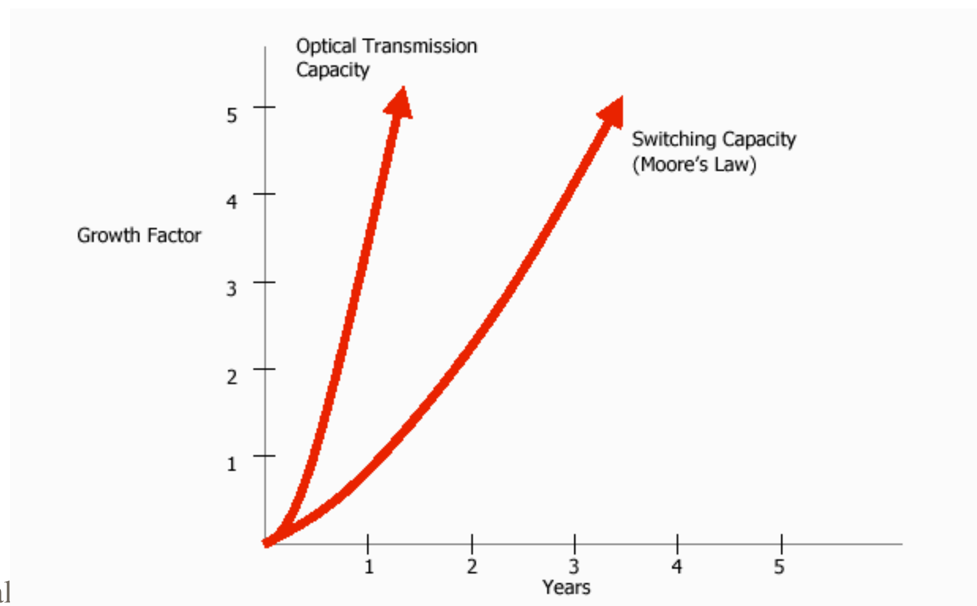
Lecture 1- Introduction to Fiber Optics

Fiber-Optic Network Applications

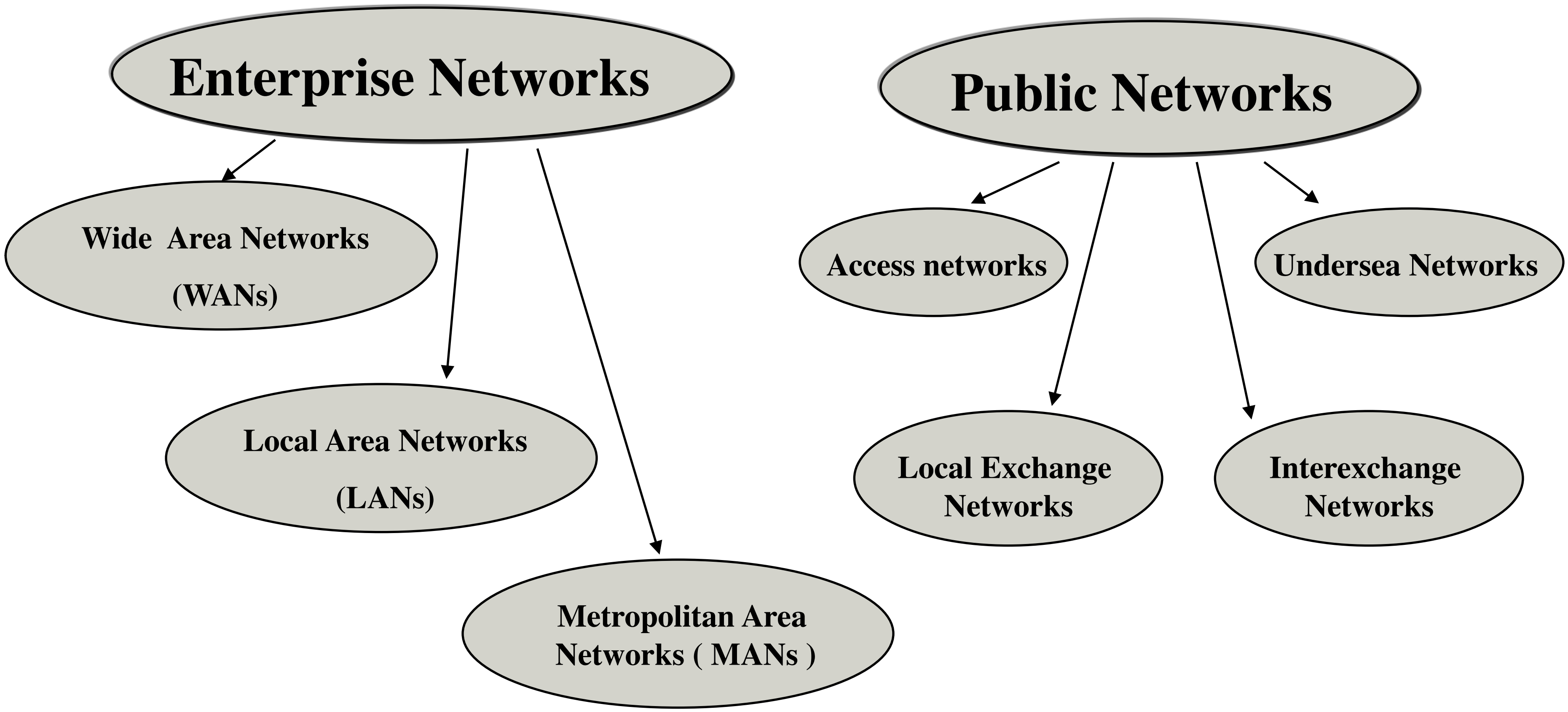
- Main application: digital transmission
  - Voice, telephone
  - Data
    - IP Networks
    - ATM, Gigabit Ethernet, FDDI, etc.
    - Distributed Computing and Databases
    - Video, Multimedia
- Microwave Photonics
  - Fiber/Wireless
  - Hybrid Fiber/Coax
- Other applications
  - Fiber/Wireless
  - Hybrid Fiber/Coax

Note:

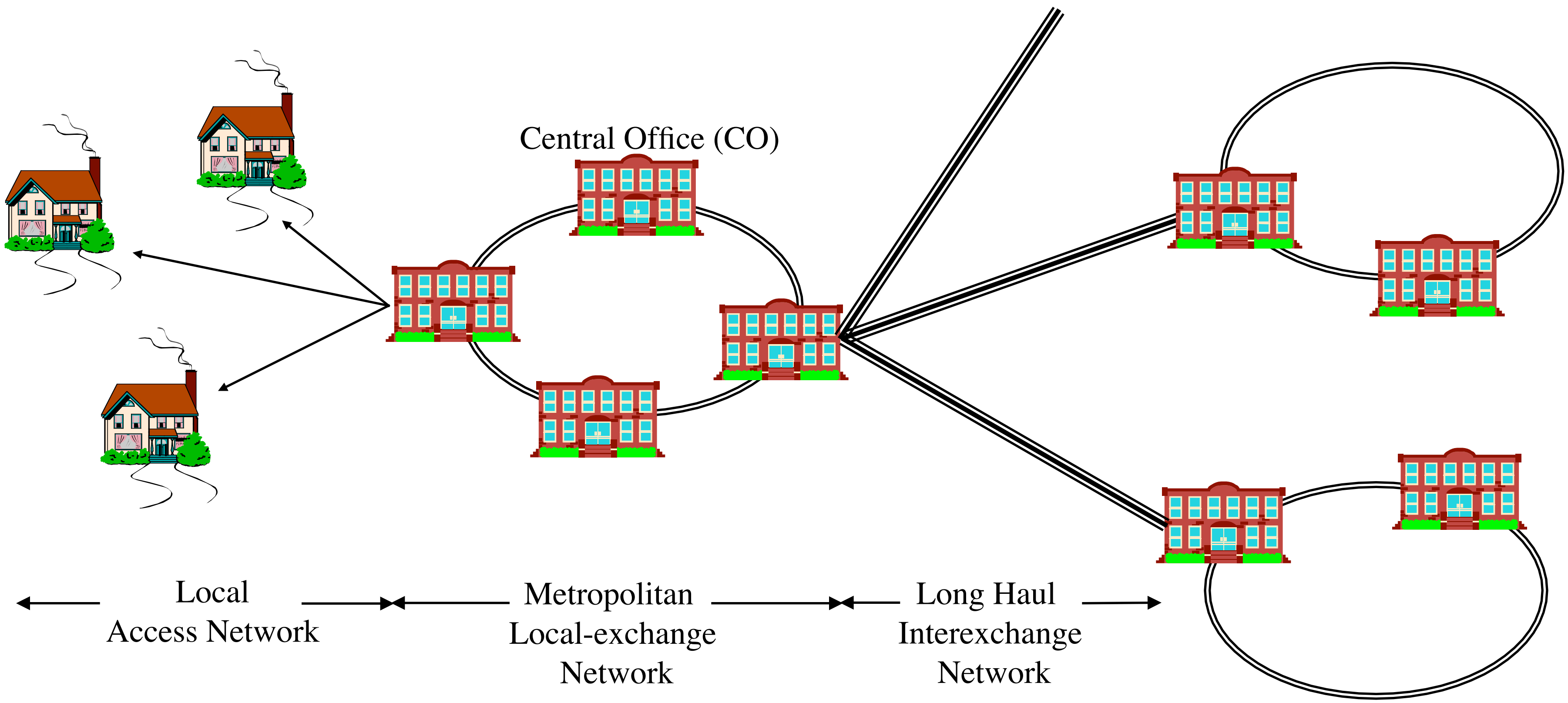
Traffic generated by data-centric application (mainly IP) is rapidly surpassing the voice-centric traffic



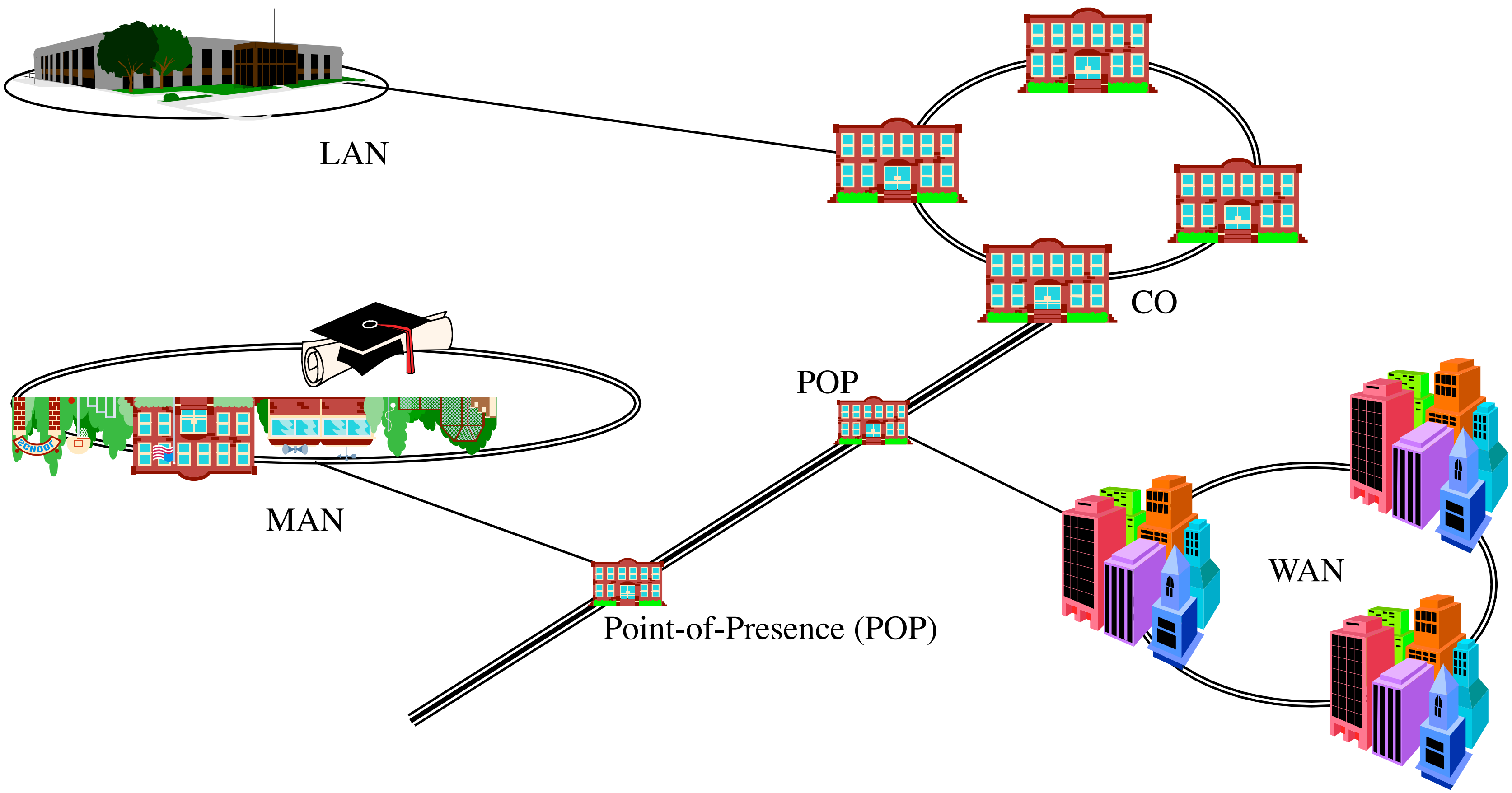
Network Classification



Public Networks



Enterprise Networks



Evolution of Fiber-Optic Point-to-Point Transmission

Early 70s
Room temperature GaAs LEDs and multimode FP Lasers @ 830 nm

Multimode fiber-optic waveguides >5dB/km attenuation

Early 80s
Low loss Single mode optical fibers 1 dB/km @ 1310 nm

Multimode Fabry-Perot 1310 nm lasers

Mid to Late 80s
Operation in the low loss window of 0.2 dB/km @ 1550 nm but high dispersion @ 1550 nm

Development of single frequency DFB 1310 nm and 1550 nm lasers

New dispersion shifted fiber yields Zero dispersion @ 1550 nm and 0.5 dB/km loss @ 1310 nm

Late 80s to Early 90s
Multichannel erbium doped fiber amplifiers (EDFAs) @ 1550 nm deployed.

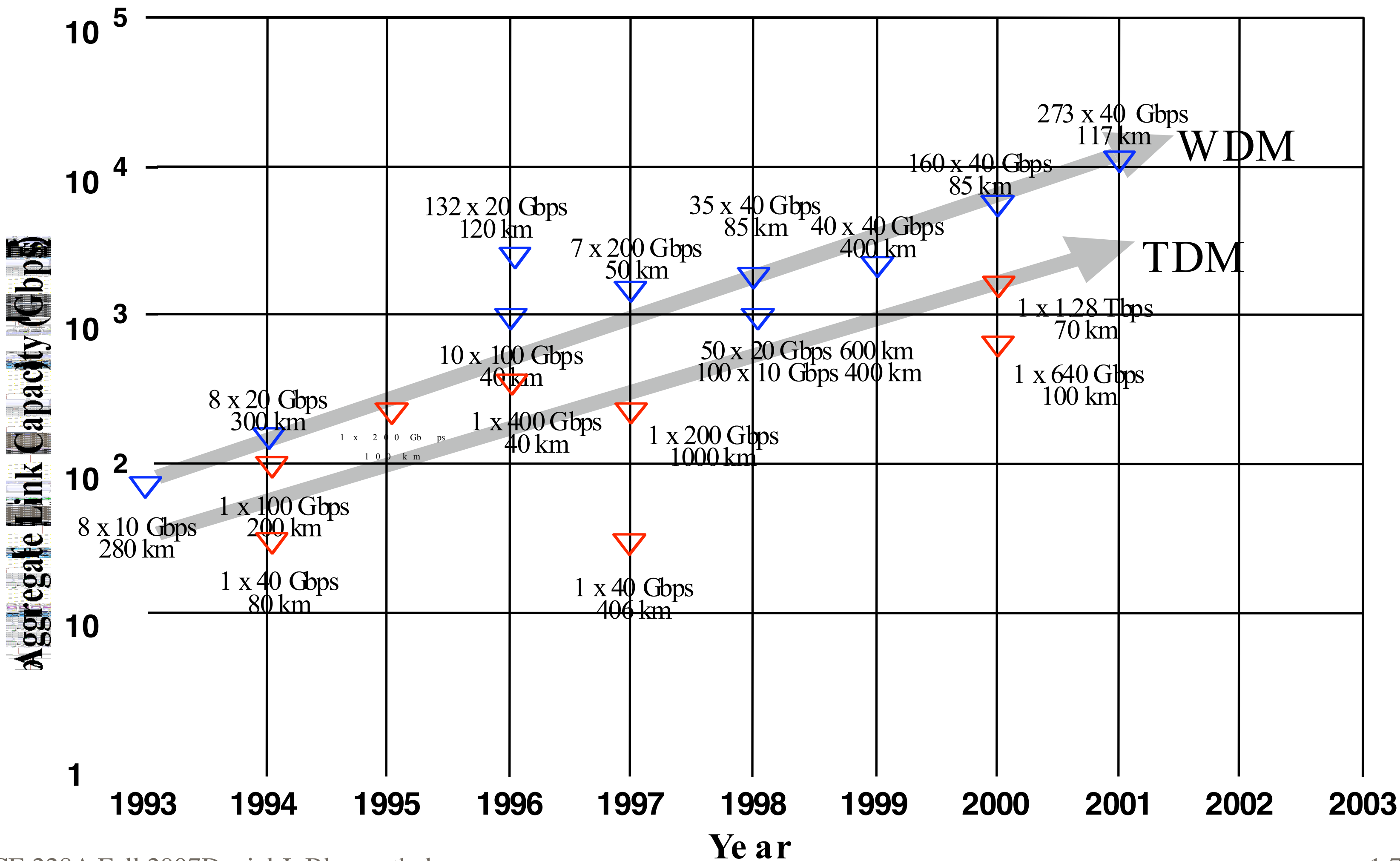
Mid 90s
Multichannel WDM @1550 nm. Number of channels and channel spacing limited by fiber four-wave mixing (FWM)

AT&T True Wave Fiber and Corning Large Optical Core Fiber reduce fiber FWM

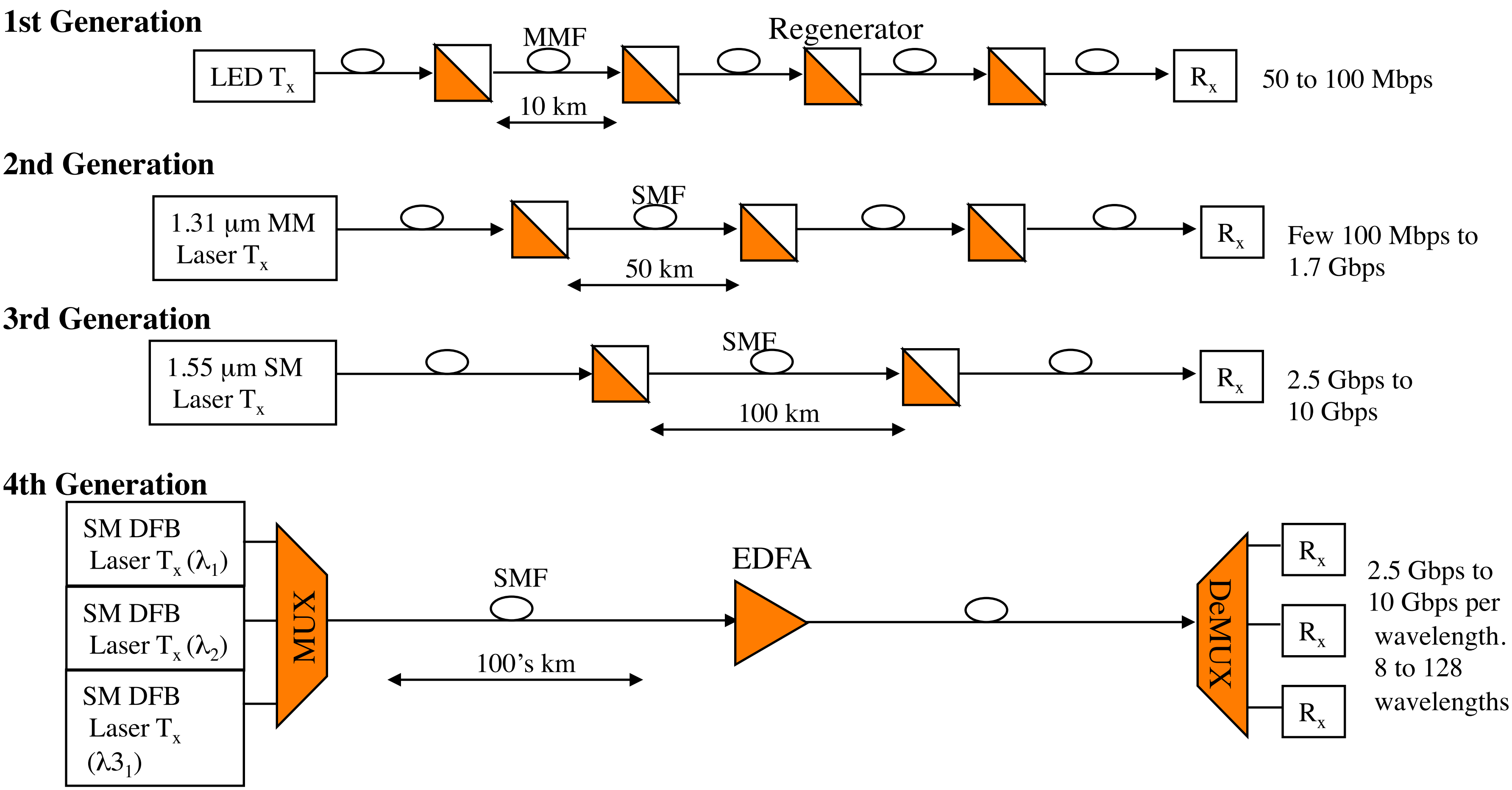
Mid 90s
Optical Solitons, dispersion compensation

1st Generation | **2nd Generation** | **3rd Generation** | **4th Generation** | **5th Generation**

Transmission Bandwidth Evolution



Capacity and Repeater Spacing



Evolution of Fiber-Optic Networks

Late 80s

Point-to-point fiber links connected to electronic switching equipment

First MANs. 100 Mbps FDDI and 200 Mbps ESCON for data communications. SONET and SDH for Telecommunications.

Mid to Late 90s

High performance data communications. Serial HIPPI standard introduced, fiber at 1.2 Gbps. Fiber Channel standard introduced at 200, 400 and 800 Mbps.

Layered Networking. ATM and IP over SONET.

Late 90s

Introduction of Optical Channel (OC) layer by the ITU. Routing in the optical layer.

Fixed wavelength add/drop multiplexing. Protection and survivability in the optical layer.

Early to late 2000

Reconfigurable WDM add/drop multiplexers. Optical crossconnects

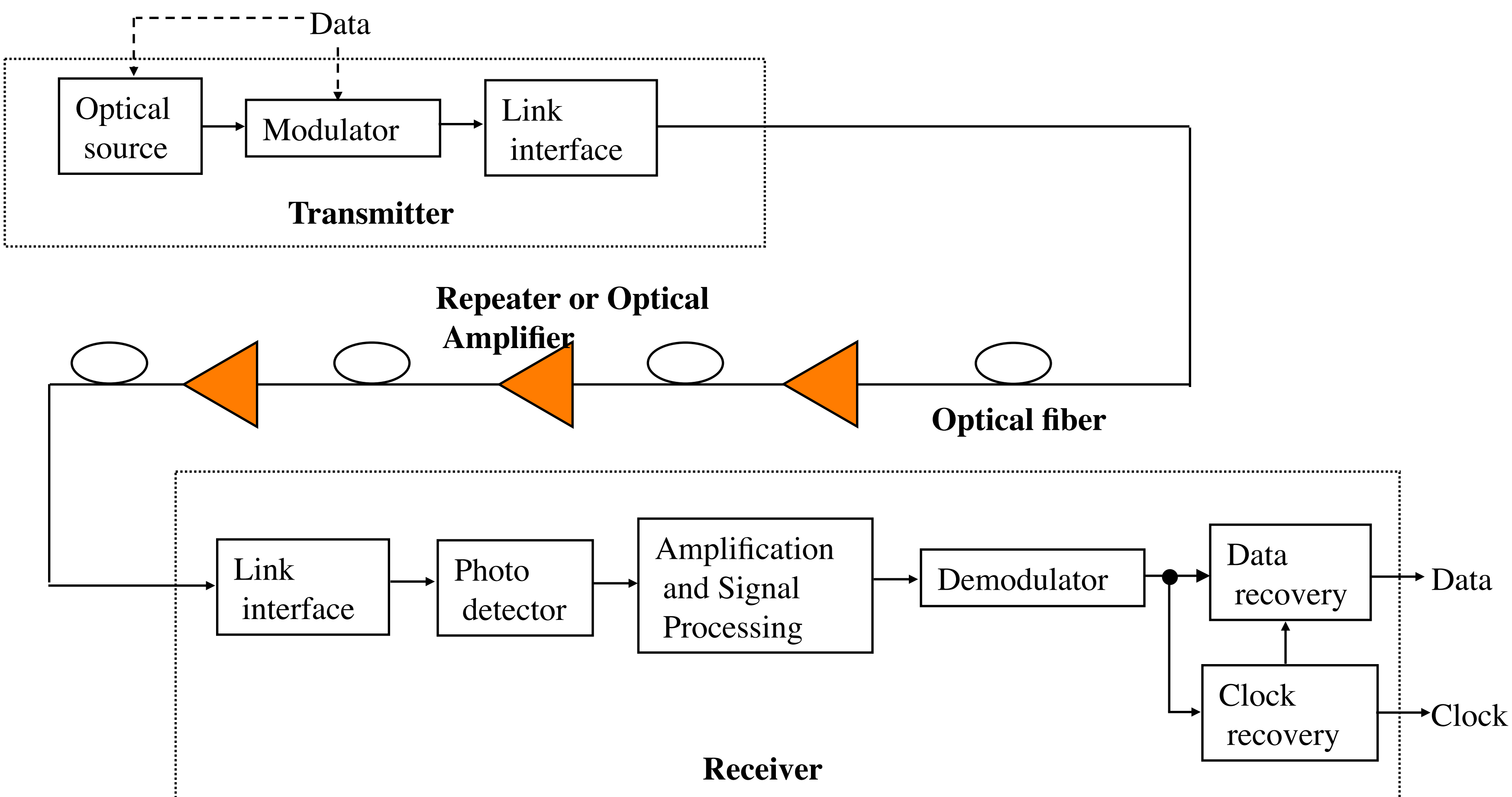
Late 00s

Optical wavelength conversion. Optical regeneration. Optical packet switching.

1st Generation | **2nd Generation** | **3rd Generation**

1.2 Basic Fiber Optic Link and Multiplexing Techniques

Basic fiber point-to-point link

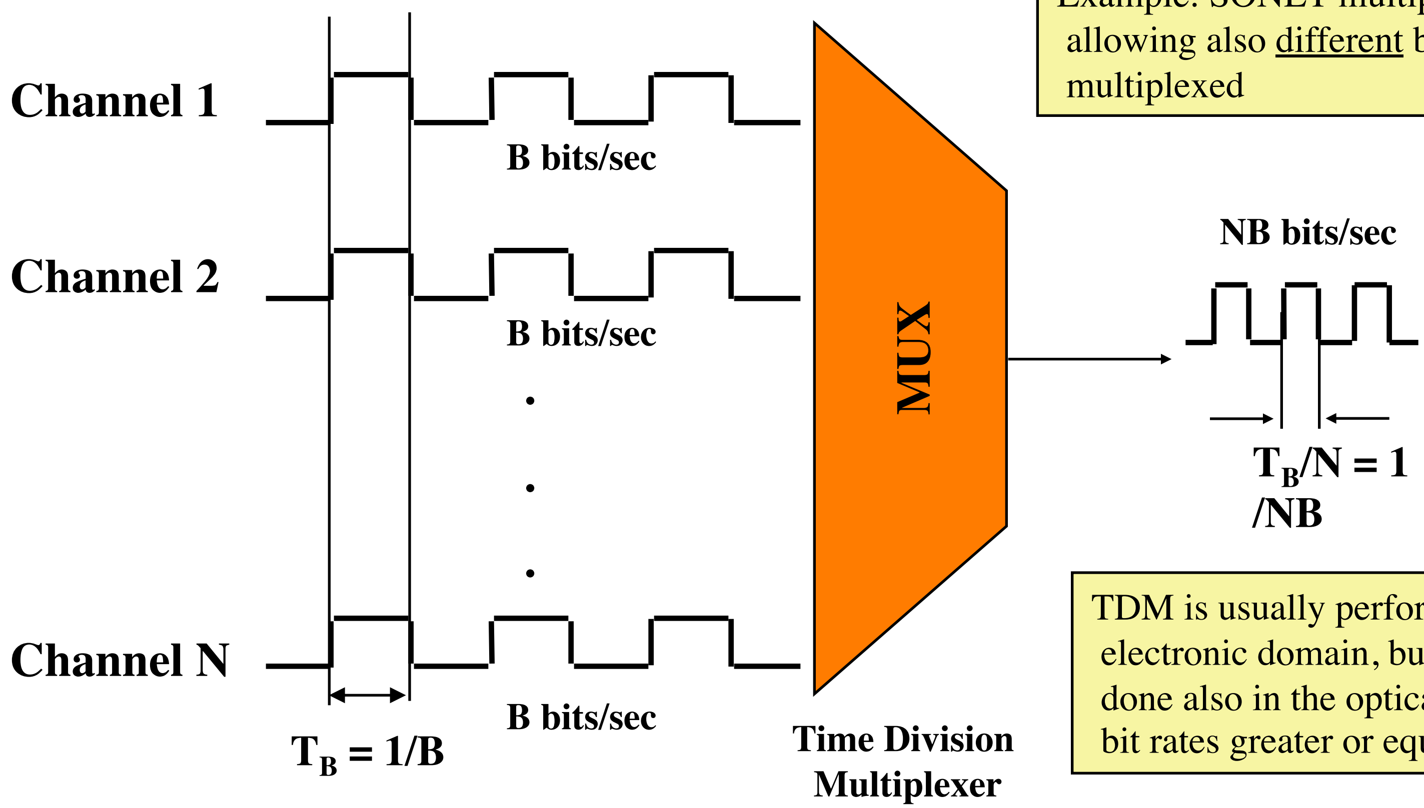


Multiplexing Techniques

- 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

Multiplexing Techniques

- Time Division Multiplexing (TDM)

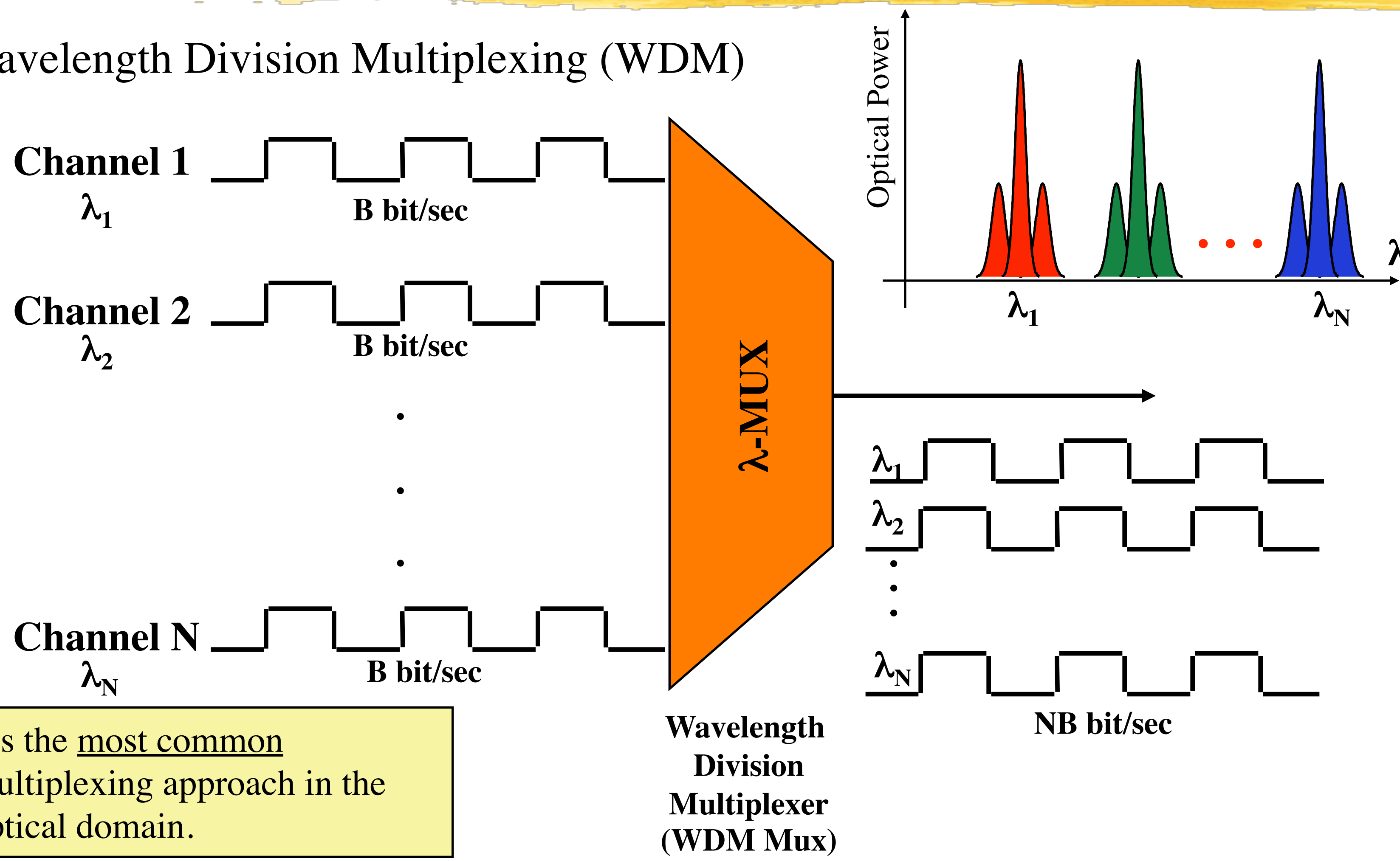


Example: SONET multiplexing, allowing also different bit rates to be multiplexed

TDM is usually performed in the electronic domain, but is is now done also in the optical domain, for bit rates greater or equal to 40Gb/s

Multiplexing Techniques

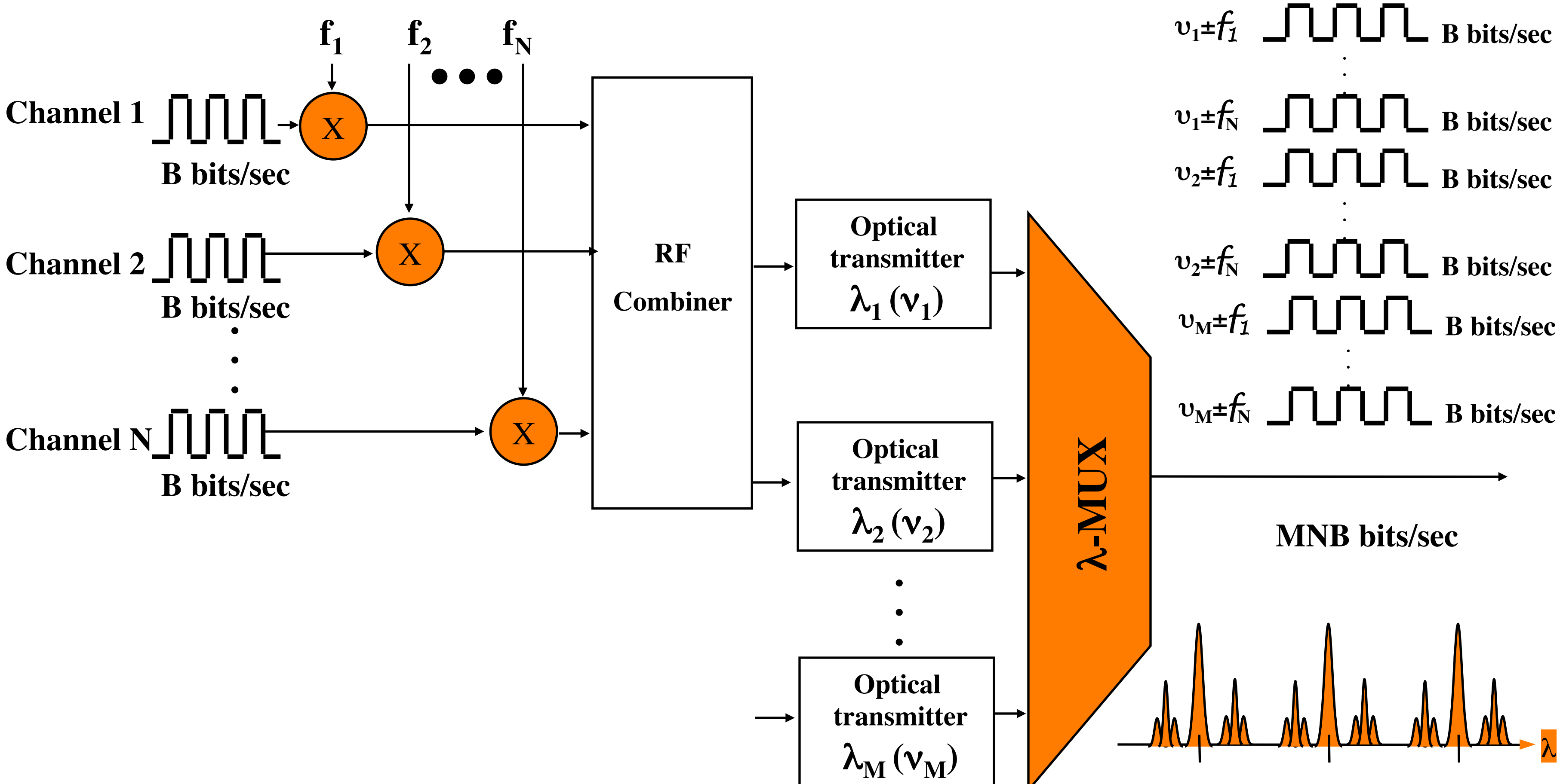
- Wavelength Division Multiplexing (WDM)



It is the <u>most common</u> multiplexing approach in the optical domain.

Multiplexing Techniques

- Wavelength Division/Subcarrier Multiplexing (WDM/SCM)



Other Multiplexing and Coding Techniques

- Space Division Multiplexing:
  - use of several fibers belonging to the same bundle
- Polarization Multiplexing:
  - Using orthogonal states of polarization in fiber to transmit independent data streams
- Code Division Multiplexing
  - Initially known as spread-spectrum, a particular kind of multiplexing based on the product between the useful signals and orthogonal pseudorandom sequences (mostly used in RF/wireless applications, like in third generation wireless phone)
- Multilevel Coding
  - Bandwidth efficient way to increase channel bit-rate without requiring more modulation bandwidth.

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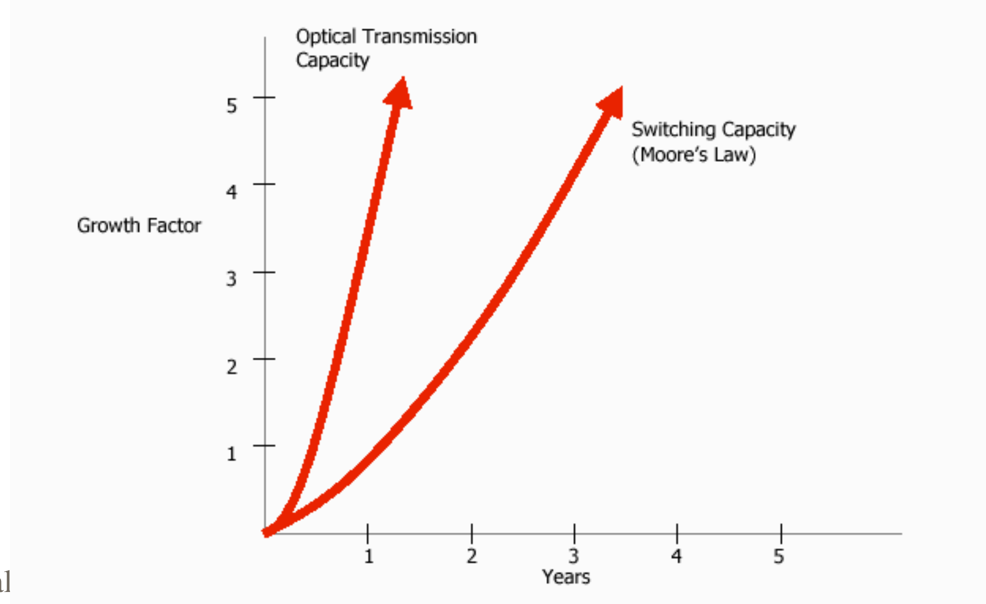

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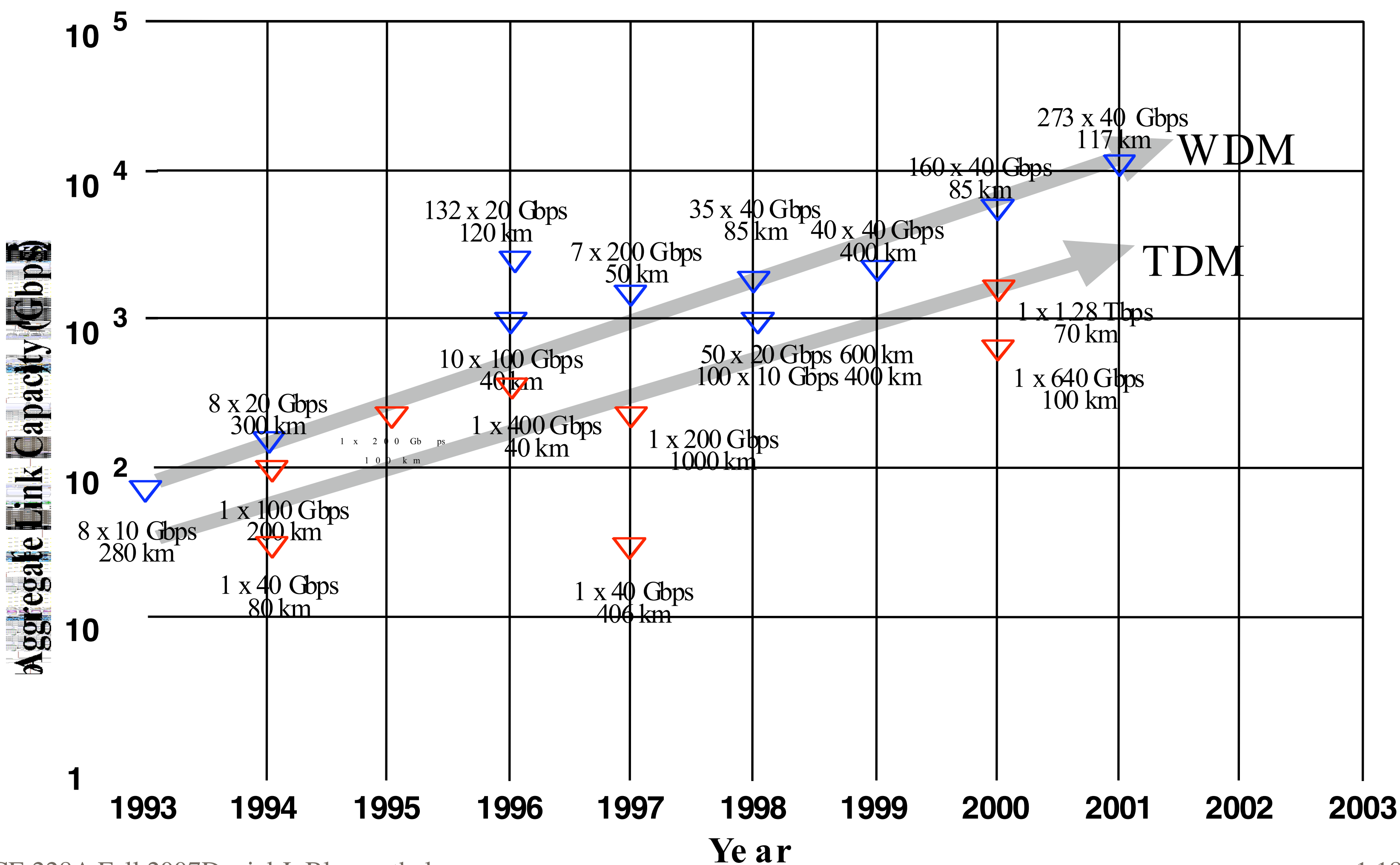

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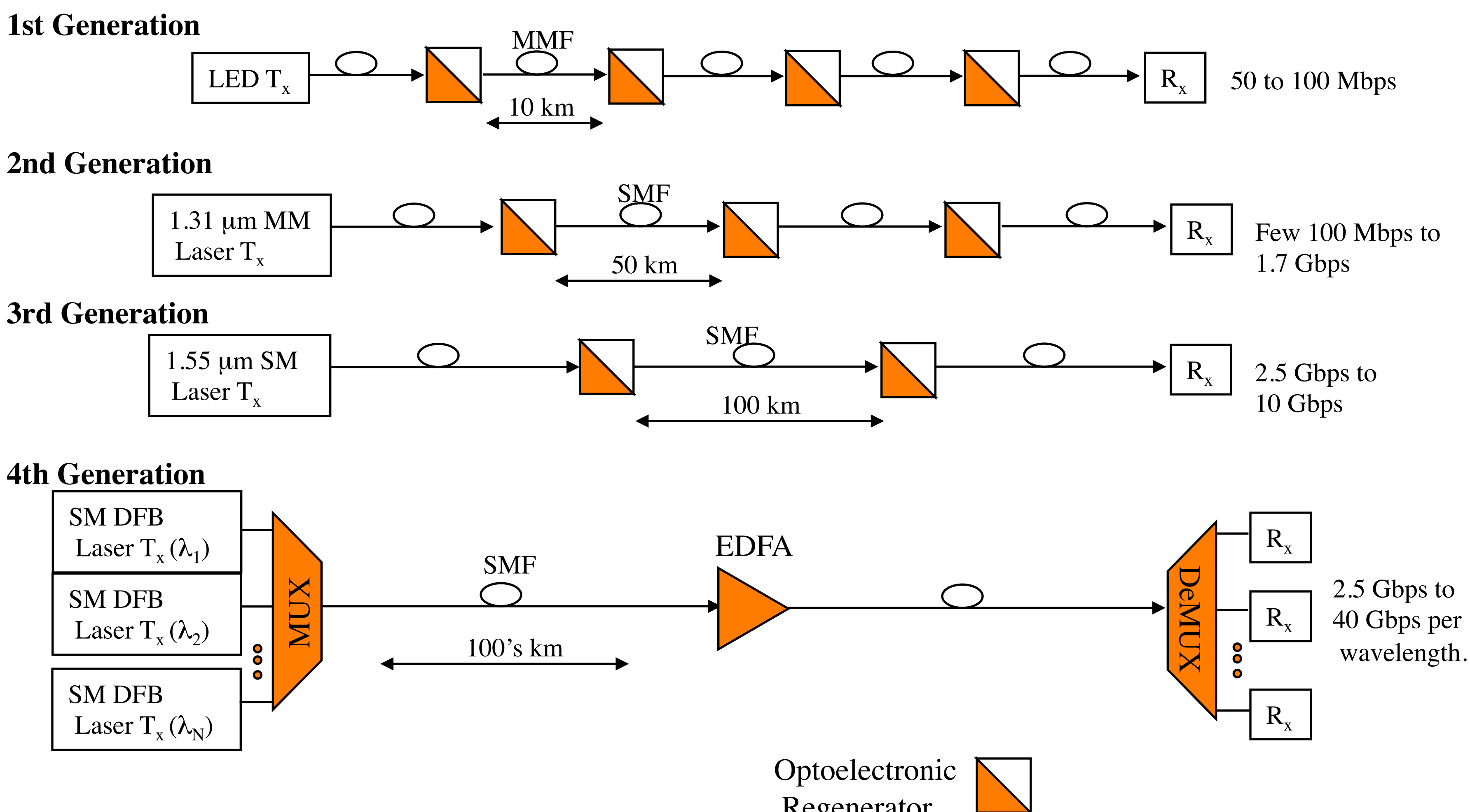
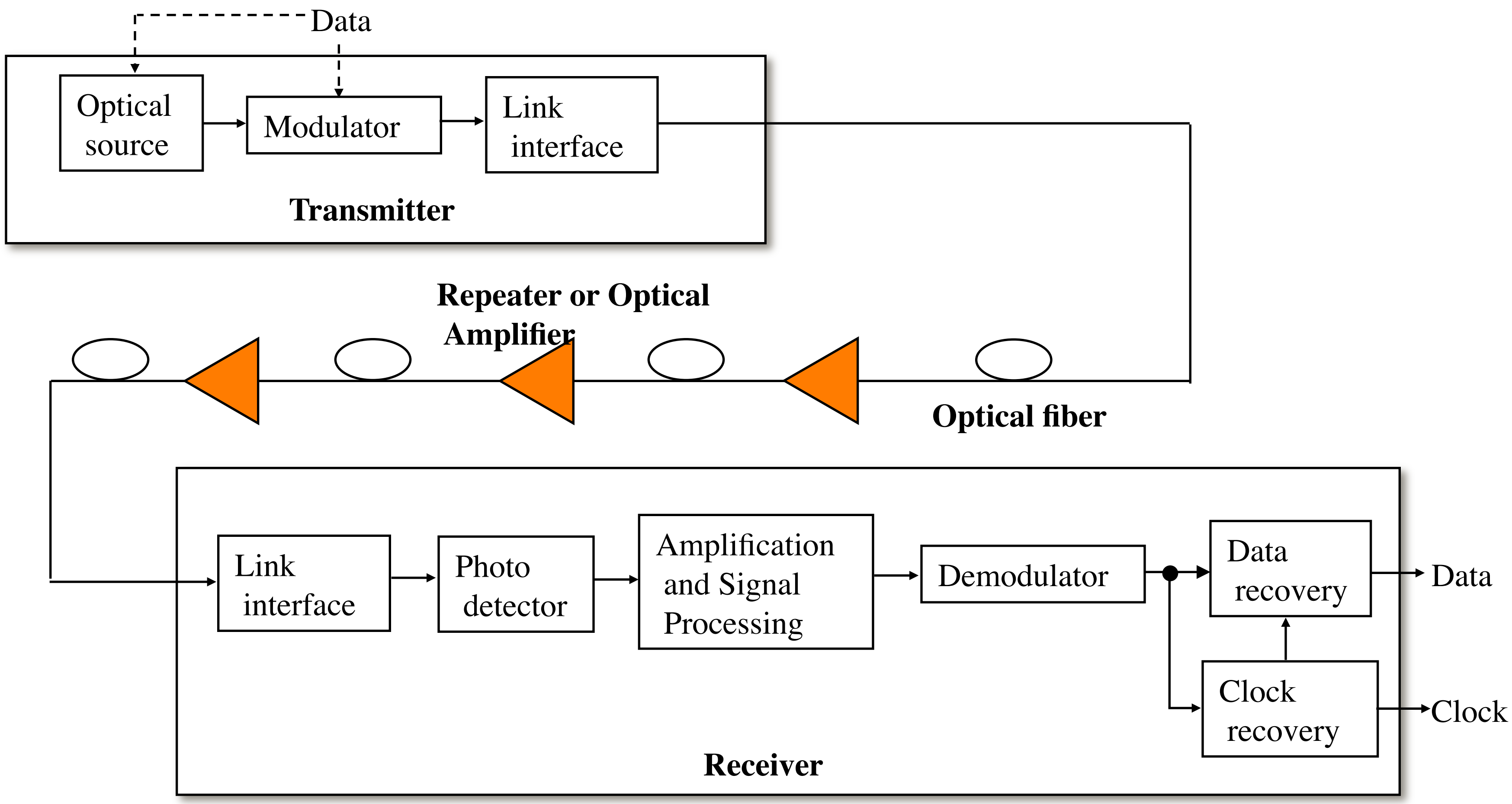
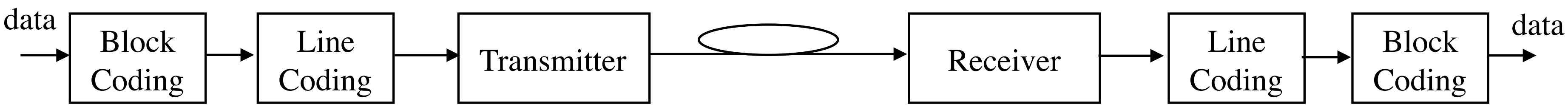
DWDM Link Evolution



Basic Fiber Optic Point-to-Point Link



Basic Communication System



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

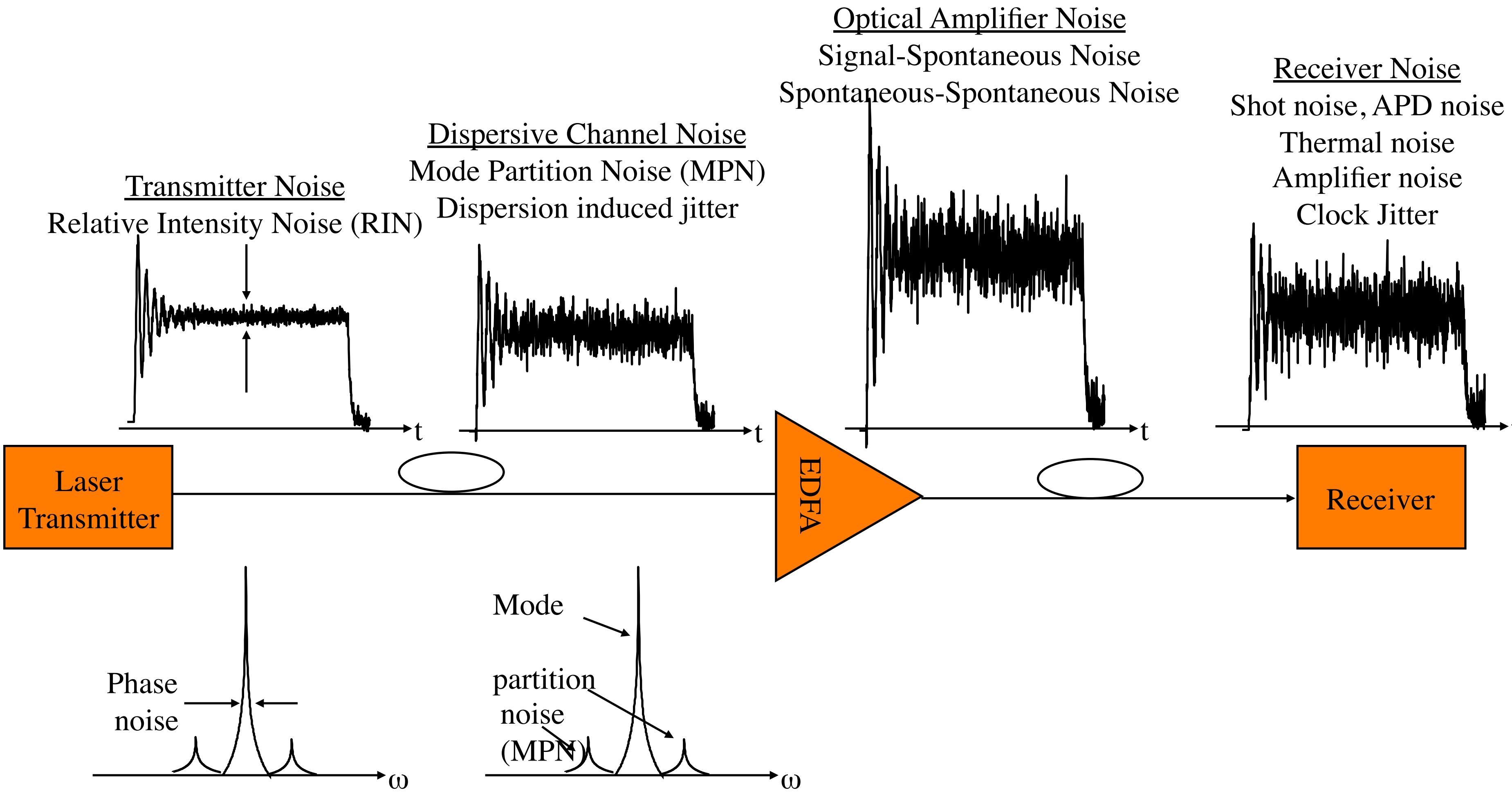
Line Coding
- DC balance
- Redundancy
- E.g Manchester Codes

Link Capacity and Spectral Efficiency

- Capacity of an optical communications channel is the maximum bit rate that can be transmitted without error for a given noise, bandwidth and power.
- Capacity can be calculated independent of modulation, coding or decoding technique
- For a WDM (Wavelength Division Multiplexed) optical communications system

$$S = \text{Spectral Efficiency} = \frac{\text{Capacity per Channel}}{\text{Channel Spacing}} = \frac{C}{\Delta f} = \frac{\text{Bits/Second}}{\text{Hz}}$$

Signal to Noise Ratio (SNR)



Optical Modulation Basics

Modulation Basics (I)

- Define
  - R_b = bit rate = bits/second
  - R_c = added redundancy per bit to improve SNR = baud = symbols/second
  - B = occupied bandwidth per channel
  - M = number of points in signal constellation
- Binary Modulation
  - One bit per symbol
- Non-Binary Modulation
  - More than one bit per symbol
- No inter-symbol interference (ISI)
  - $R_s \leq B$
- Error correction
  - $R_c \leq 1$
- No error correction
  - $R_c = 1$

Information bit rate per channel in one polarization state

$$R_b = R_s R_c \log_2 \mathrm{M}$$

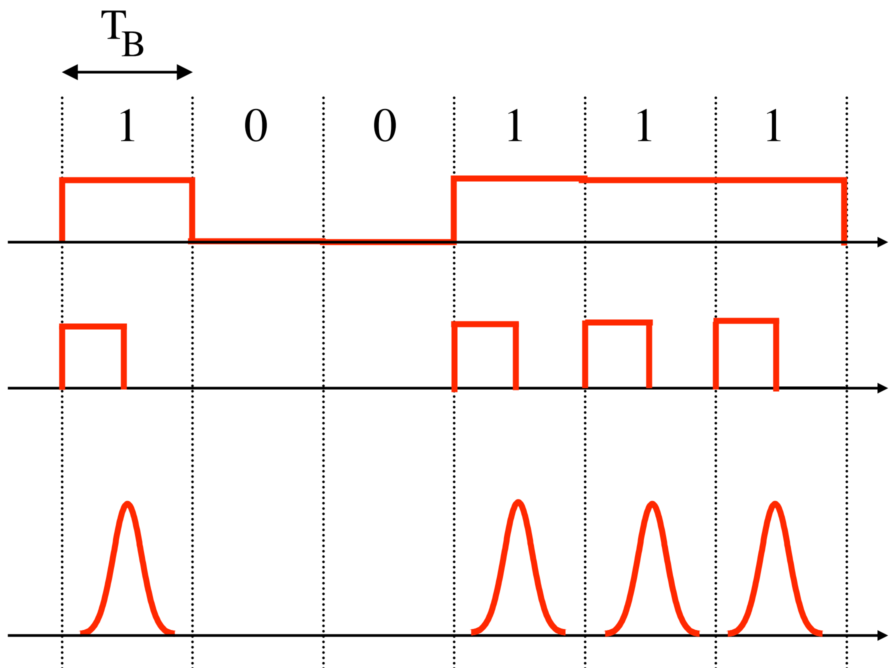
Binary Intensity Modulation

- The primary modulation format used for commercially deployed optical systems are intensity modulation (optical power modulation)

Non Return to Zero
NRZ

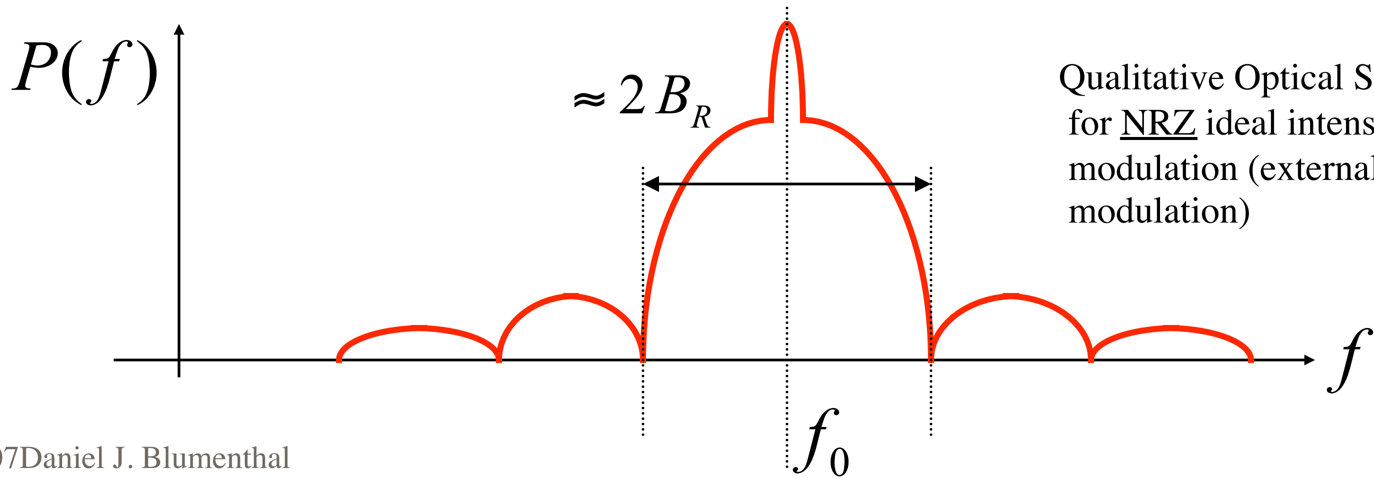
Return to Zero
RZ (50 % dc)

Pulsed
RZ (gaussian-like or soliton -like pulses, can be less than 50% dc)



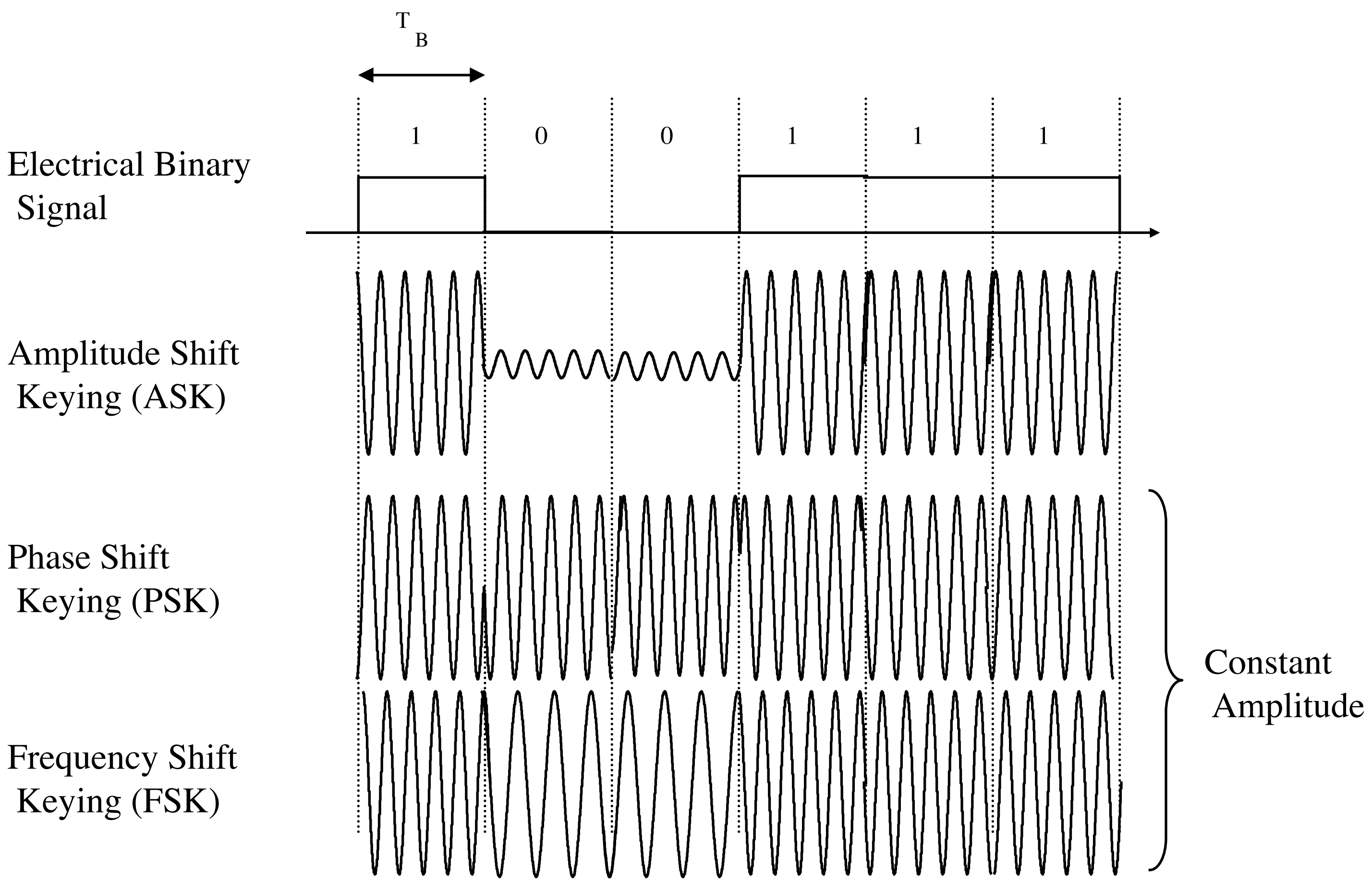
Optical spectrum for intensity modulation

- If the intensity modulation is imposed to the optical signal together with unwanted phase or frequency modulation (e.g chirp under direct laser modulation, excess laser phase noise)
  - The resulting optical spectrum is larger than the bit rate
- If the modulation is a (nearly) pure intensity modulation, without any accompanying phase/frequency shift (e.g. external modulation)
  - The resulting spectrum has a primary lobe that occupies the order of the bit rate



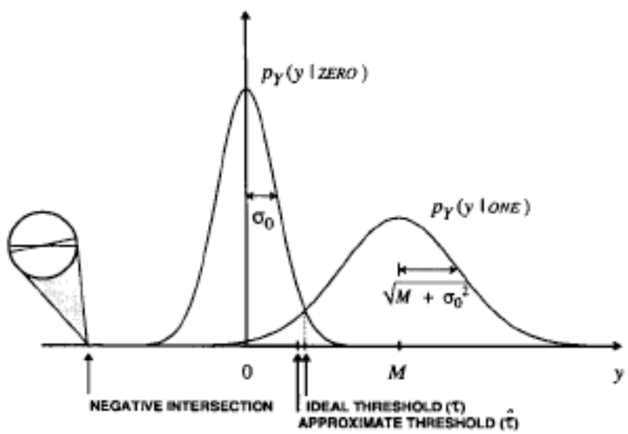
Qualitative Optical Spectrum for NRZ ideal intensity modulation (external modulation)

Coherent Binary Modulation

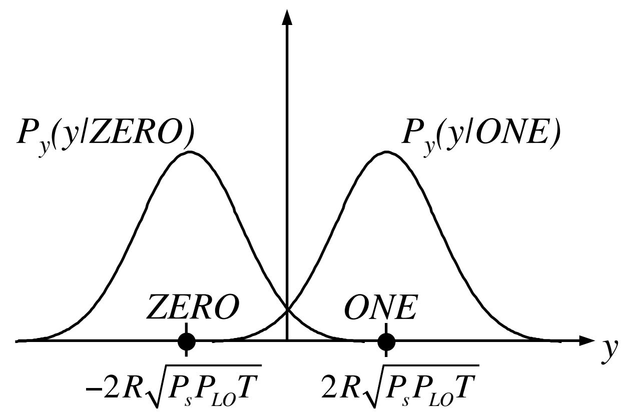


Binary Signal Constellations

Binary Intensity Modulation/Direct Detect (IM/DD)



Two-Level PSK



M = average power in 1 bit
σ_0 = variance of signal independent noise
P_s = average signal power
P_{LO} = average local oscillator power
T = bit period

Quadrature Multi-Level Modulation

- Both optical phase and amplitude can be used to code symbols per bit
- N-ASK is N-level amplitude shift keying (generalization of ASK): along amplitude axis
- N-PSK is N-level phase shift keying (PSK): along phase axis
- N-QAM is quadrature amplitude modulation: 2D in amplitude and phase
- Receiver must isolate one point in constellation per bit
- Noise makes more difficult to isolate symbol (SNR)
- 2-D space can be increased to 3 and 4-D by allowing temporal modulation of phase and amplitude