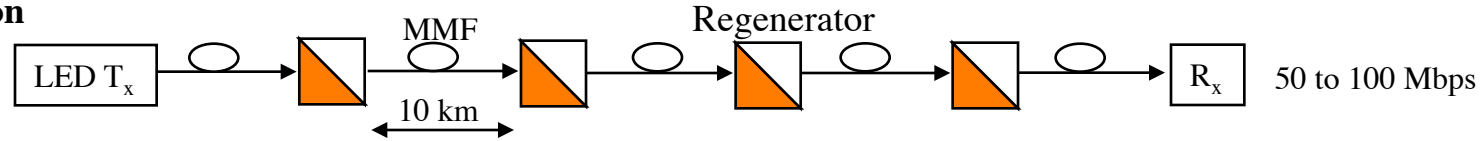
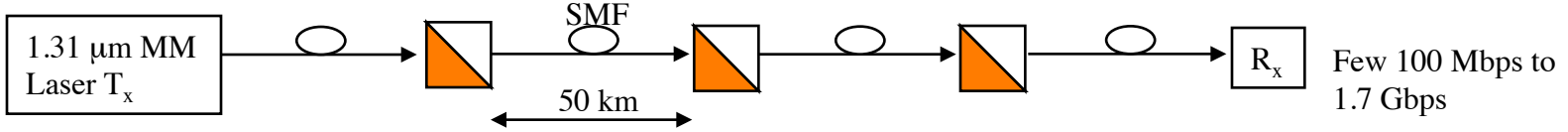
Capacity and Repeater Spacing

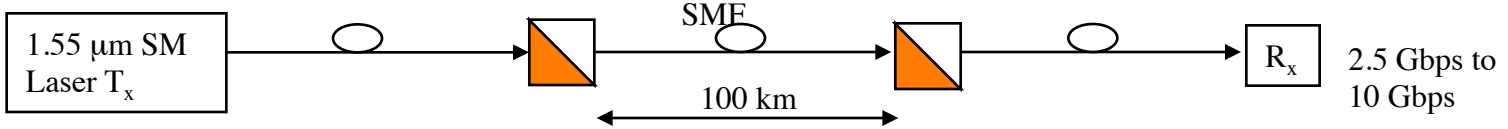
1st Generation



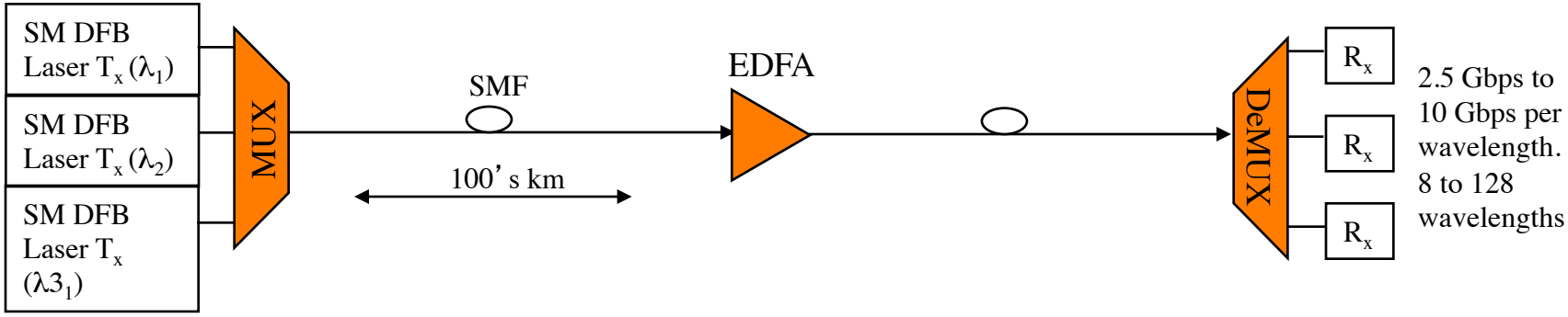
2nd Generation



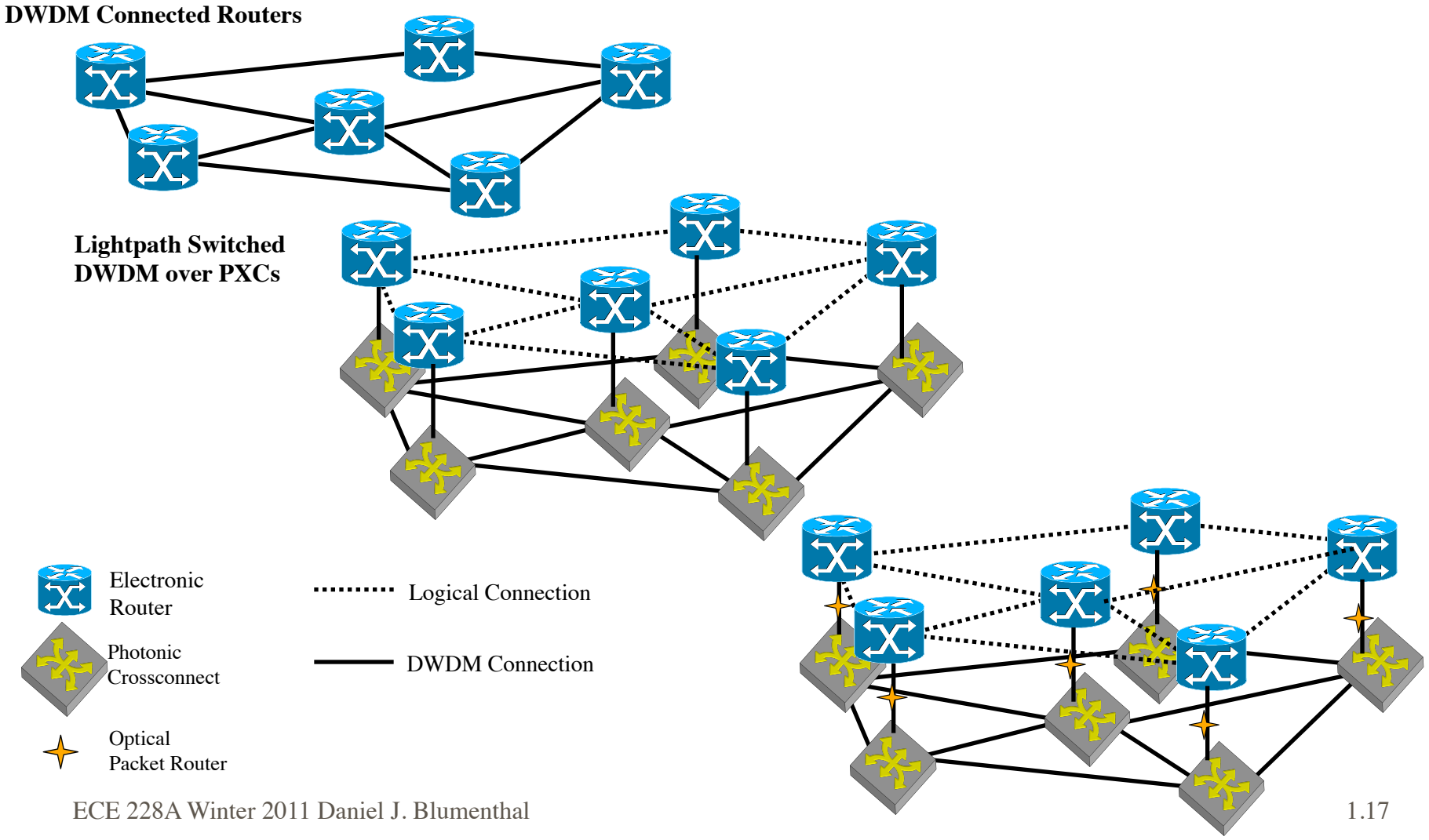
3rd Generation



4th Generation

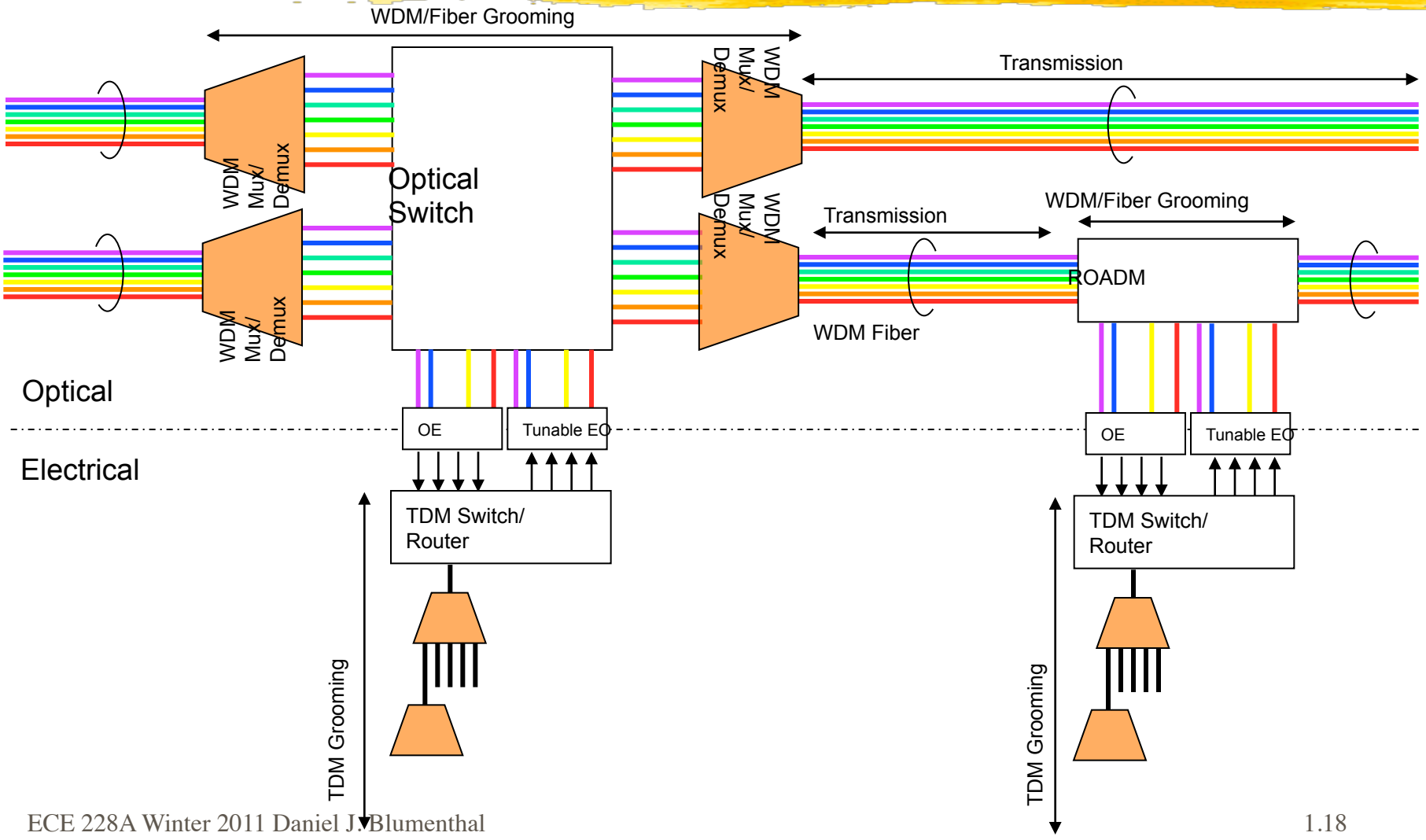


Optical Network Evolution

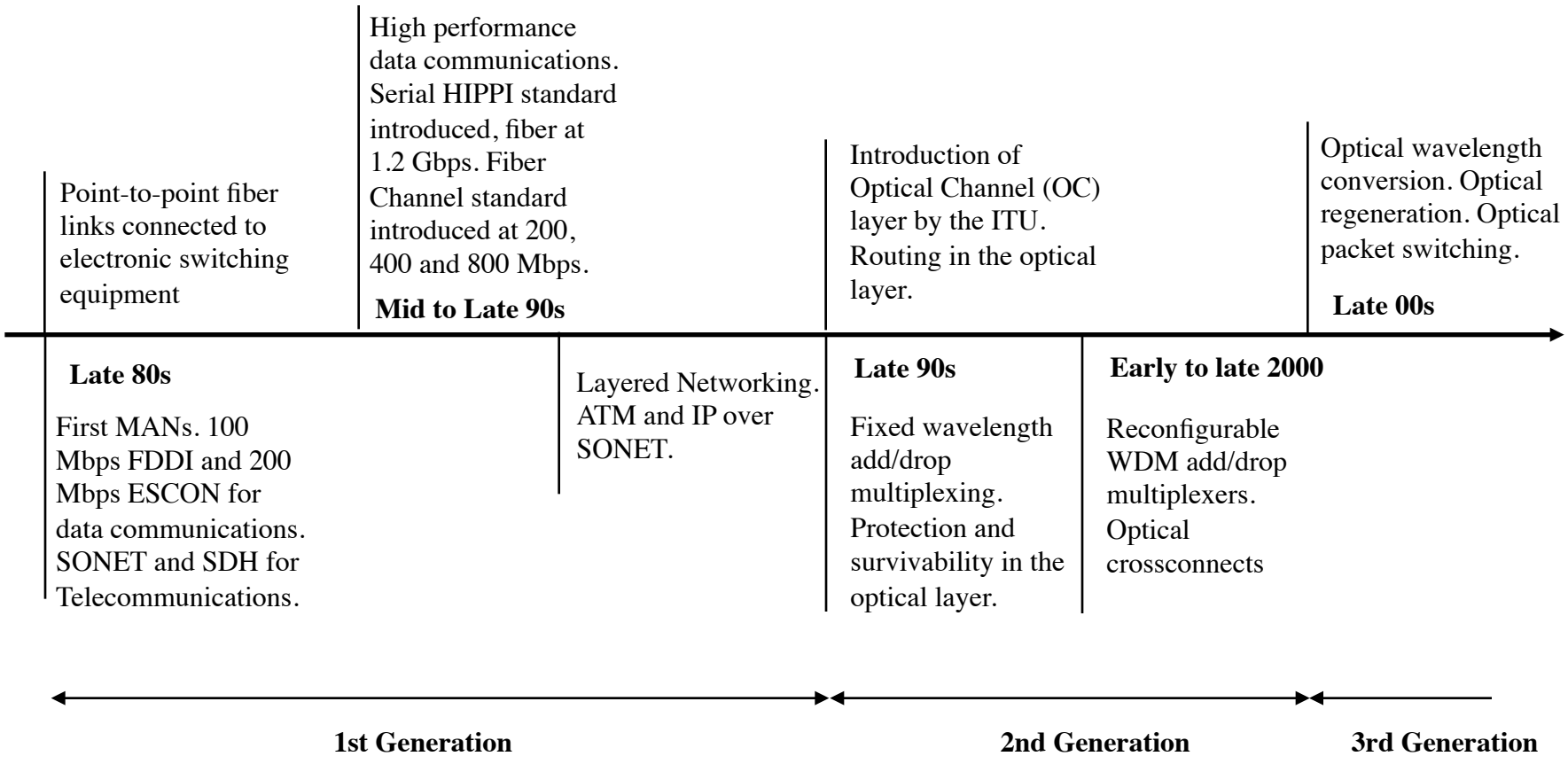


Reconfigurable WDM Optical Nets

⇨ Has increased the functionality and role of optics in the routing and switching at the wavelength circuit level



Evolution of Fiber-Optic Networks



Commercially and Research Deployed Optical Network Status

- National networks with long haul links being deployed with fixed wavelength add/drop (2nd Generation)
- Regional networks being deployed with photonic switches (3rd Generation).
- Experimental and research networks with photonic switches deployed (3rd Generation): National Lambda Rail (NLR), GENI (NSF)
- Metropolitan area networks with reconfigurable add/drop and photonic switches are in progress

100G ULH DWDM Transport

verizon

Courtesy of Bert Basch

- Modulation Techniques
  - Polarization-Multiplexed QPSK with Coherent Detection
    - 4 bits per modulation symbol resulting in very good spectral efficiency
    - Excellent chromatic dispersion and PMD tolerance using electrical equalization
    - High tolerance to narrow band filtering; compatible with 50 GHz grid
    - Constant-envelope format minimizes non-linear effects in neighboring channels
    - More sensitive to non-linear cross-phase modulation than DQPSK
    - Needs improvement in FEC coding gain to reach current 40 Gb/s reach
    - Under development by NSN, ALU, and others
  - Other modulation techniques being evaluated include DQPSK, several QAM formats, PolMux DQPSK, inverse multiplexing techniques using multiple wavelengths or OFDM
    - Currently these techniques don't achieve the performance anticipated with PolMux QPSK

Verizon 100-Gb/s Trials

Courtesy of Bert Basch

- 107 Gb/s DQPSK Trial with Alcatel-Lucent
  - LambdaXtreme Network between Tampa and Miami
  - Real-time video traffic over 500 km link with 6dB margin
  - Uses asymmetic interleaver with 65 GHz passband on 50 GHz grid
- 111 Gb/s Coherent PolMux QPSK with Nokia-Siemens
  - Field fiber route consisting of thirteen 80 km spans, EDFA only
  - Standard 50 GHz spacing
  - Off-line digital processing using data stored on storage scope
  - Examined impact of neighboring channels and PMD
- 100 Gb/s Coherent PolMux QPSK with Nortel
  - Standard 50 GHz grid but uses 2 PolMux QPSK wavelengths in the pass band, uses real-time processing
  - Examines impact of neighboring channels and high PMD

Optical Transport Network

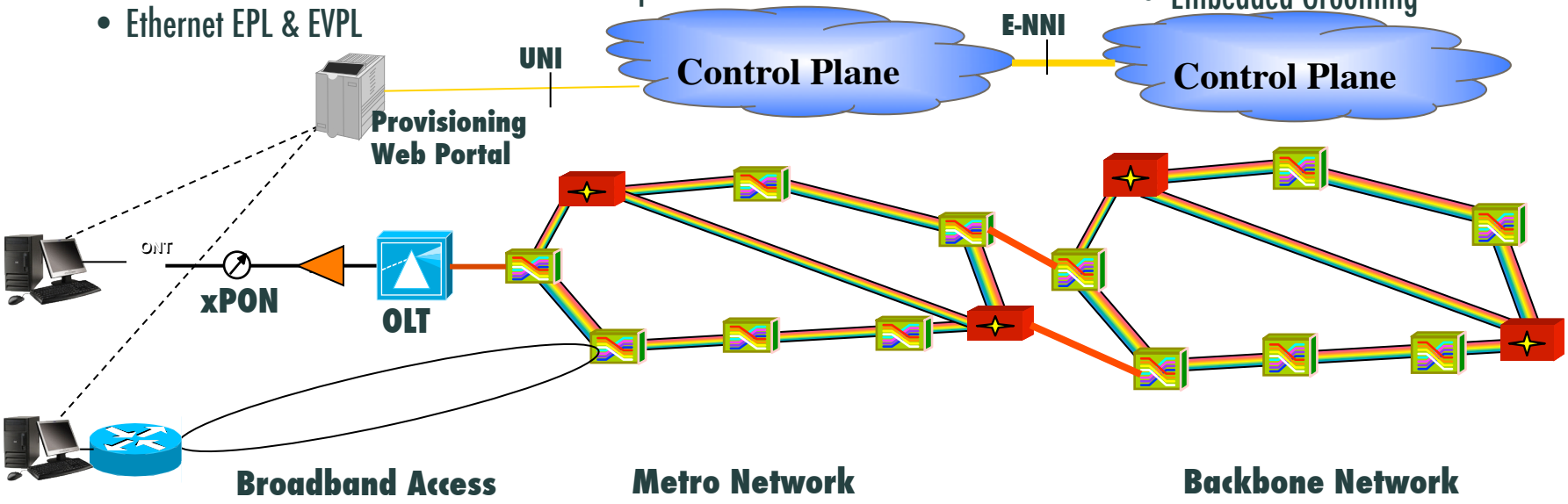
The Vision

xPON
- Per Premise:
  1G – 10Gbps Down
  10-100Mbps UP
- Flexible BW allocation
- Ethernet Centric
- >20km reach

Enterprise
- 10Gbps; λs
- Ethernet EPL & EVPL

- 40G per λ
- 100 λs
- Mesh
- >1000km reach
- Ethernet Capable
- Packet ADM
- ADM on a λ
- Uni-directional Optics
- Optical Broadcast

- 100G per λ
- 100s of λs
- Mesh
- > 4000km reach
- Ethernet Capable
- Embedded Grooming



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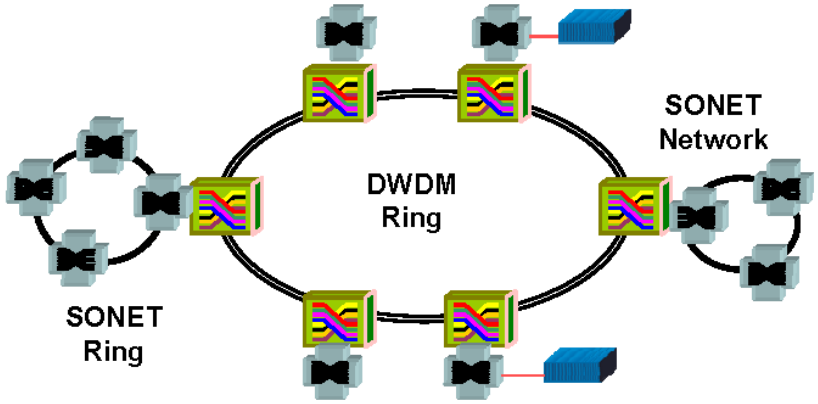
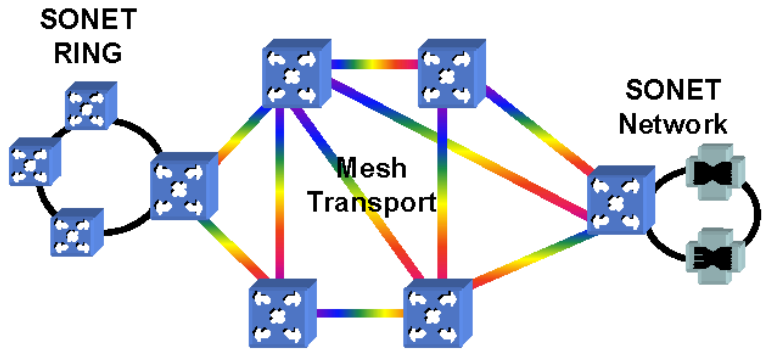
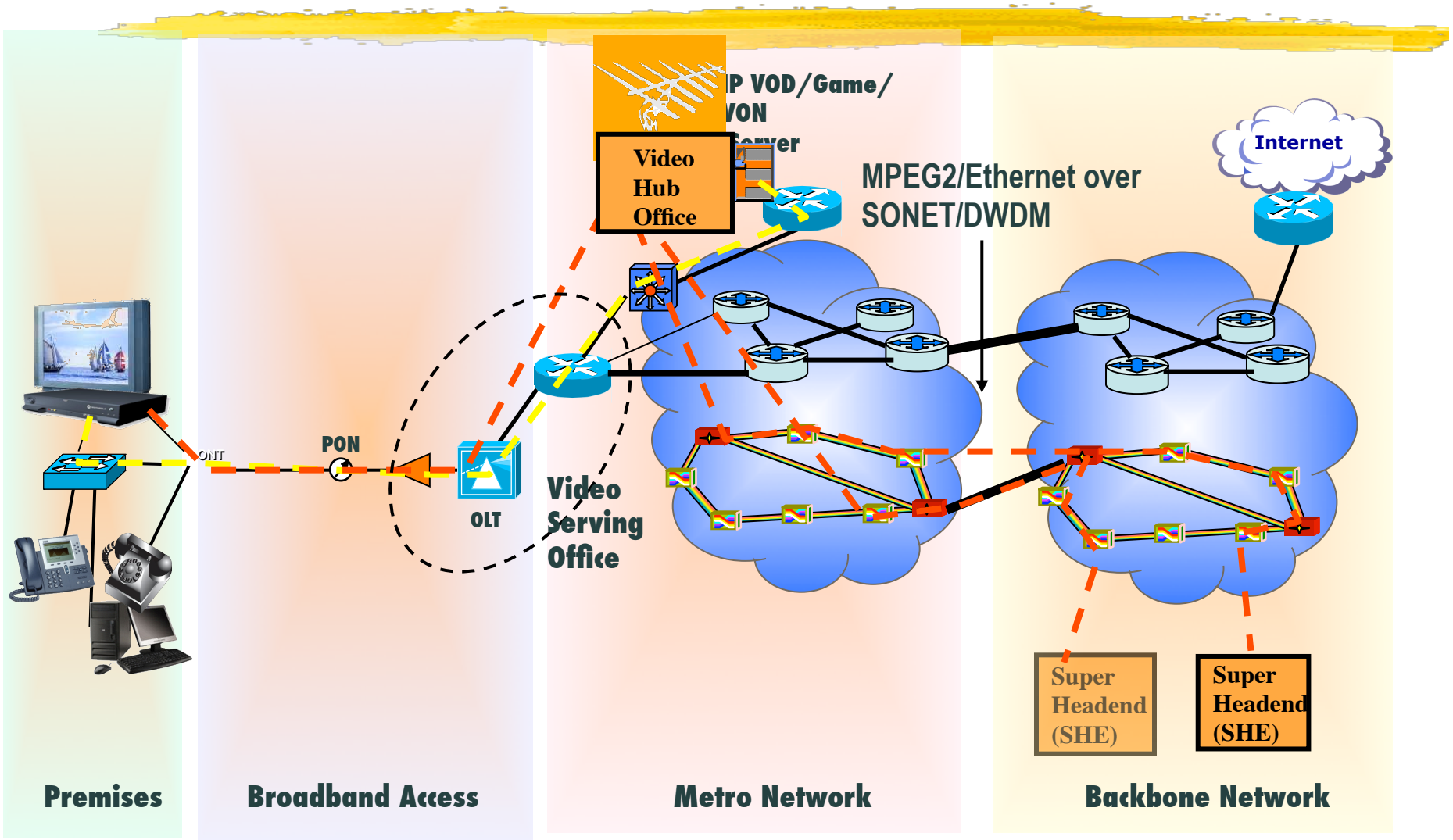
OTN Evolution



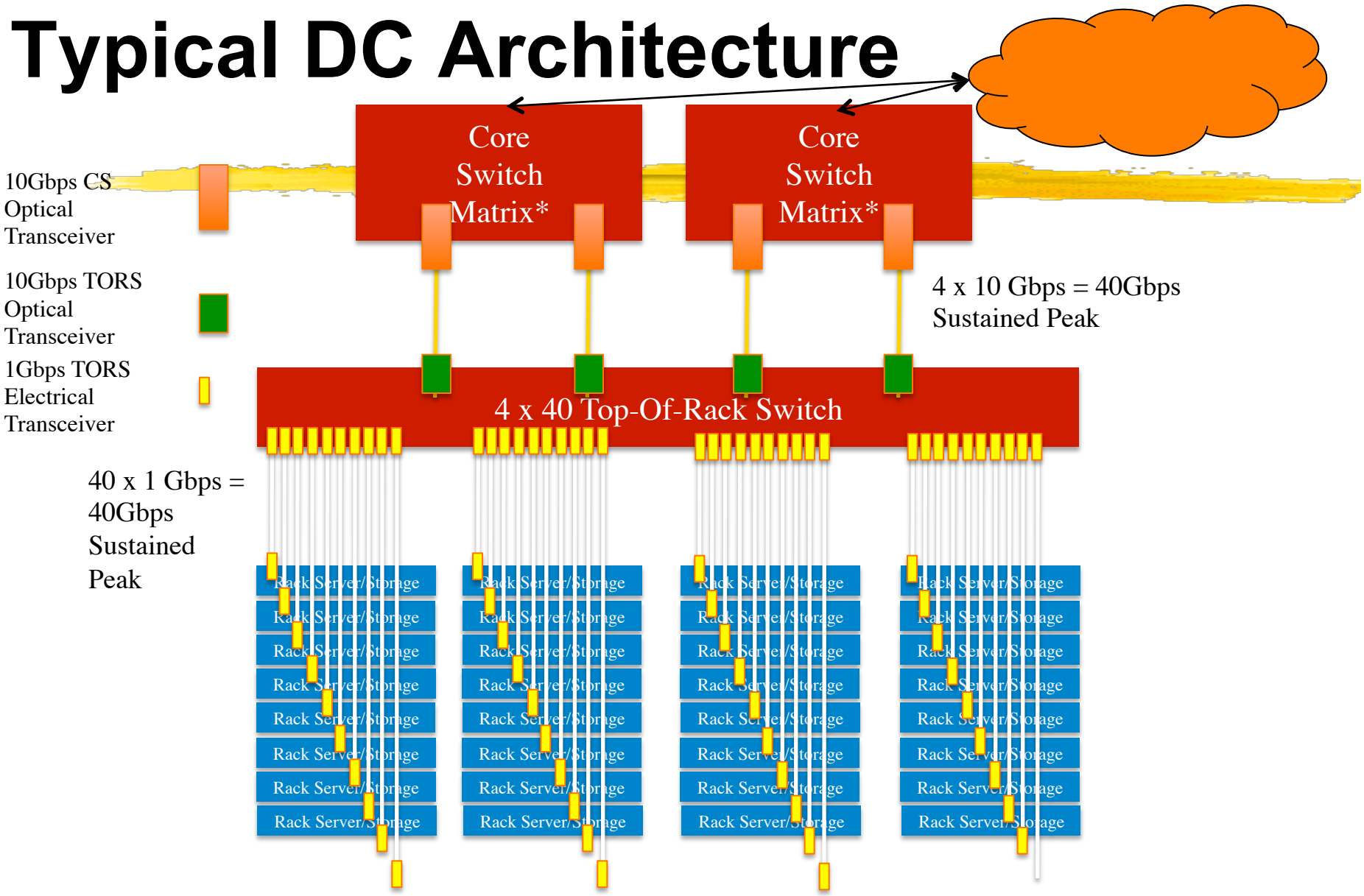


- Present Mode of Operation
  - Separate DWDM and SONET network elements
  - DWDM supports only ring and linear configurations
  - EN switches used for data aggregation/grooming
- Future Mode of Operation
  - ADM-on-wavelength and integrated fabric allow TDM and DWDM functionality to be combined
  - SONET rings over optical mesh
  - Wavelength switching enables mesh
  - Native Ethernet capability

FTTP Video Architecture

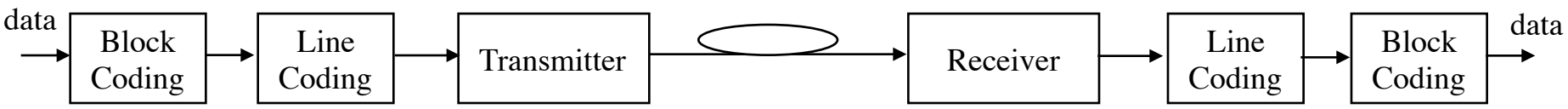


Typical DC Architecture



1.2 Basic Fiber Optic Link and Multiplexing and Modulation Techniques

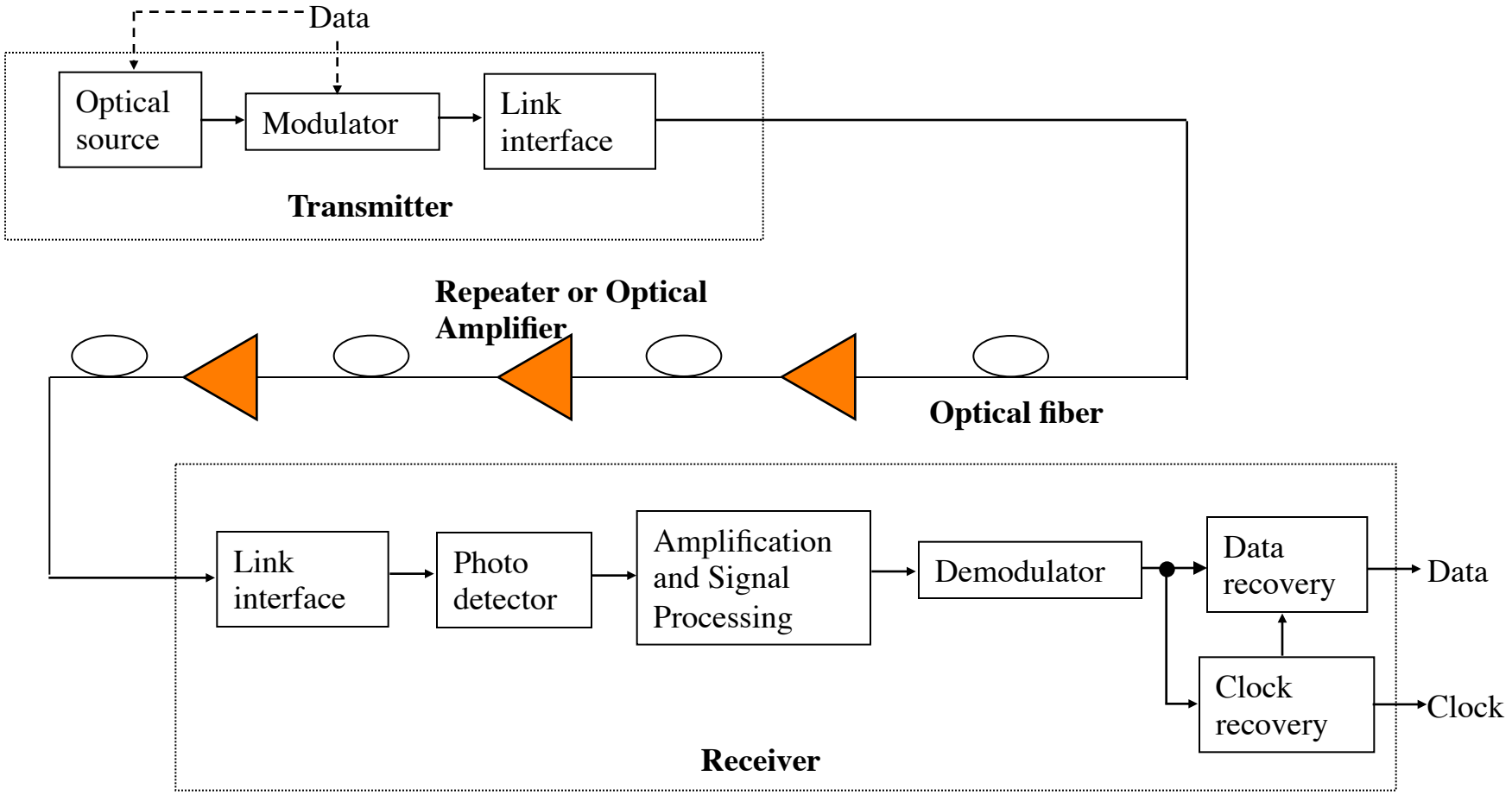
Basic Communication System



Block Coding
- Error Correction
- Redundancy
- Overcome noise and transmission impairments
- E.g. FEC, Turbo-Codes

Line Coding
- DC balance
- Redundancy
- E.g Manchester Codes

Basic fiber point-to-point link



Multiplexing Techniques

- Multiplexing is the technique used to carry several different information channels on a common physical medium. The four alternatives are:
  - Time Division Multiplexing (TDM)
  - Frequency Division Multiplexing, indicated as "Wavelength Division Multiplexing" (WDM) in optics
  - Space Division Multiplexing (SDM)
  - Code Division Multiplexing (CDMA)
  - Multilevel coding