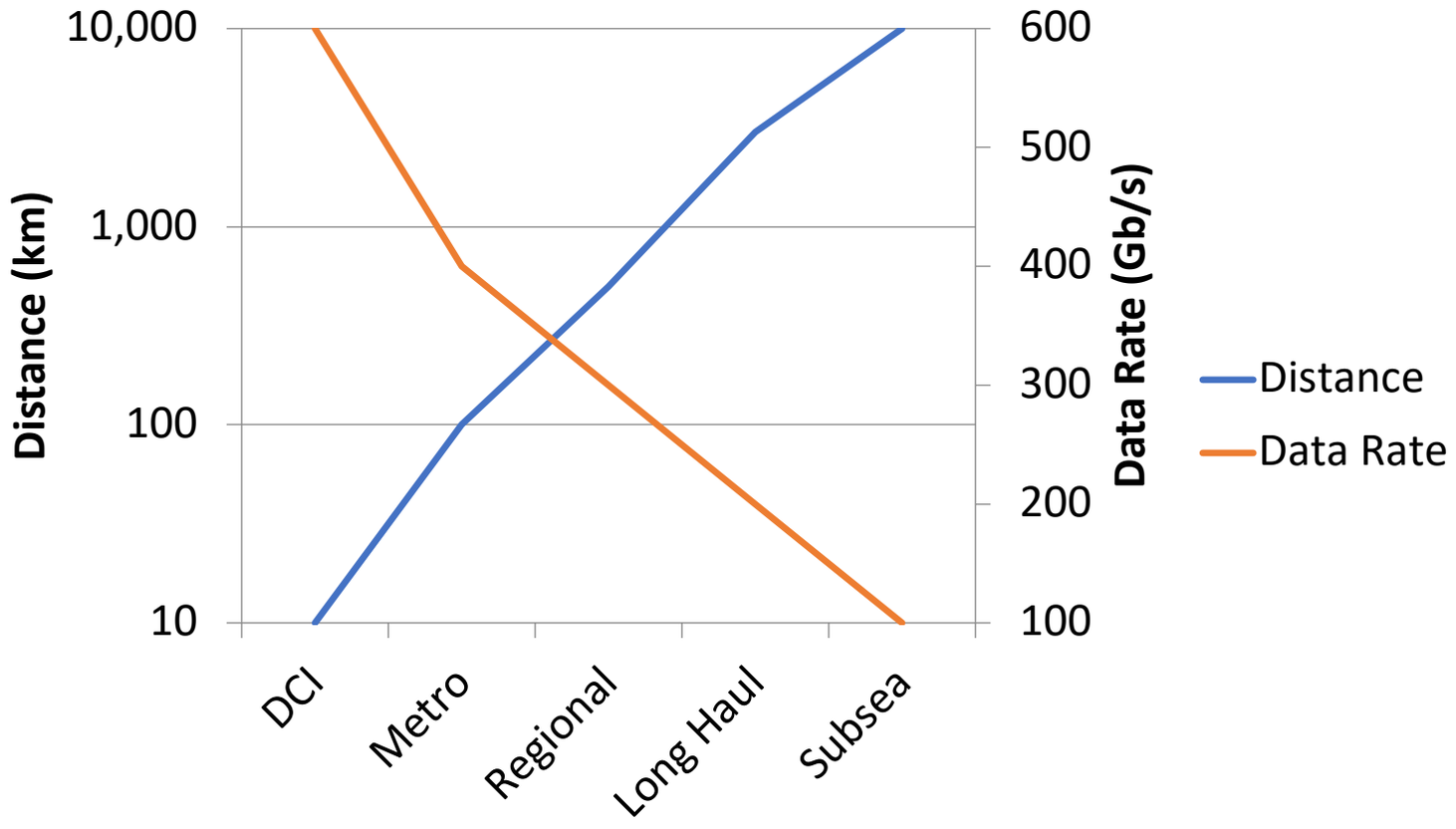
Applications

- DCI – Data Center Interconnect (<10km)
- Metro Networks (<100km)
- Regional Networks (<500km)
- Long Haul (>500km)
- Subsea

Applications

- Data bucket sizes depend on the application
- 400G pipes may be too course for Long Haul applications
- DCI applications require big buckets
- 100G/200G pipes may be the preferred size for Long Haul & Subsea

Applications



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Summary

- Understand elements of an optical network
  - Amplifiers (cost, Noise Figure)
  - Filters (Bandwidth Narrowing, Future Proofing)
  - Lasers (SE/cost/distance tradeoffs)
  - Stranded Spectrum/Bandwidth
- Aggregation Techniques
  - DWDM, how much bandwidth do you need
  - Stat Mux, IP over DWDM, TDM, OTN
  - Required Services (Ethernet, Sonet, Fiber Channel)
- Applications
  - Right-size buckets/pipes for your application
  - Cost/performance tradeoffs – 64QAM not for Long Haul