Optical Communications

Lecture 1: Introduction

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Contents

Reading List

- J M Senior, Optical Fibre Communications, Prentice-Hall
- G P Agrawal, Fiber-Optic Communication Systems, J Wiley
- J N Sibley, Optical Communications, Macmillan
- R J Ross, Fiber Optic Communications - Design Handbook, Prentice Hall.
- T E Stern, et al, Multiwavelength Optical Networks, Addison Wiley
- R Ramaswami et al, Optical Networks - A practical perspective, Morgan Kaufmann

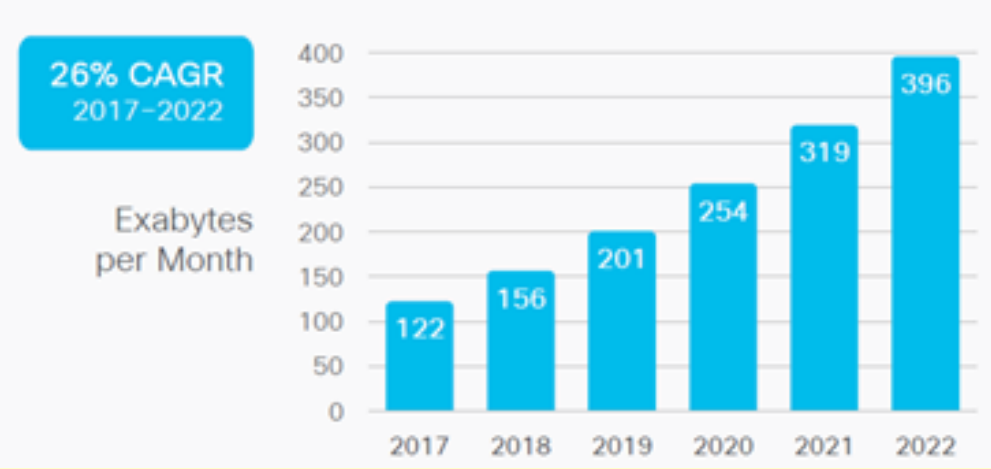
Transmission Media

- Transmission medium, or channel, is the actual physical path that data follows from the transmitter to the receiver.
- Copper cable is the oldest, cheapest, and the most common form of transmission medium to date.
- Optical fiber is being used increasingly for high-speed applications.

Transmission by Light: *why*?

- Growing demand for faster and more efficient communication systems
- Internet traffic is tripling each year
- It enables the provision of Ultra-high bandwidth to meet the growing demand
- Increased transmission length
- Improved performance
- etc.

Demand for Bandwidth



Typical data bandwidth requirement

20,000 x

- **Raw text = 0.0017 Mb**
- **Word document = 0.023 Mb**
- **Word document with picture = 0.12 Mb**
- **Radio-quality sound = 0.43 Mb**
- **Low-grade desktop video = 2.6 Mb**
- **CD-quality sound = 17 Mb**
- **Good compressed (MPEG1) video = 38 Mb**

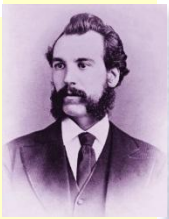
https://www.stl.tech/blog/bandwidth-demands-growing-incessantly-3-things-well-need-to-do-to-meet-them/

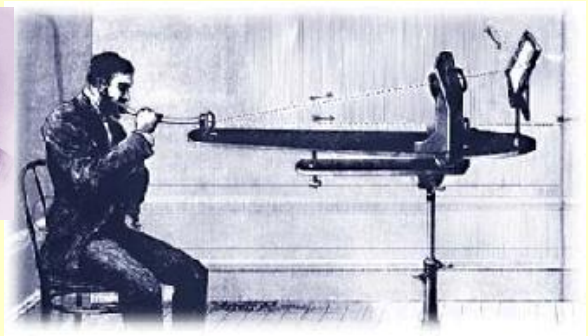
Historical Developments

- 800 BC Use of fire signal by the Greeks
- 400 BC Fire relay technique to increase transmission distance
- 150 BC Encoded message
- 1876 Elisha Gray and Alexander Bell Invent Telephone

First commercial Telephone

- 1880 Invention of the photophone by Alexander Graham Bell
- 1897-Rayleigh analyzes waveguide





Historical Developments - *contd.*

- 1880 Glass rods used for illumination
- 1930 Experiments with silica fibres, by Lamb (Germany)
- 1950-55 The birth of clad optical fibre, Kapany et al (USA)
- 1962 The semiconductor laser, by Natan, Holynal *et al* (USA)
- 1960 Line of sight optical transmission using laser:
  - Beam diameter: 5 m
  - Temperature change will effect the laser beam

Therefore, not a viable option

- 1966- A paper by **C K Kao** and Hockham (UL) was a break through
  - Loss < 20 dB/km ✔
  - Glass fibre rather than crystal (because of high viscosity)
  - Strength: 14000 kg /m^2.

Contd.

Historical Developments - *contd.*

- 1970 Low attenuation fibre, by Apron and Keck (USA) from 1000 dB/km - to - 20 dB/km
  - Dopent added to the silica to in/decrease fibre refractive index.
- Semiconductor Laser

I. Hayashi

- Late 1976 Japan, **Graded index multi-mode fibre**
  - Bandwidth: 20 GHz, but only 2 GHz/km

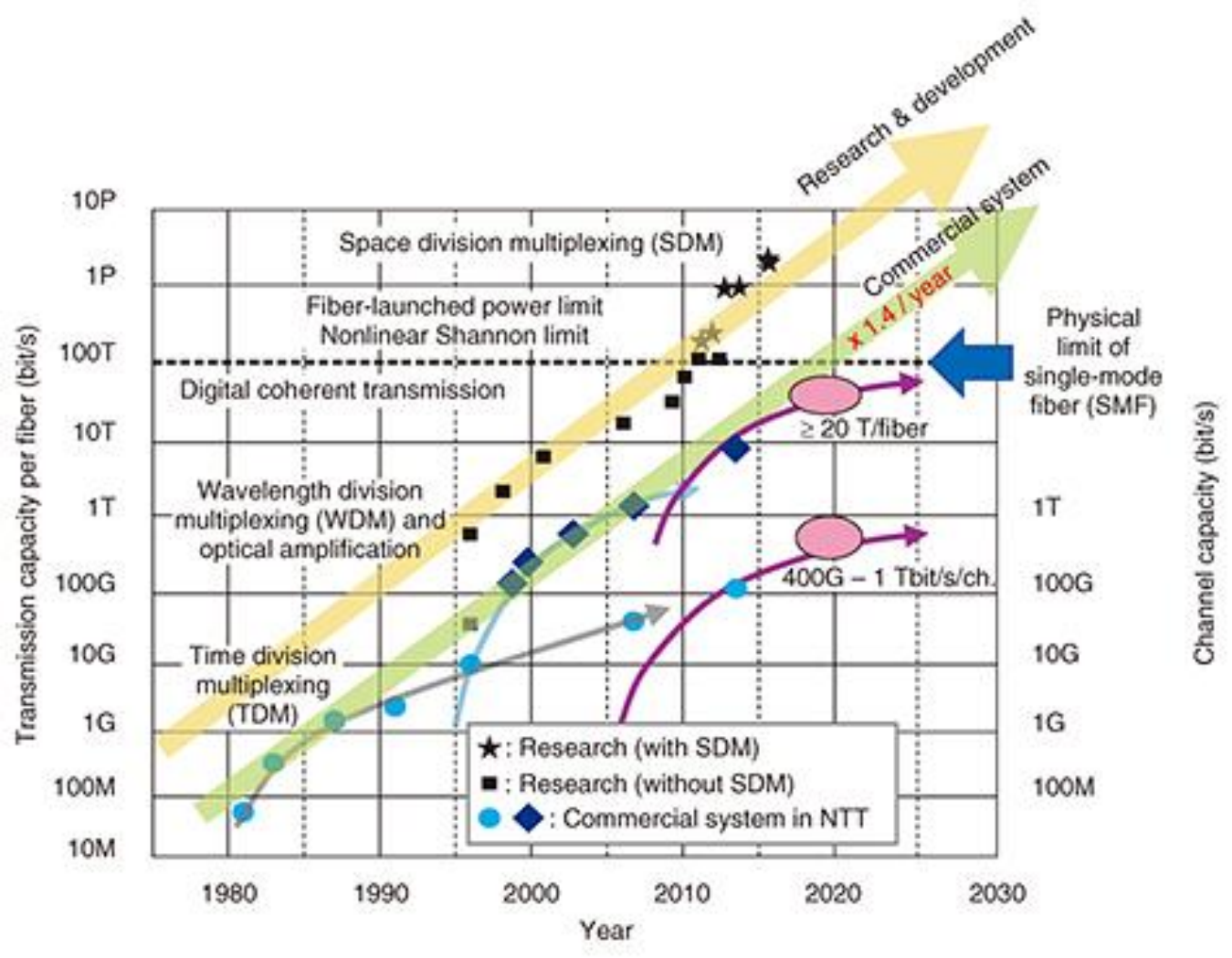
Start of fibre deployment.

- 1976 800 nm Graded multimode fibre @ 2 Gbps/km.
- 1980's
  - 1300 nm Single mode fibre @ 100 Gbps/km
  - 1500 nm Single mode fibre @ 1000 Gbps/km
  - Erbium Doped Fibre Amplifier

Historical Developments - *contd.*

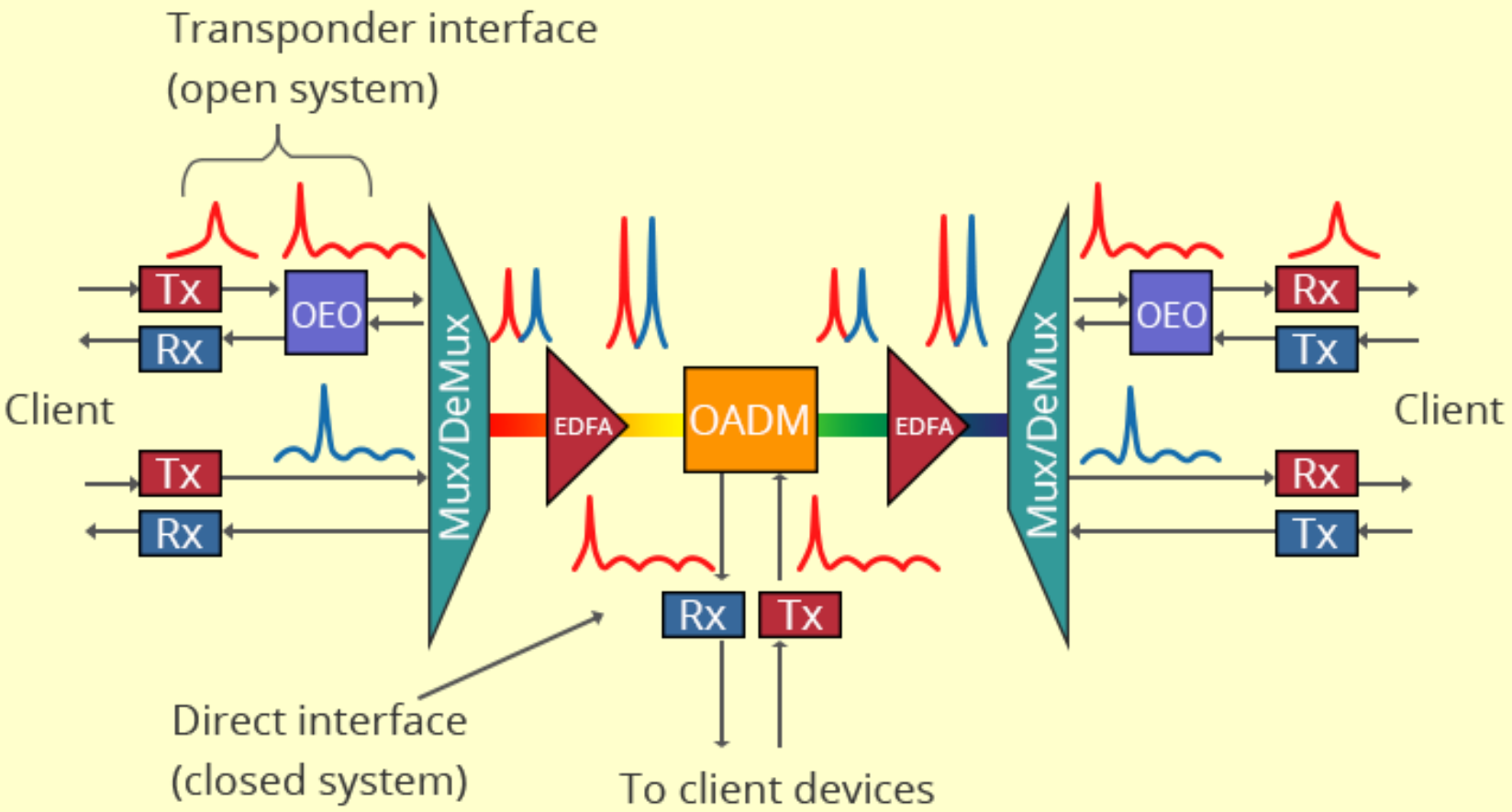
- 1990's
  - Soliton transmission (exp.): 10 Gbps over 10^6 km with no error
  - Optical amplifiers
  - Wavelength division multiplexing,
  - Optical time division multiplexing (experimental) OTDM
- 2000 and beyond
  - Optical Networking
  - Dense WDM, @ 40 Gbps/channel, 10 channels
  - Hybrid DWDM/OTDM
    - ~ 50 THz transmission window
    - > 1000 Channels WDM
    - > 100 Gbps OTDM
    - Polarisation multiplexing
    - Space division multiplexing
  - Intelligent networks

Lightwave Evolution



https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201706fa1.html

High Speed Systems



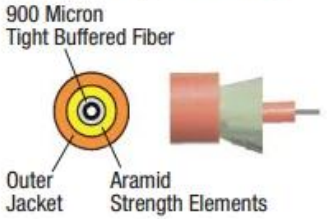
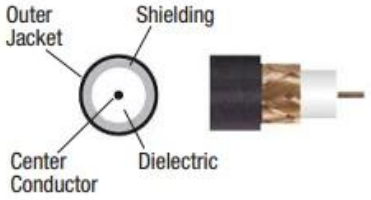
Commercial Systems

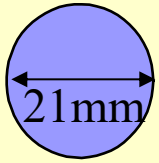
System	Year	WDM chan - nels	Bit rate/ channel	Bit rate/ Fibre	Voice channels per fibre	Regen spans
FT3	1980	1	45 Mb/s	45 Mb/s	672	7 km
FTG -1.7	1987	1	1.7 Gb/s	1.7 Gb/s	24,192	50 km
FT-2000	1992	1	2.5 Gb/s	2.5 Gb/s	32,256	50 km
NGLN	1995	8	2.5 Gb/s	20 Gb/s	258,000	360 km
WaveStar ™ 400G	1999	80 40	2.5 Gb/s 10 Gb/s	200 Gb/s 400 Gb/s	2,580,000 5,160,000	640 km 640 km
WaveStar ™ 1.6T	2001	160	10 Gb/s	1.6 Tb/s	20,640,000	640 km
LambdaXtreme	2003	128 64	10 Gb/s 40 Gb/s	1.28 Tb/s 2.56 Tb/s	16,512,000 33,0 24,000	4000 km 1000 km

H. Kogelnik, ECOC 2004

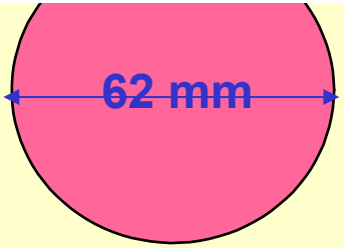
Optical Technology - Advantages

Tip *Bandwidth and application differences, between copper and fiber optic cabling*

Type:	Fiber Optic Cabling	Unshielded Twisted Pair Cabling (Copper)	Coaxial Cabling (Copper)
			
Typical Bandwidth:	<10 GHz	<100 MHz (cat 5E)	<1 GHz (RG6)
Typical Use:	Data communication Broadcast	Structured wiring in local area networks	Cable TV / Broadcast Test and instrumentation
Benefits:	Most bandwidth. Fastest transmission speeds. Immune to EMI/RFI.	Inexpensive, relatively easy to install and terminate	Inexpensive, relatively easy to install and terminate. Can span longer distances than UTP.
Limitations:	Difficult to terminate. Most expensive cost / foot.	Maximum distance of 100m. Can be affected by EMI/RFI.	Can be affected by EMI/RFI.



648 optical fibres
363 kg/km



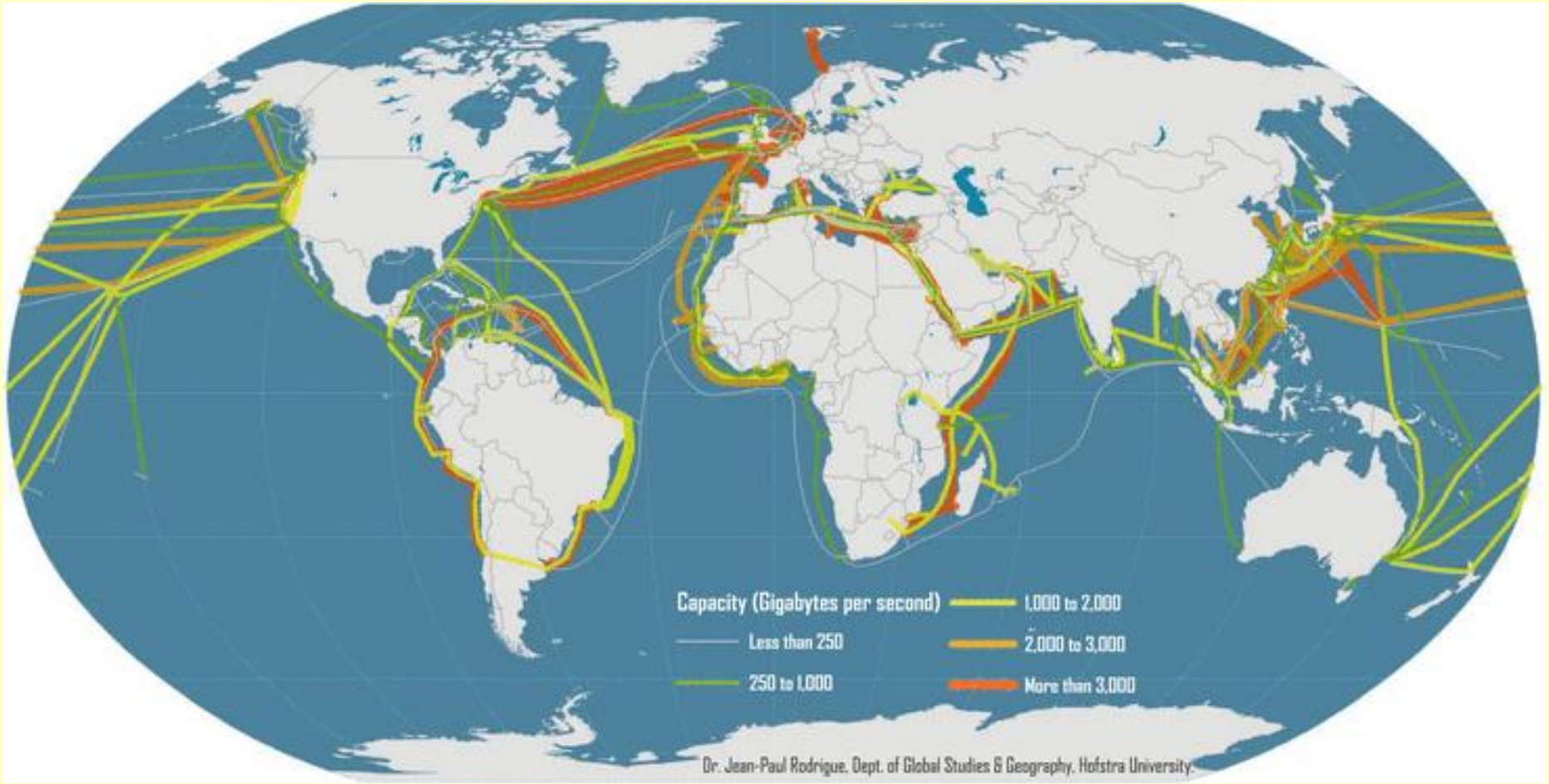
448 copper pairs
5500 kg/km

Applications

- Electronics and Computers
- Broad Optoelectronic
- Medical Application
- Instrumentation
- **Optical Communication Systems**
  - High Speed Long Haul Networks ✓
    (Challenges are transmission type)
  - Metropolitan Area Network (MAN) ✓?
  - Access Network (AN)?
    Challenges are:
    - Protocol
    - Multi-service capability
    - Cost

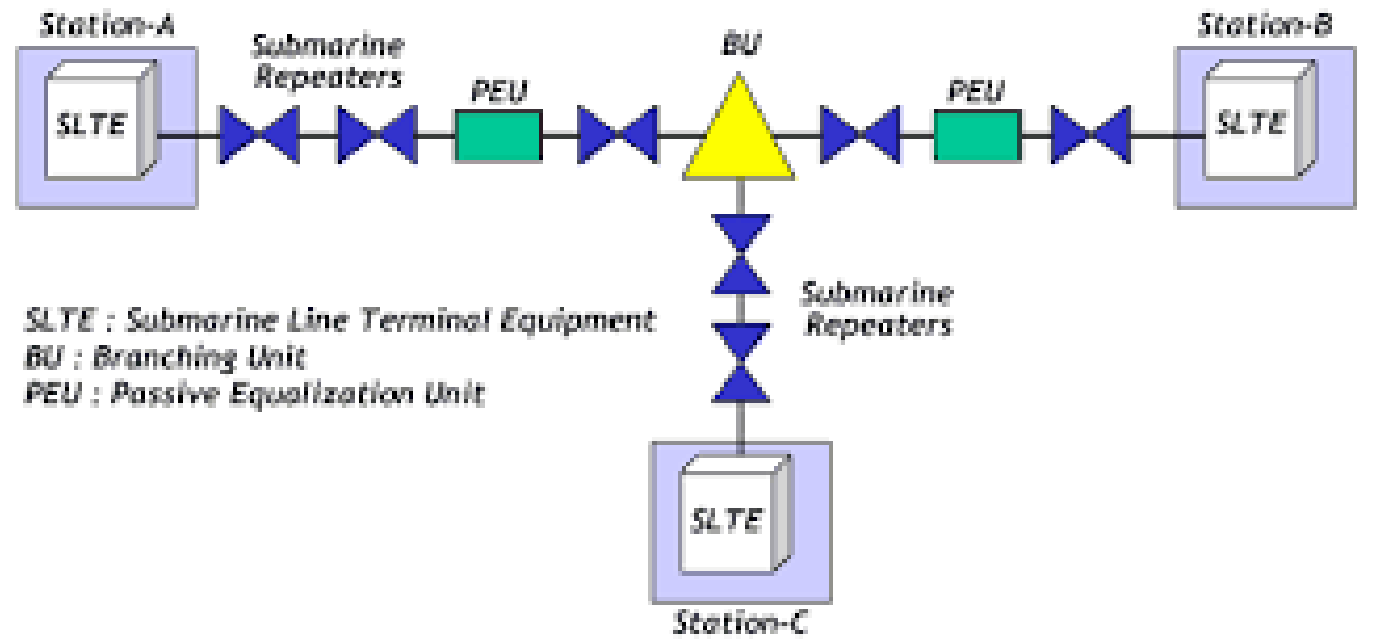
Optics is here to stay for a long time.

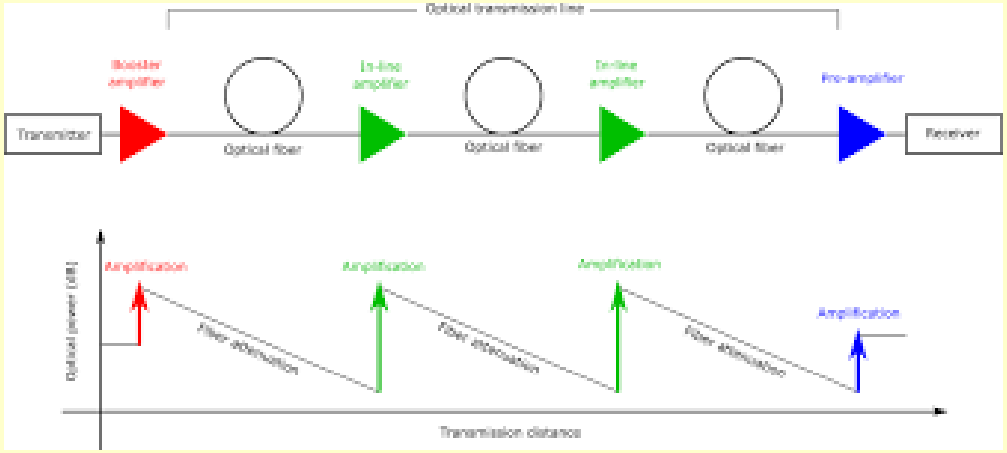
Undersea Cables



International submarine cable network of fiber-optic communication systems around 2015 (*source*: dataset encoded by Greg Mahlknecht, http://www.cablemap.info)

Optical Submarine Cable Systems

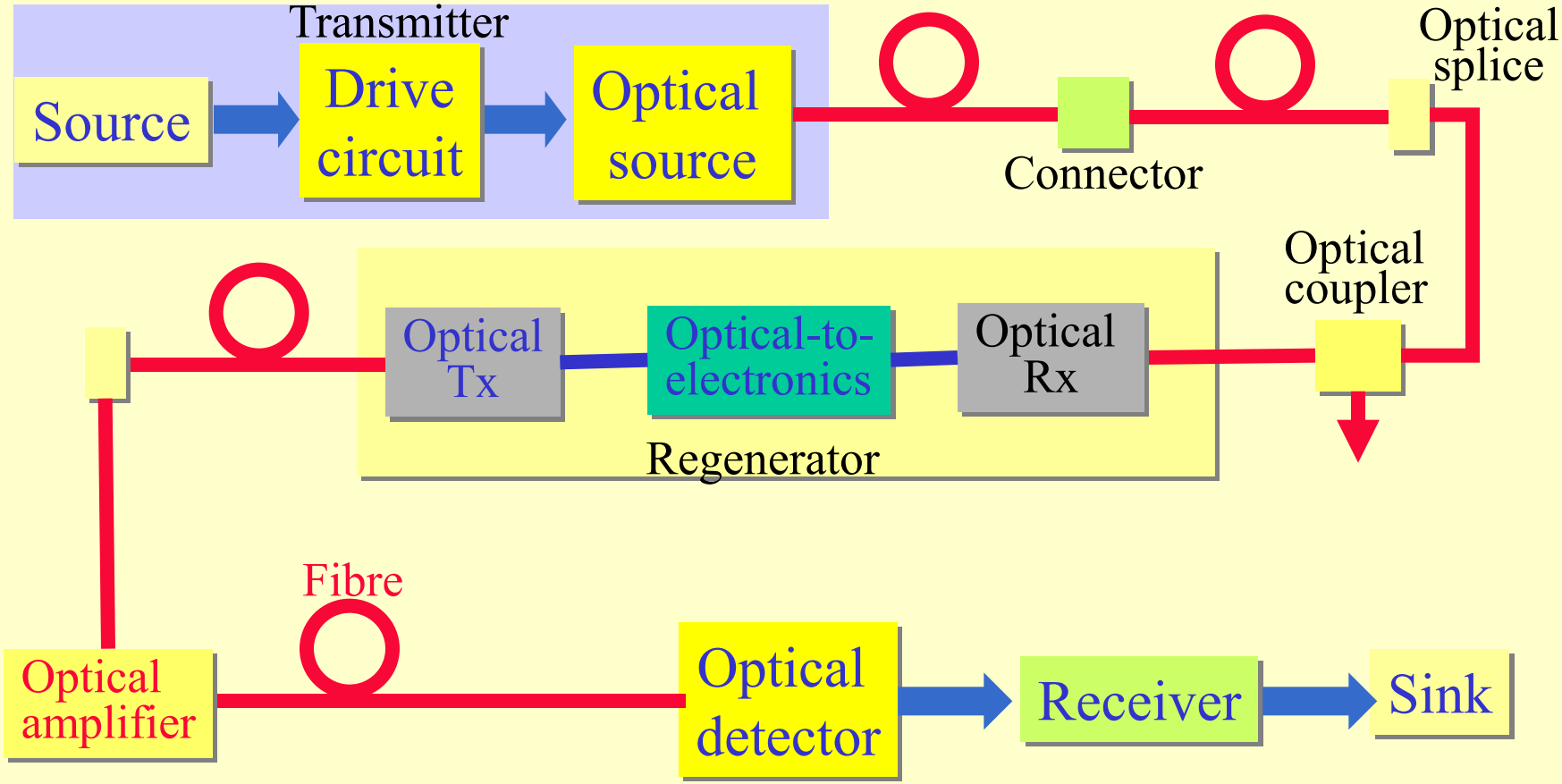




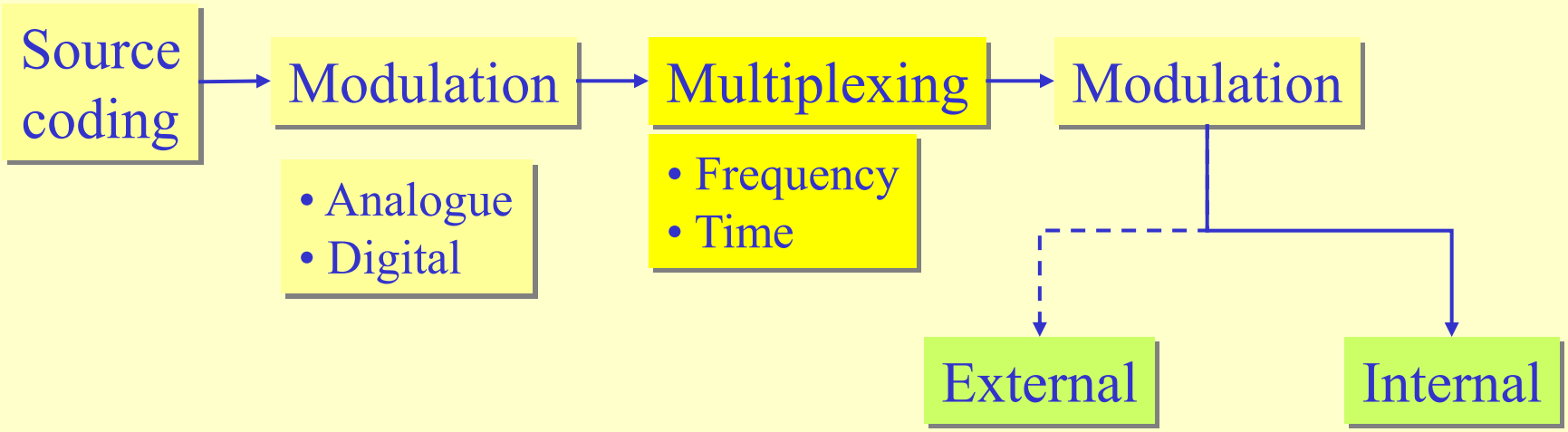
High-capacity Submarine fibre-optic Systems

Systems	Year	Capacity (Tb/s)	Length (km)	WDM channels	Fibre pairs
VSNL Transatlantic	2001	2.56	13,000	64	4
FLAG	2001	4.8	28,000	60	8
Apollo	2003	3.2	13,000	80	4
SEA-ME-WE 4	2005	1.28	18,800	64	2
Asia–America Gateway	2009	2.88	20,000	96	3
India-ME-WE	2009	3.84	13,000	96	4
African Coast to Europe	2012	5.12	13,000	128	4
West Africa Cable System	2012	5.12	14,500	128	4
Arctic Fibre	2015	8.0	18,000	50	4

System Block Diagram

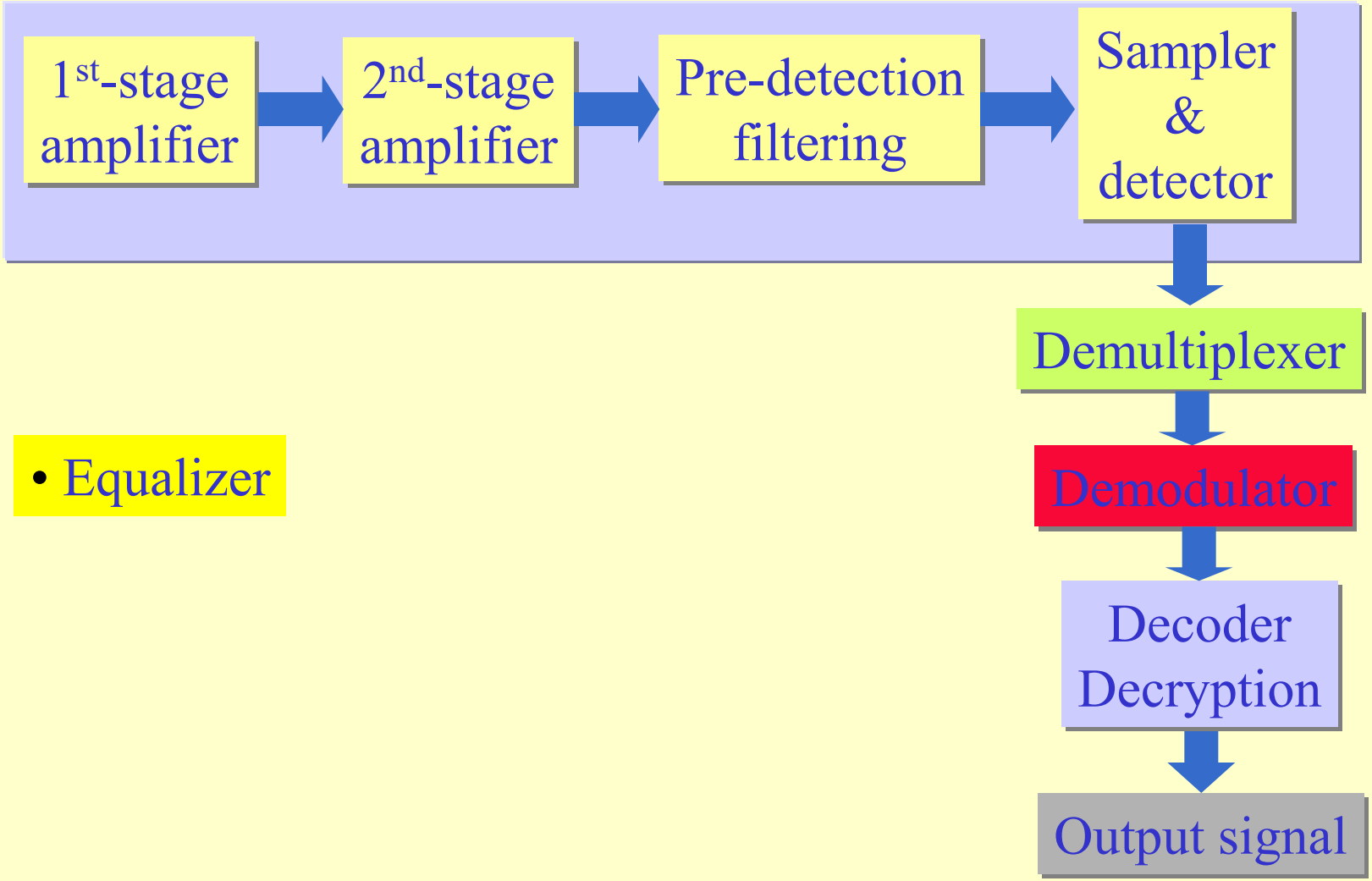


Source



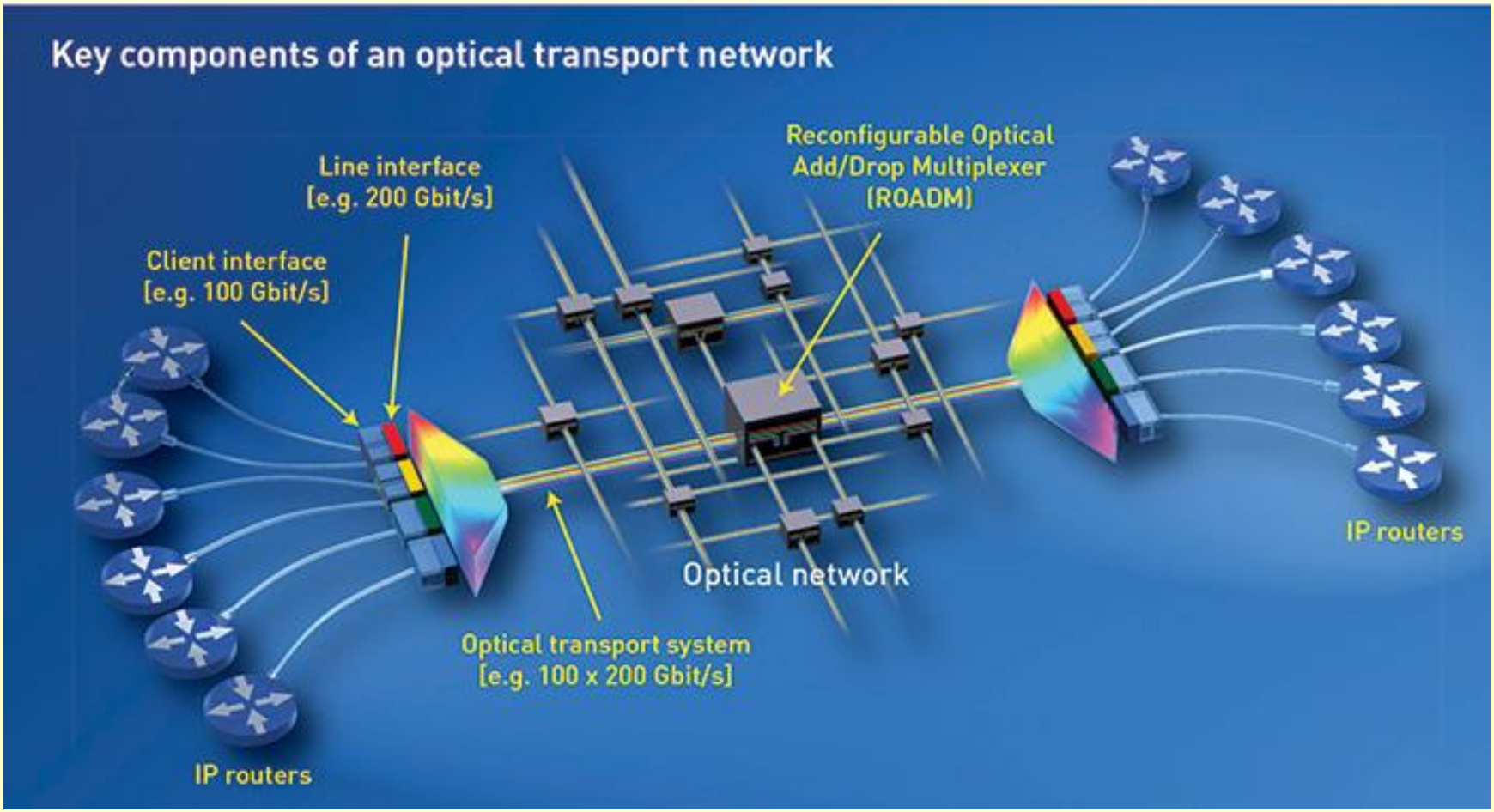
- Pulse shaping
- Channel coding
- Encryption
- etc.

Receiver



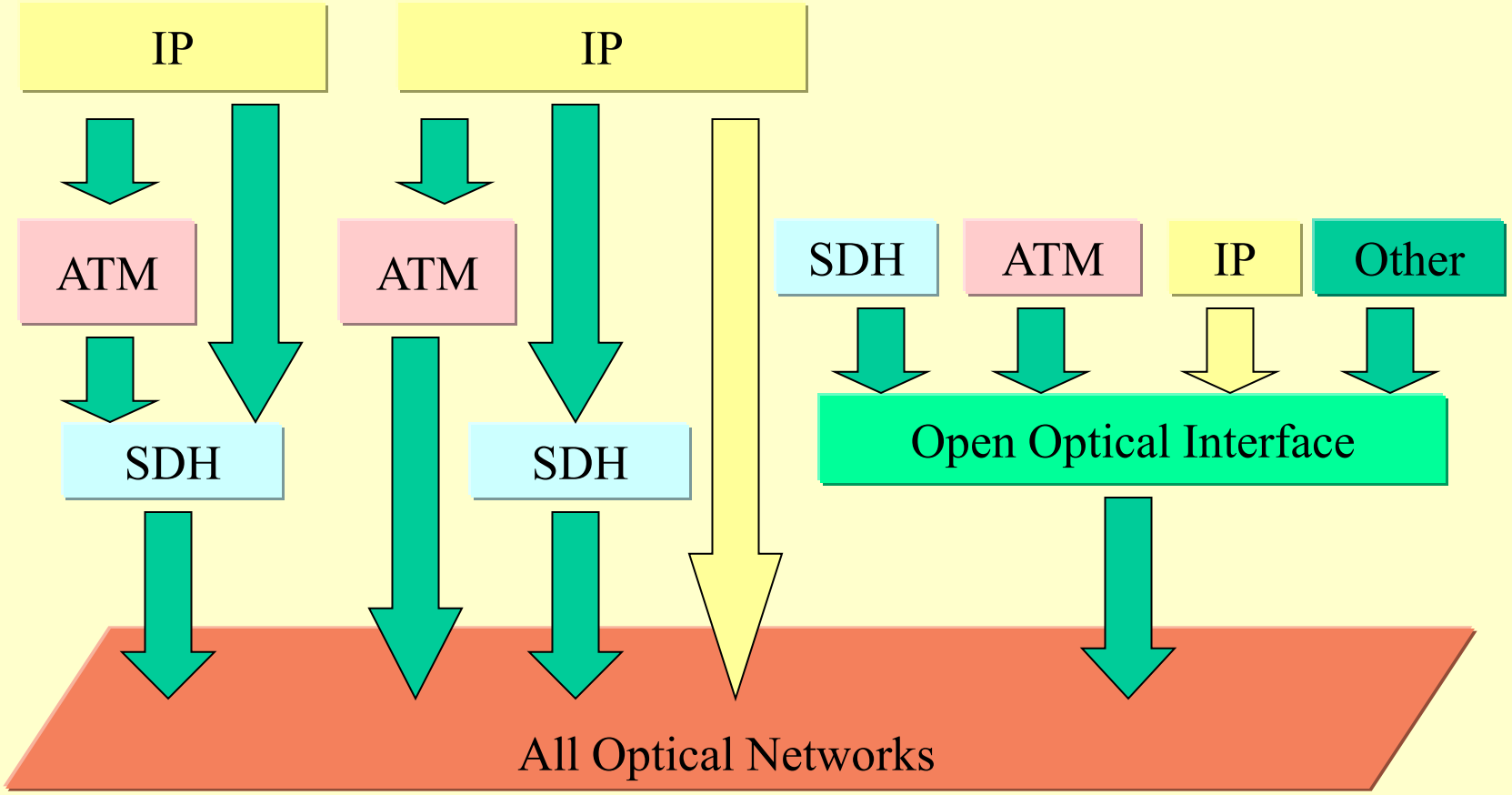
- Equalizer

All Optical Network



https://www.osa-opn.org/home/articles/volume_26/march_2015/features/scaling_optical_fiber_networks_challenges_and_solu/

All Optical Network



Challenges ahead:

- Network protection
- Network routing
- True IP-over-optics

Challenges Ahead

- Modulation and detection and associated high speed electronics
- Multiplexer and demultiplexer
- Fibre impairments:
  - . Loss
  - . Chromatic dispersion
  - . Polarization mode dispersion
  - . Optical non-linearity
  - . etc.
- Optical amplifier
  - . Low noise
  - . High power
  - . Wide bandwidth
  - . Longer wavelength band **S**

Challenges Ahead - *contd.*

- Dedicated active and passive components
- Optical switches
- All optical regenerators
- Network protection
- Instrumentation to monitor QoS

Next Lecture: Nature of Light and Light Propagation