Optical Networks
[EENGM0003]

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Optical Networks unit: Main outcomes

- **Networks requirements** for supporting current, emerging and future Internet applications

- Different **types** of modern optical networks

- State-of-the-art and emerging optical network **transport technologies**

- Modern techniques and mechanism for **control and managements** of optical networks

Complementary to

Optical Communications Systems and Data Networks   EENGM2001

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Outline of the course

- **Session1 (Jan. 25):** Introduction to modern optical networks

- **Session2 (Feb.1):** Fundamental optical network technologies and topologies

- **Session3 (Feb.8):** Introduction to Wavelength Division Multiplexing (WDM)

- **Session4 (Feb.15):** WDM Network topologies

- **Session5 (Feb.22):** Advanced WDM routing

- **Session6 (Mar.8):** Higher order modulation formats

- **Session7 (Mar.15):** Elastic networks and Sub-wavelength Optical networks

- **Session8 (Mar.22):** Client layers of optical networks

- **Session9 (Mar.29):** Optical network control and management

- **Session10 (Apr 26):** Optical network security and quantum networking

- **Session11 (May 3): revision class**

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assessment methods

1 Formative assessment/ related to the lab

- Summative Assessment
  - 100% final Exam

All information will be available to Blackboard

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Reading material

- Textbook (required): Optical Networks: A Practical Perspective , Rajiv Ramaswami, Kumar Sivarajan, and Galen Sasaki, , 3rd Edition, Morgan Kaufman Publishers, 2009

- Textbook (required): Optical WDM Networks, Biswanath Mukherjee, Springer, 2006

- Texbook: Enabling Optical Internet with Advanced Network Technologies, Javier Aracil, Franco Callegati, Springer, 2009

- Textbook: Advanced Optical Communication Systems and Networks, Artech House, 2013

- Textbook: Next Generation Transport Networks: Data, Management, and Control Planes,Manohar Naidu Ellanti, Springer, 2005

- Textbook: IP over WDM: Building the Next Generation Optical Internet, Sudhir Dixit, Wiley , 2003

- Textbook: Optical Network Control: Architecture, Protocols, and Standards, Greg Bernstein, Bala Rajagopalan, Debanjan Saha, Addison Wesley, 2004

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HPN Group/ University of Bristol

http://www.bristol.ac.uk/engineering/research/hpn/

- HPN is one the UK's most recognised network research centre

- world leadership on open innovation

- one of the largest experimental infrastructure including optical, 5G and Smart City networks

- more than £80M of research grants over the last five years

- collaborate with leading partners across the UK, Eur

- Nokia/BT/Bristol City council
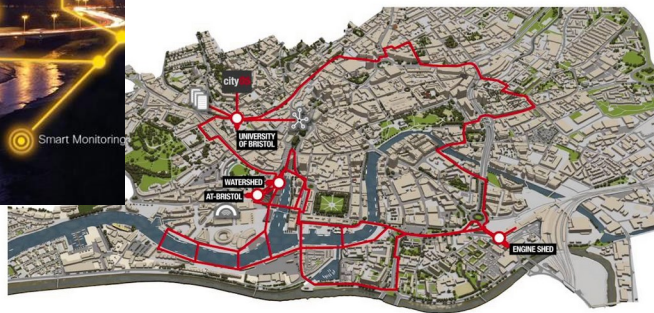
Part of NDFIS network

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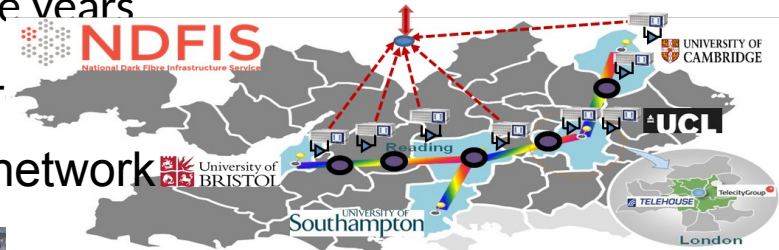
Part 1

- Introduction to modern optical networks

  ➢ **Session1:** Introduction to modern optical networks

  ➢ **Session2**: Fundamental optical network technologies and topologies

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Introduction to modern optical networks

- Optical Networks : Why?

- What is an optical network

- What is an optical communication link

- Optical transmission and modulation techniques

- Different types of optical network connectivity and topology

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Internet of Things (IoT)
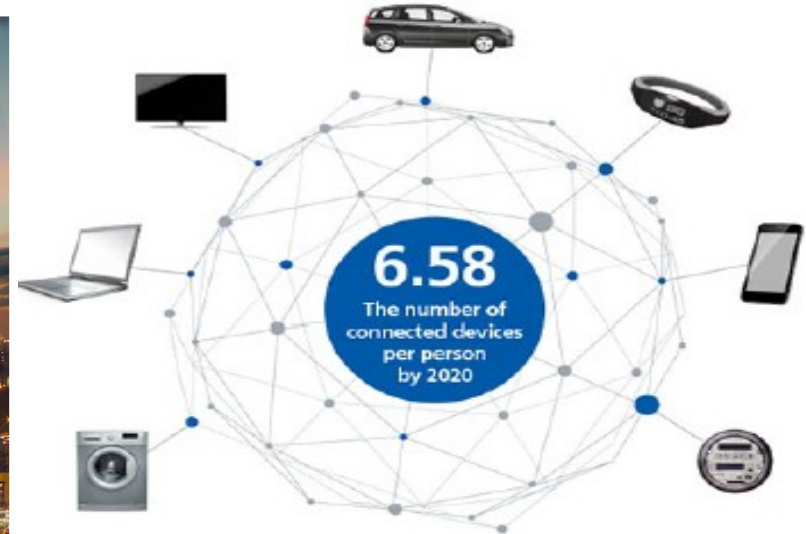
Number of interconnected devices drastically affects IP traffic
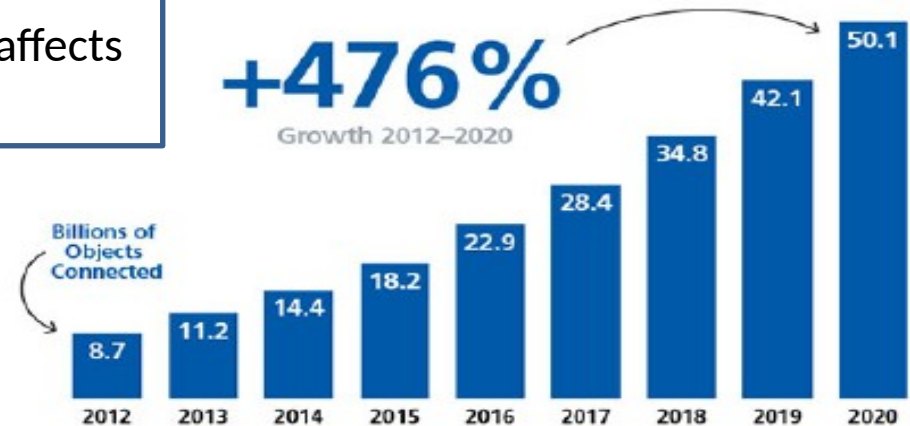
Cloud Computing

CLOUD COMPUTING SERVICES

cloud computing means storing and accessing data and programs over the Internet

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How cloud affects Internet traffic

What Happens in an Internet Minute?

1,572,877 GB of global IP data transferred[1]

10 Million ads displayed[2]

347,222 Tweets[3]

3.3 Million pieces of content shared[4]

6.9 Million messages sent[4]

Netflix + Youtube = more than ½ of all traffic[5]

$400 Million during Alibaba peak day sales[6]

438,801 Wiki page views[7]

10 Million WeChat messages at its peak[9]

34.7 Million instant messages (MIM) sent[8]

194,064 app downloads[10]

$133,436 in sales[11]

31,773 hours of music played[12]

38,194 photos uploaded[13]

57,870 page views[14]

100 hours of video uploaded[16]

138,889 hours of video watched[16]

4.1 Million searches[15]

23,148 hours of video watched[17]

And Future Growth is Staggering

2012 2017

By 2017, mobile traffic will have grown **13X** in just 5 years[1]

In 2017, there will be **3X** more connected devices than people on Earth[1]

All digital data created reached **4 zettabytes** in 2013[18]

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Global Internet traffic

Exabytes per Month

Nearly 4X Increase

Legend:
- Other (0.1%, 0.2%)
- M2M (0.6%, 4.2%)
- Tablet (1.0%, 12.7%)
- Smartphone (2.4%, 15.1%)
- TV (4.0%, 6.8%)
- PC (91.9%, 60.9%)

Source: Cisco VNI, 2013
The percentages within parenthesis next to the legend denote the relative traffic shares in 2012
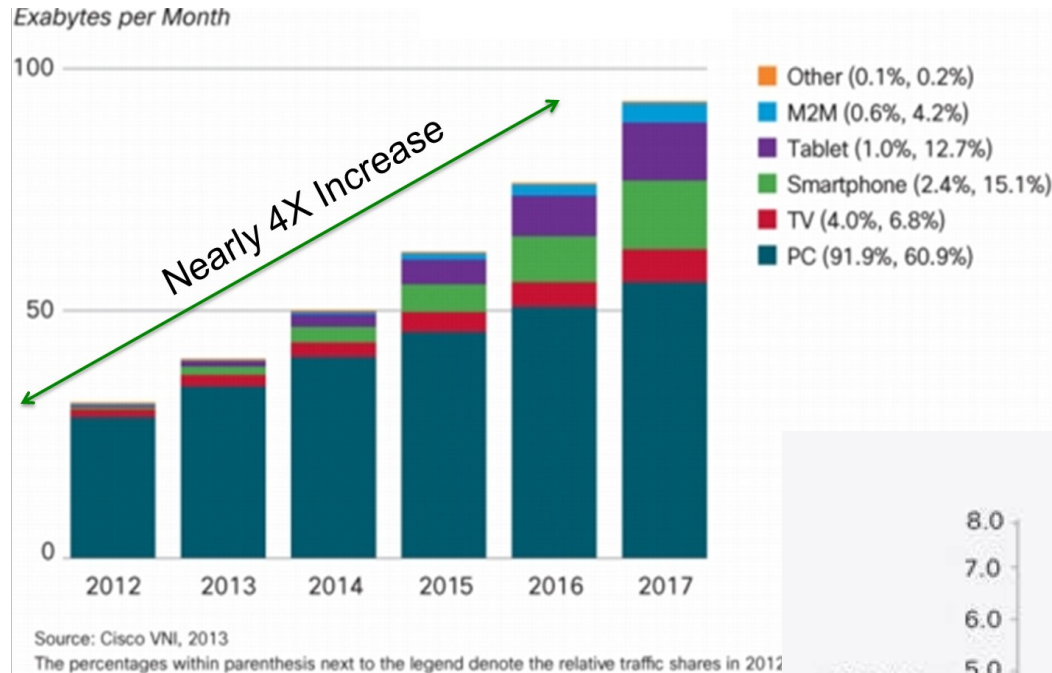
Cisco reveals an annual global Cloud-IP traffic growth of 21% to 7.4 ZB by the end of 2021 !!!!

Nearly 5X Increase

Zettabytes per year

% Share of Within Data Center Traffic

28%   33%   37%   40%   50%

1.4   2.2   3.1   4.2   5.6   7.4

Source: Cisco Global Cloud Index, 2016–2021.

Internet Network requirements

How internet really looks like

https://internet-map.net/
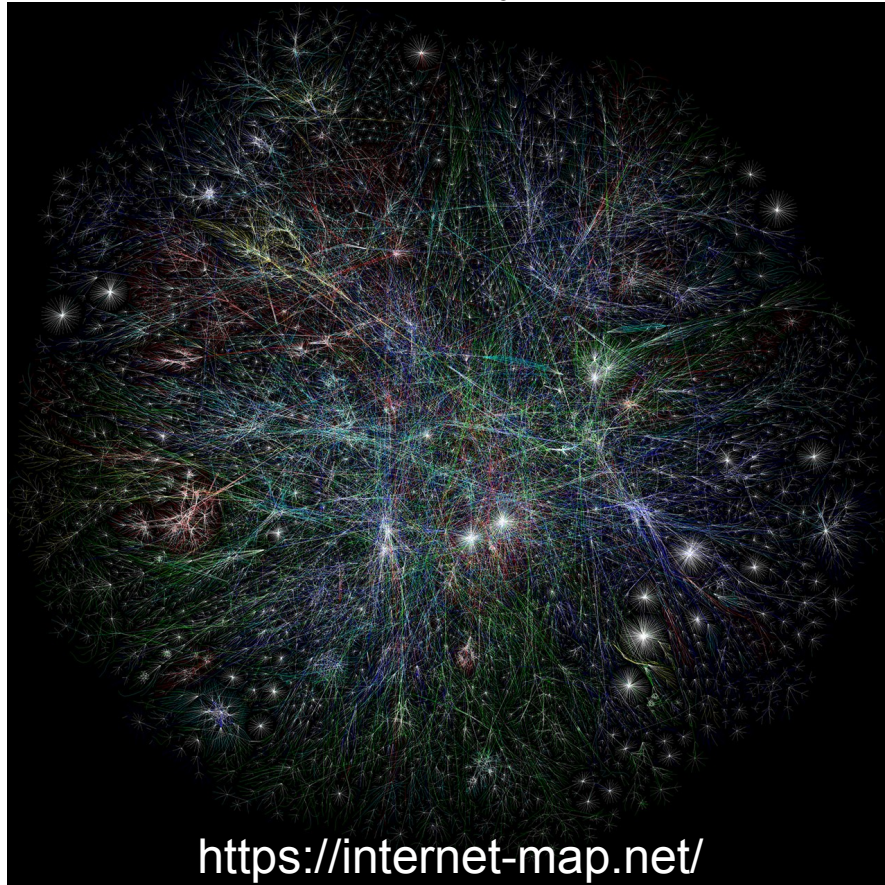
90% of internet are fiber-optic cables that carry the data around the world

➤ **Bandwidth per connection** is increasing:
- from 155Mbit/s to 2.5/10Gbit/s even 40 Gbit/s

➤ **Total core bandwidth** is increasing:
- Reaching Zeta-byte per month by end of decade

➤ **High availability**, full redundancy & fast recovery

➤ **Low latency** for novel applications (autonomous cars, VR/AR, e-health etc)

➤ **Energy efficient**

➤ **Low Cost:** Network Providers to provide more services at higher capacity at lower prices!
- A positive feedback business model!
- More users

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Optics Communications

Optical fiber to transmit light:
~ 90% of networks total cables length is optical fiber

~ light frequency: 193 THz

~ propagation losses: 0.2 dB/Km
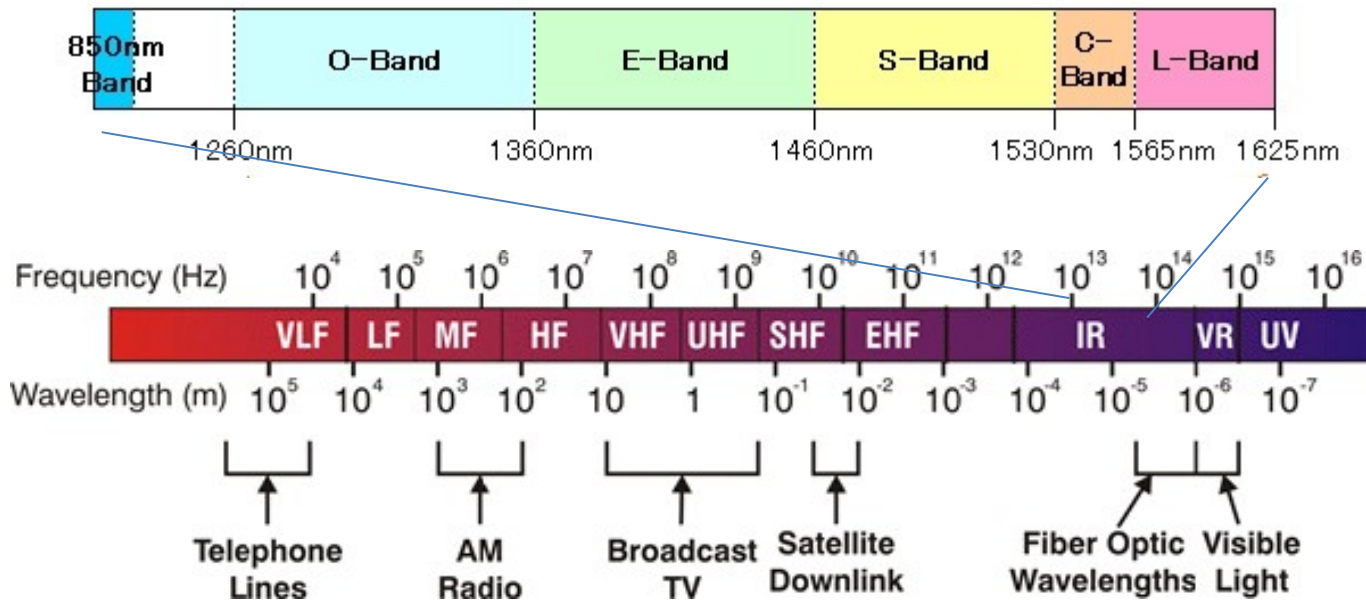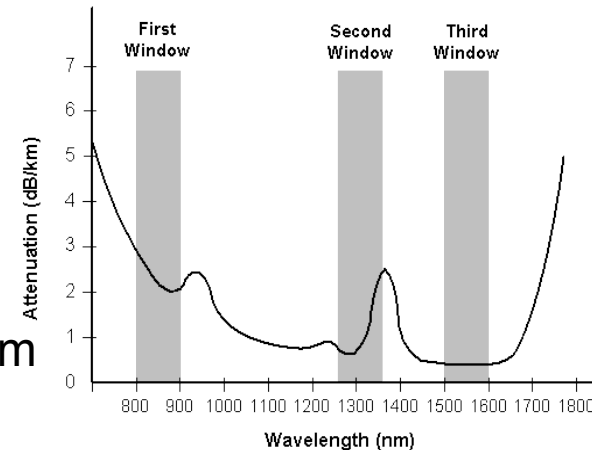
So how does this work?

Opto-Electronic Conversion

Optical Communication systems:

Optical fibre is the most cost effective way to move huge amounts of information) quickly and reliably over lor

- Huge Bandwidth
- Long Reach
- Low loss
- Cost effective
- Secure links

Bandwidth x Distance product
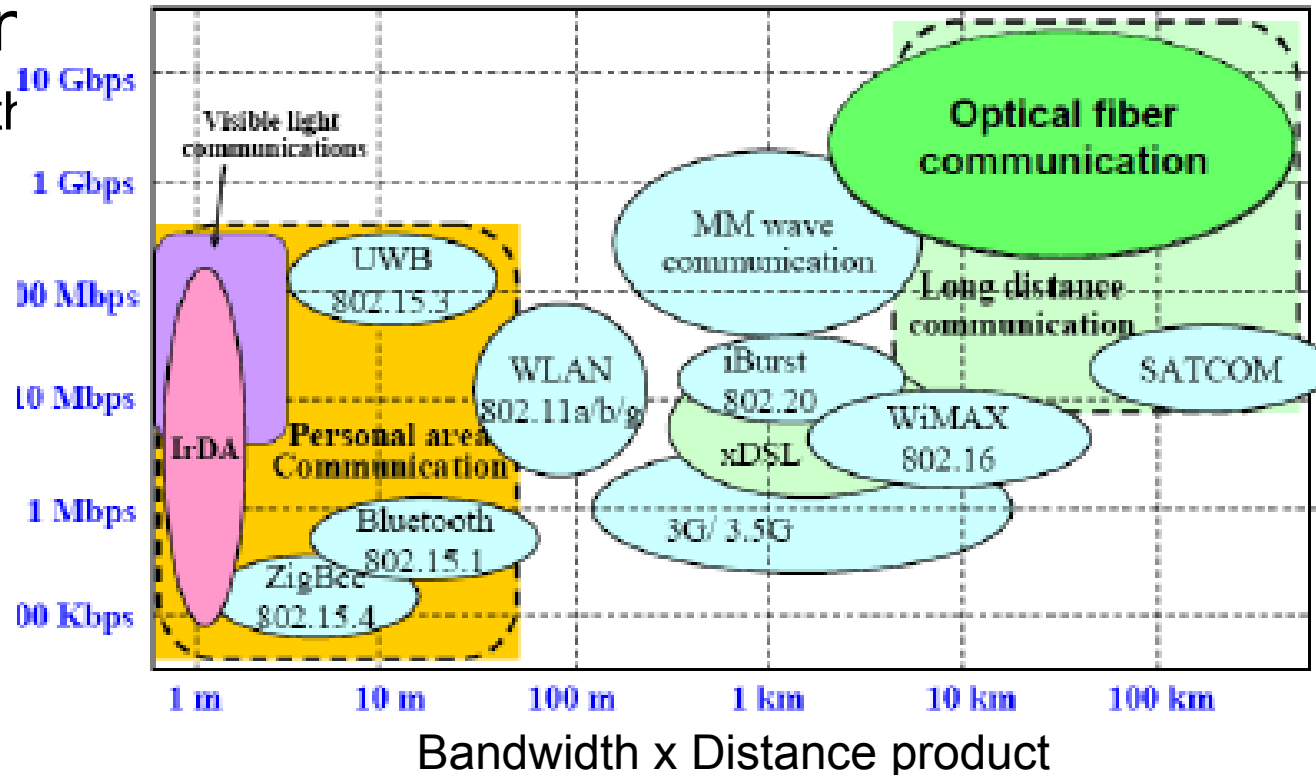
Why Optical Networking II – advanced networks

Internet backbone network needs more than just simple high bandwidth point-to-point

> Large number of different types of users

> Application with heterogeneous bandwidth and service requirements

> Delivery of bandwidth in minutes/hours and not days/months

Modern optical networks provide:

➢ Dynamic allocation of connectivity and bandwidth

➢ Routing and signaling of bandwidth connectivity

➢ significant energy efficiency

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Optical transmission bandwidth evolution
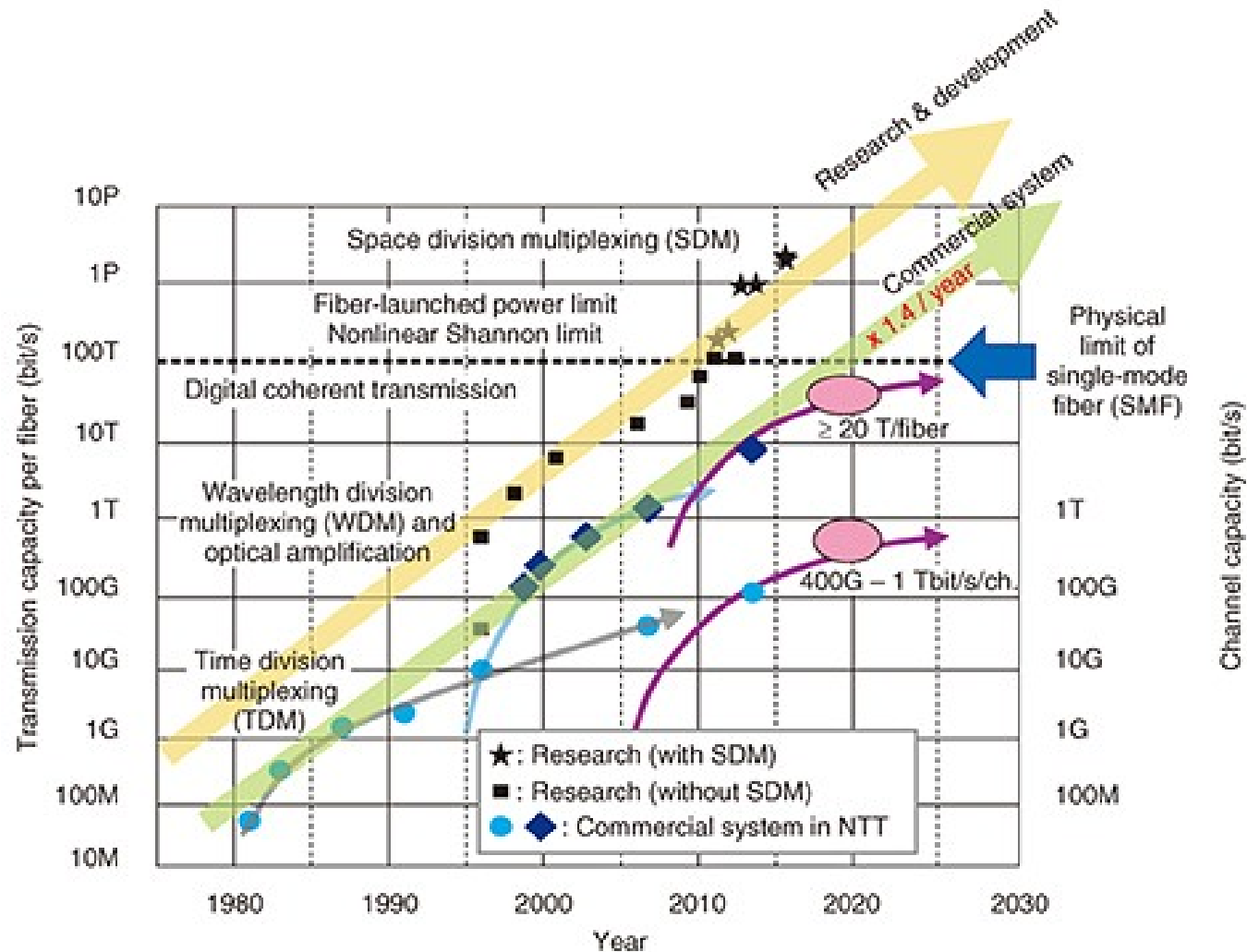
State-of-the-art Space Division Multiplexing Technologies for Future High-capacity Optical Transport Networks

What is optical networking

- **Optical Communication System**
    - Three basic components
        - Optical Transmitter
        - Optical Receiver
        - Optical Communication Channel
            - Optical Fibre

Optical communication channel

transmitter

receiver
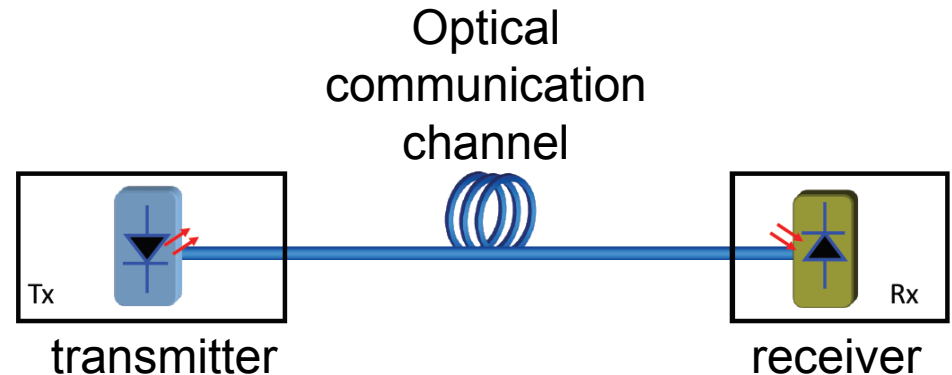
Optical Network

- Deploying optical communication system within context of a network topology
- To build a network topology interconnecting multiple end points
- Transmission, moving and routing data efficiently across the network

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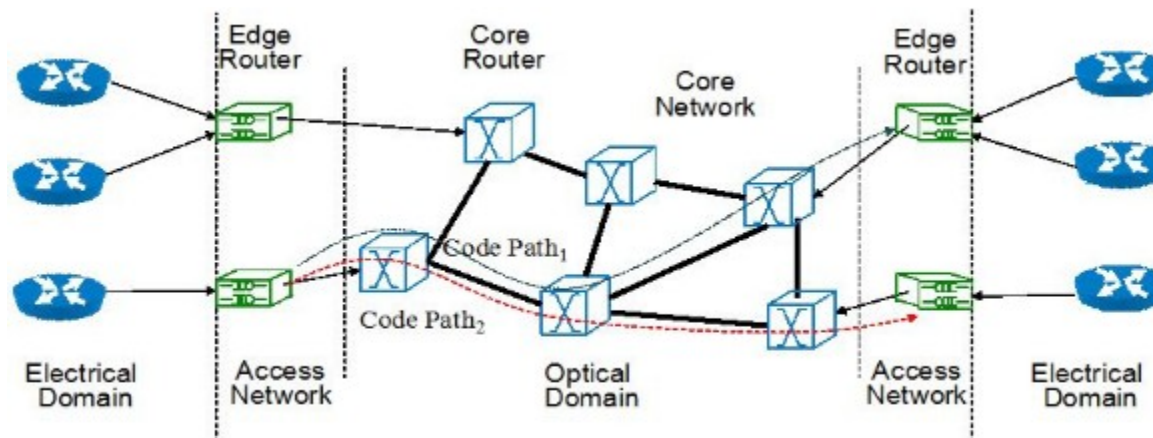
Optical communication link

- ## Basic principle:
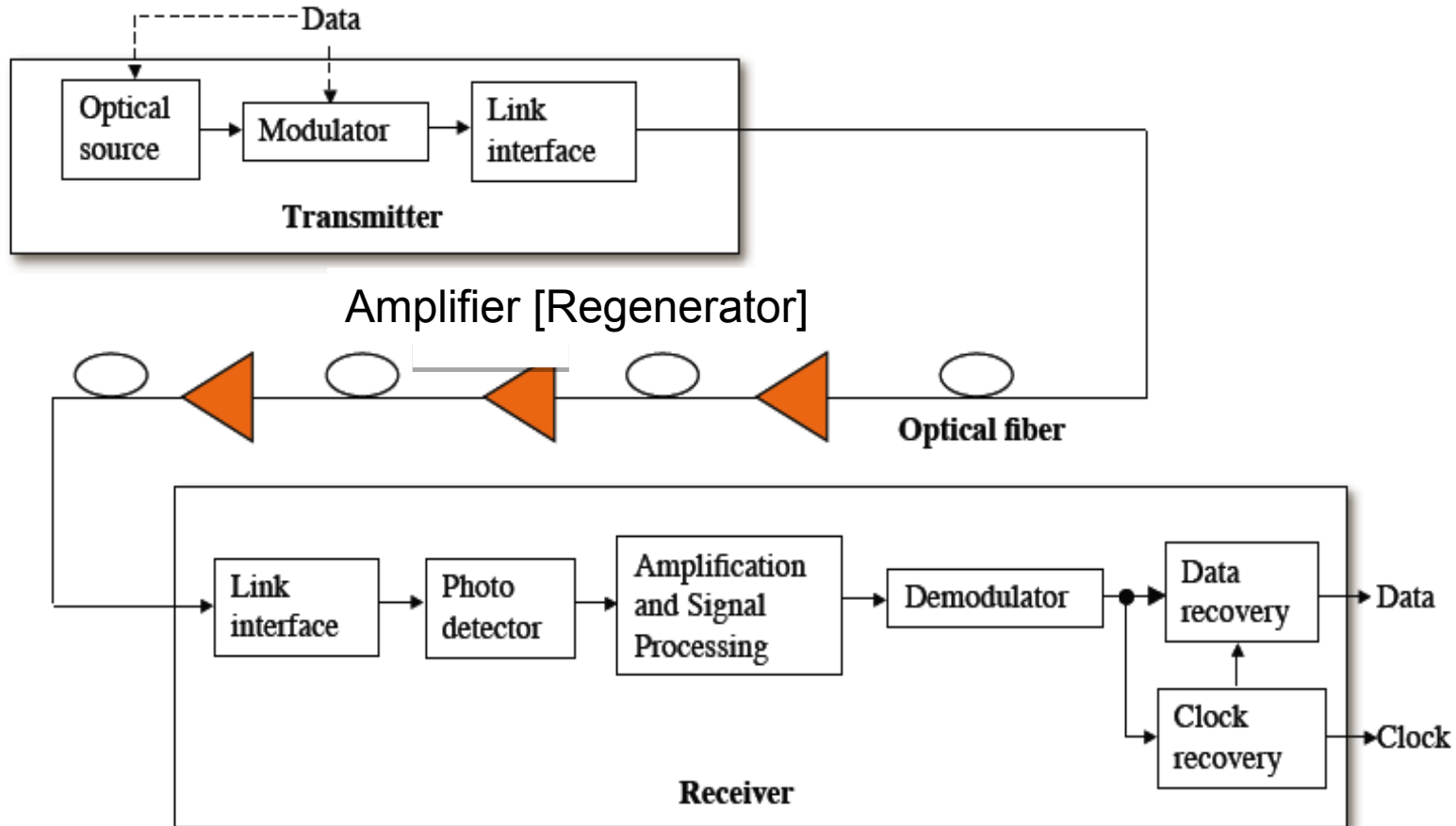
Key parameters of optical communication link
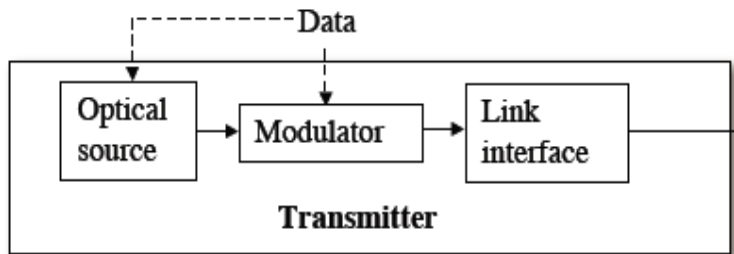
Channel:
➢ Laser Optical Power
➢ Wavelength(s)

Capacity:
➢ Data Format
➢ Line bit rate
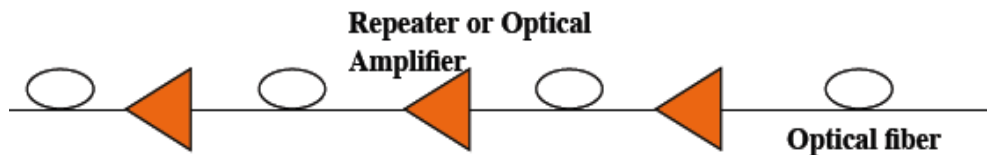
Fiber:
➢ Multimode/Singlemode/Multicore
➢ Link power budget and losses
➢ length

Amplifiers/Repeaters:
➢ 2R/3R regenerator
➢ EDFA, SOA, Raman
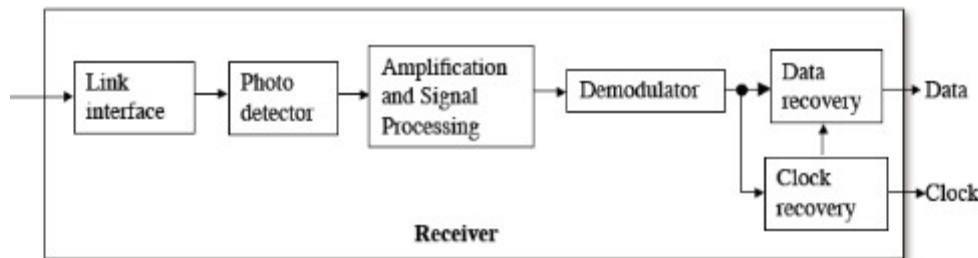
Receiver:
➢ PIN/APD - electrical output power
➢ Sensitivity

Channel:
➢ Noise level (OSNR)
➢ Quality of Signal (Bit Error Rate)

What is an optical carrier /channel/frequency/Lambda

Fibre attenuation

Windows of low loss in fibre

Channel rates

Year 1980:
1 channel

140 Mbit/s

year 1990:
2 channels

2.5 Gbit/s

year after 200
> 50 channe

20 Gbps

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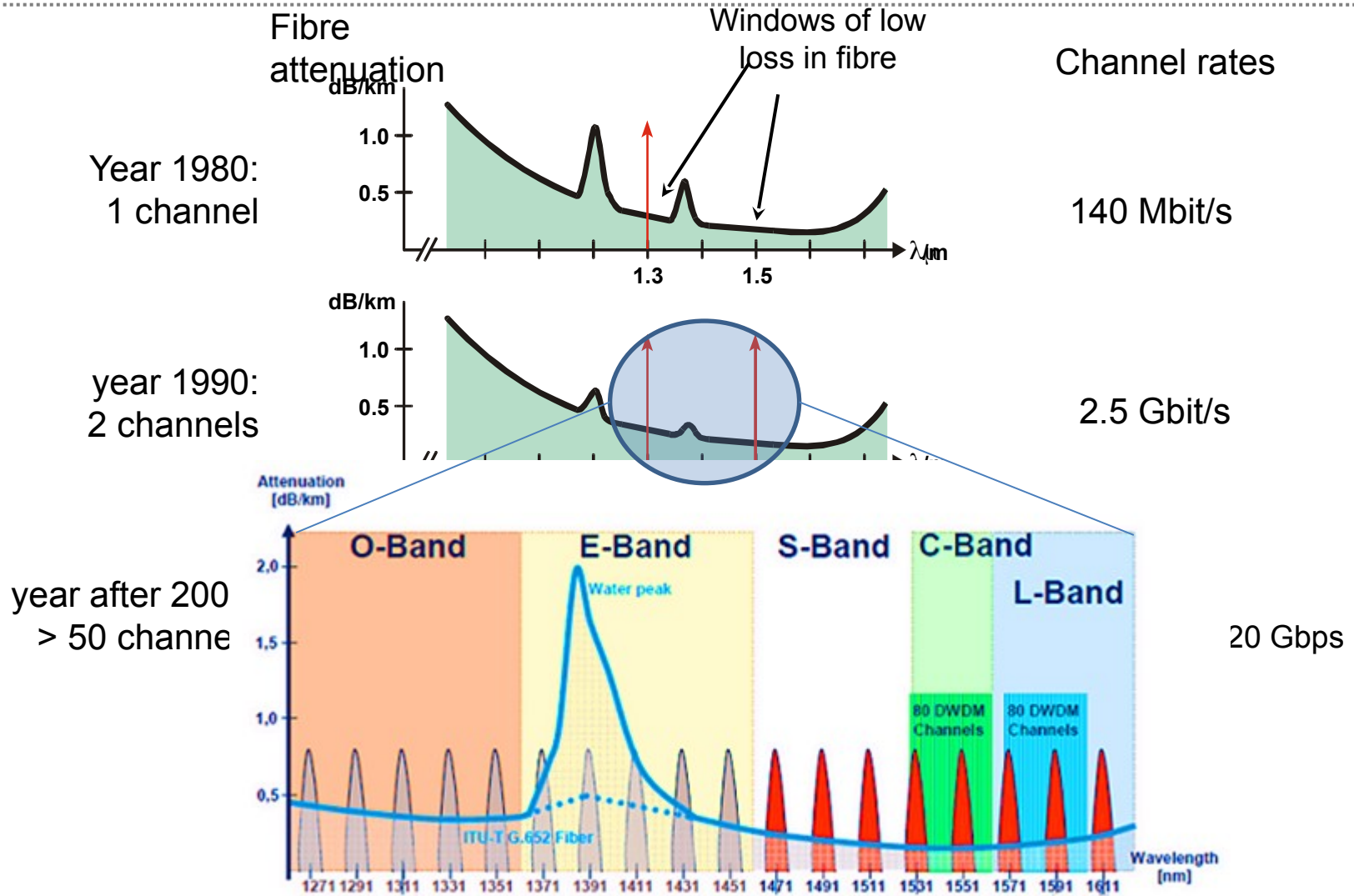
Information Bandwidth of Fibre

- Around 1.55 μm carrier frequency there is a low attenuation range of 180 nm where light can be transmitted

- Centered at 1.3 μm there is a low attenuation region of 80nm

Theoretical Upper bound
BW ~ 25 THz

$$BW(Hz) = c \times \frac{\Delta\lambda}{(\lambda)^2}$$
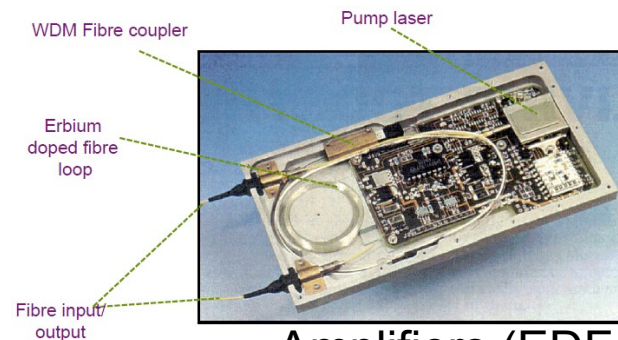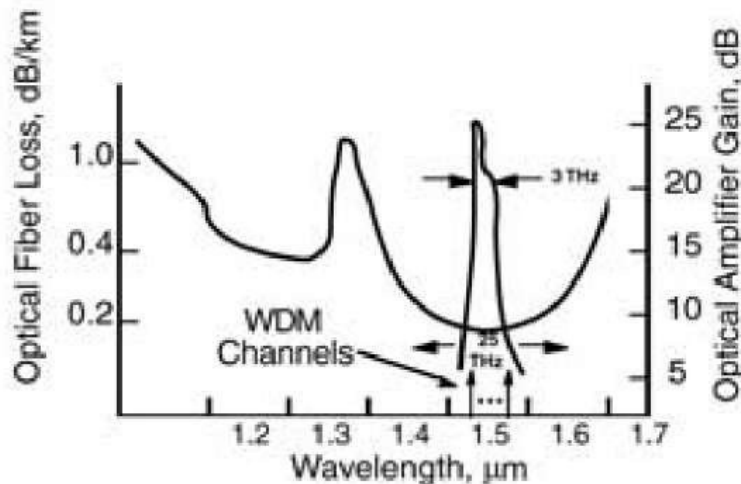
Amplifiers (EDFA) bandwidth restricts available bandwidth to 4THz

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Multiplexing in optical communication

- How to increase an optical communication link capacity
  - About 4THz of available bandwidth per amplified fibre
  - Install more fibers
  - Increase modulation bit rate
  - Use Multiplexing techniques

Bit rate/data format

More channels/
Wavelength multiplexing

More fibers/
Spatial multiplexing
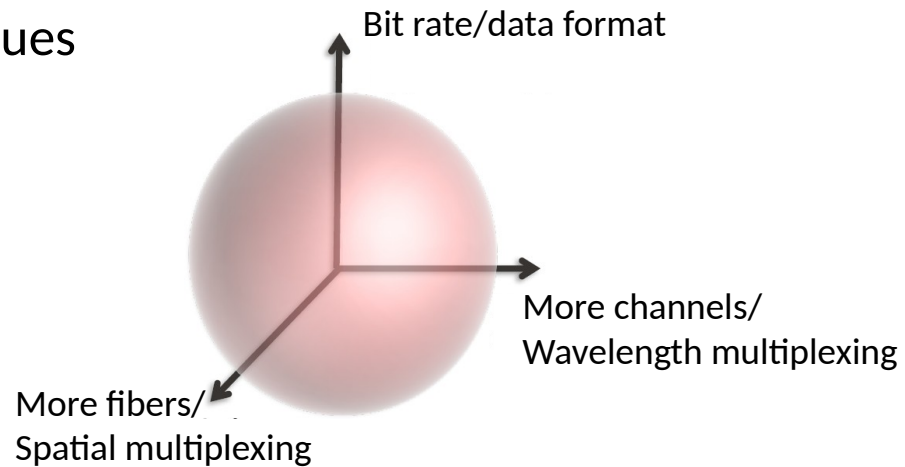
Multiplexing is preferred choice and it is a networking technique
  - less complex and less expensive than other solutions
  - It can be used in combination with other techniques

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Key multiplexing formats of optical networks
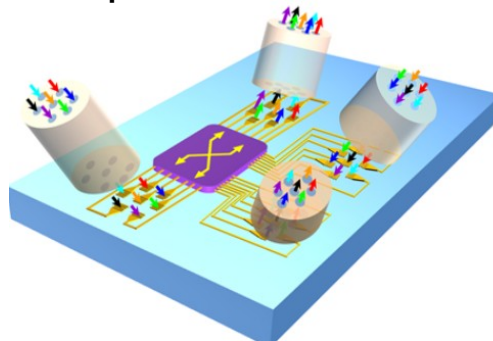
Optical Time Division Multiplexing - OTDM
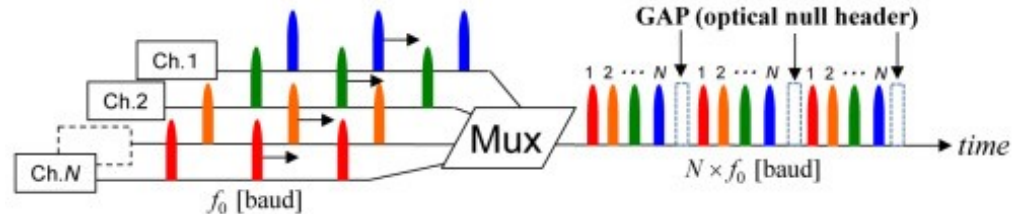
Wavelength Division Multiplexing - WDM
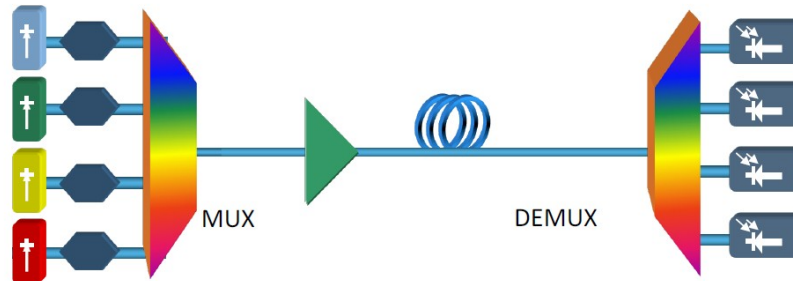
- ➢ Light has different colours
- ➢ Fundamental ability to parallelize

Spatial Division Multiplexing - SDM
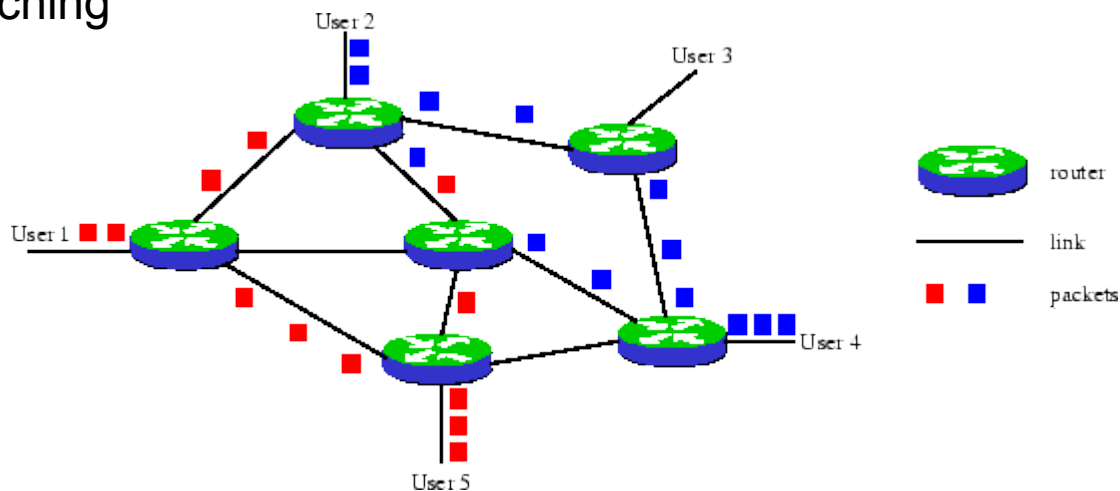

Multicore fibers

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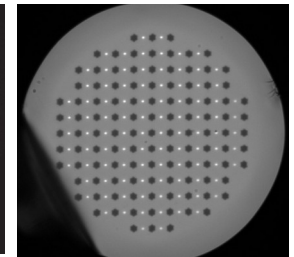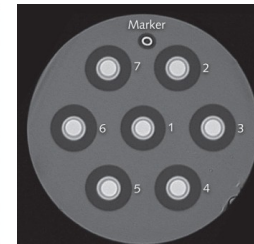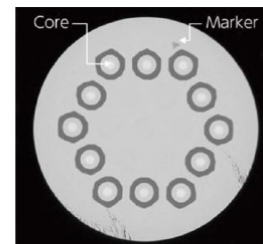
Switching/Routing in optical networks

Circuit switching

Optical Switch

Optical Switching

Packet switching

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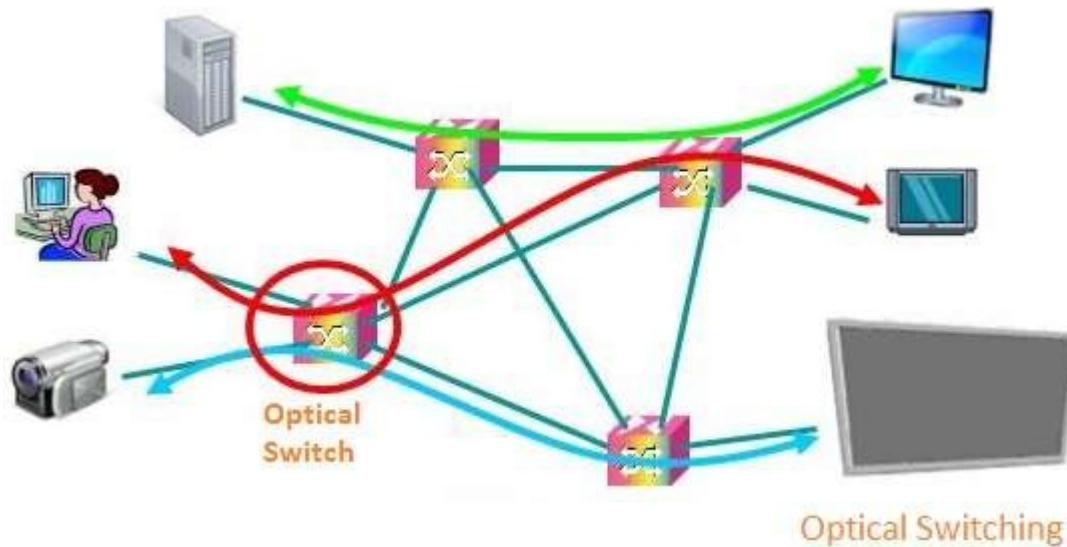
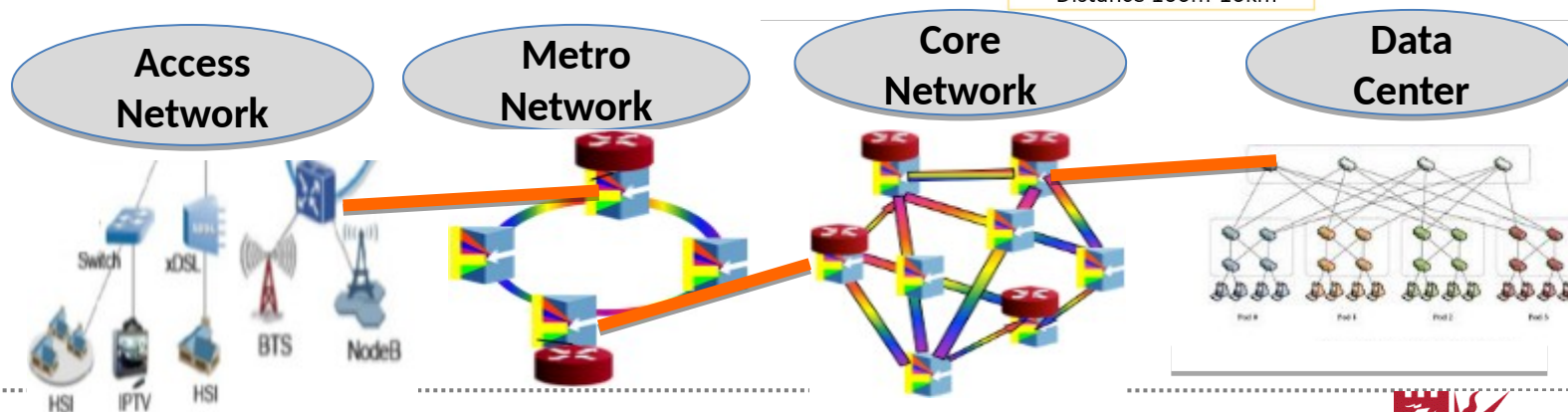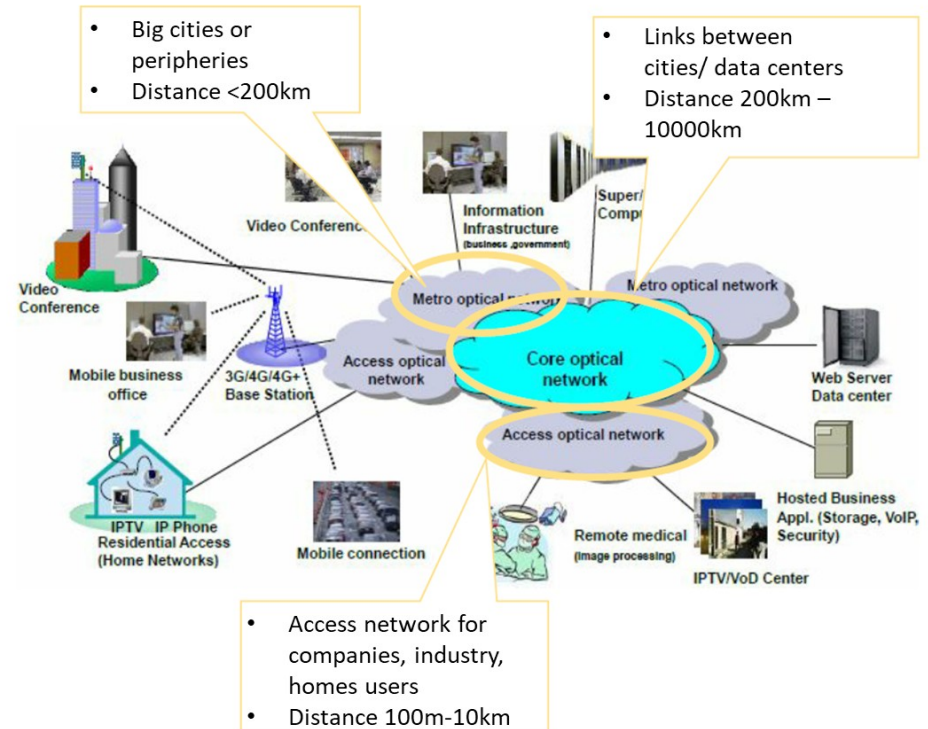# Optical networks hierarchy

Different optical fiber networks:
- Bandwidth
- Reach
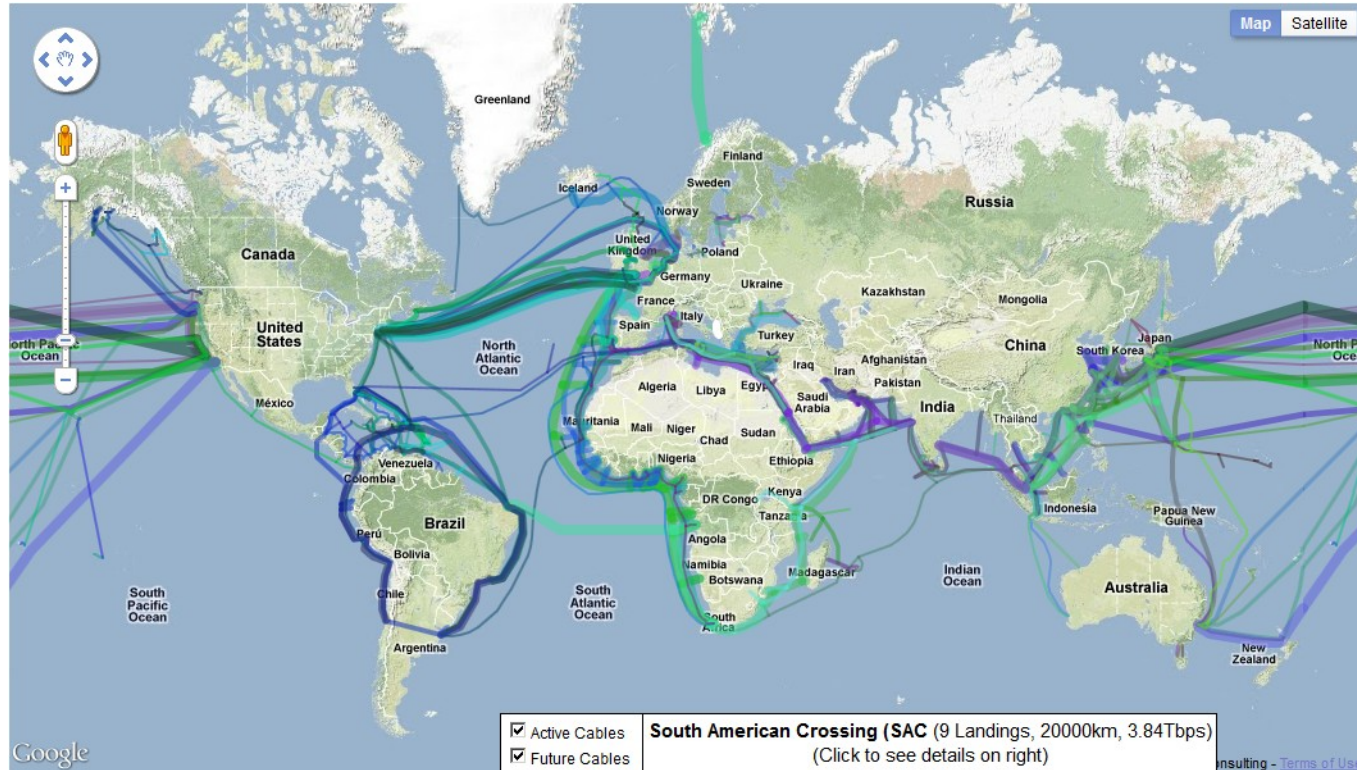- Cost

❑ Wide Area Networks (WAN)
or backbone/core networks
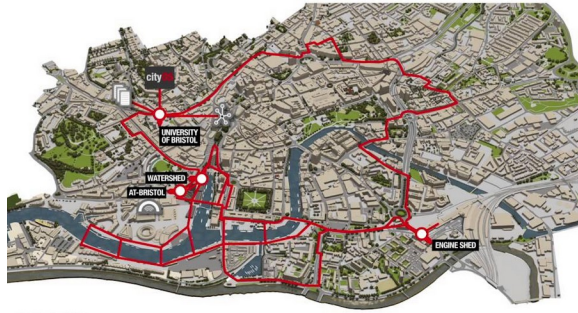
❑ Metropolitan Area Networks (MAN)

❑ Access Networks

- Big cities or peripheries
- Distance <200km

- Links between cities/ data centers
- Distance 200km – 10000km

- Access network for companies, industry, homes users
- Distance 100m-10km

Access Network **Metro Network** **Core Network** **Data Center**

Core/Long Haul Networks

https://www.submarinecablemap.com/#/

> From 2010, All continents connected (except Antarctica)
> Point-to-Point links with WDM multiplexing (**mesh networks**)
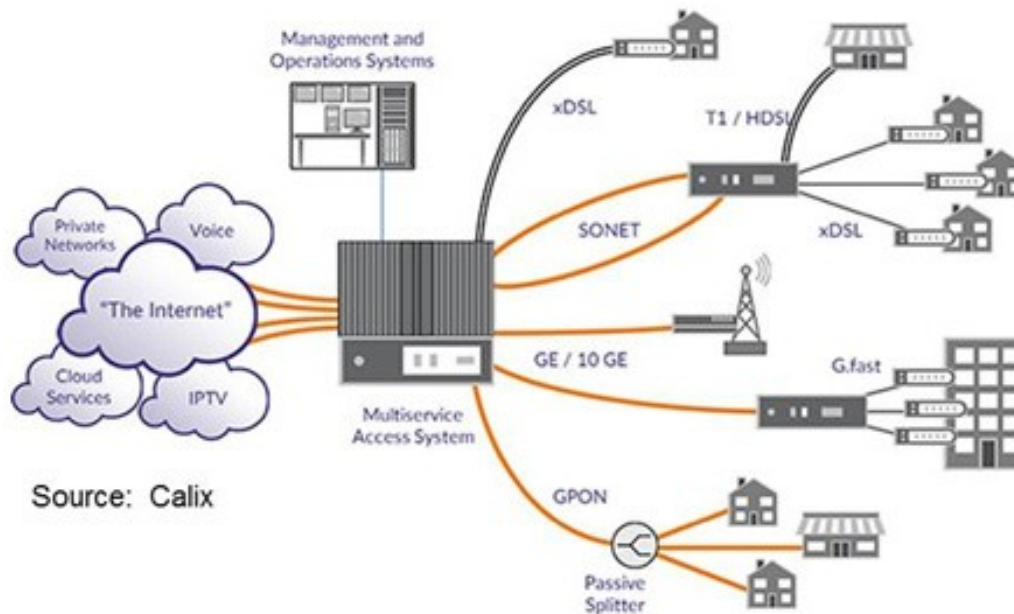> Optical wavelength routing
> Optical cross connects

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Metro Networks

- Metro networks are national/city wide networks
- WDM technology
- Usually deployed as **ring topology**
- Optical wavelength routing
- Optical cross connects

Access networks

Source: Calix

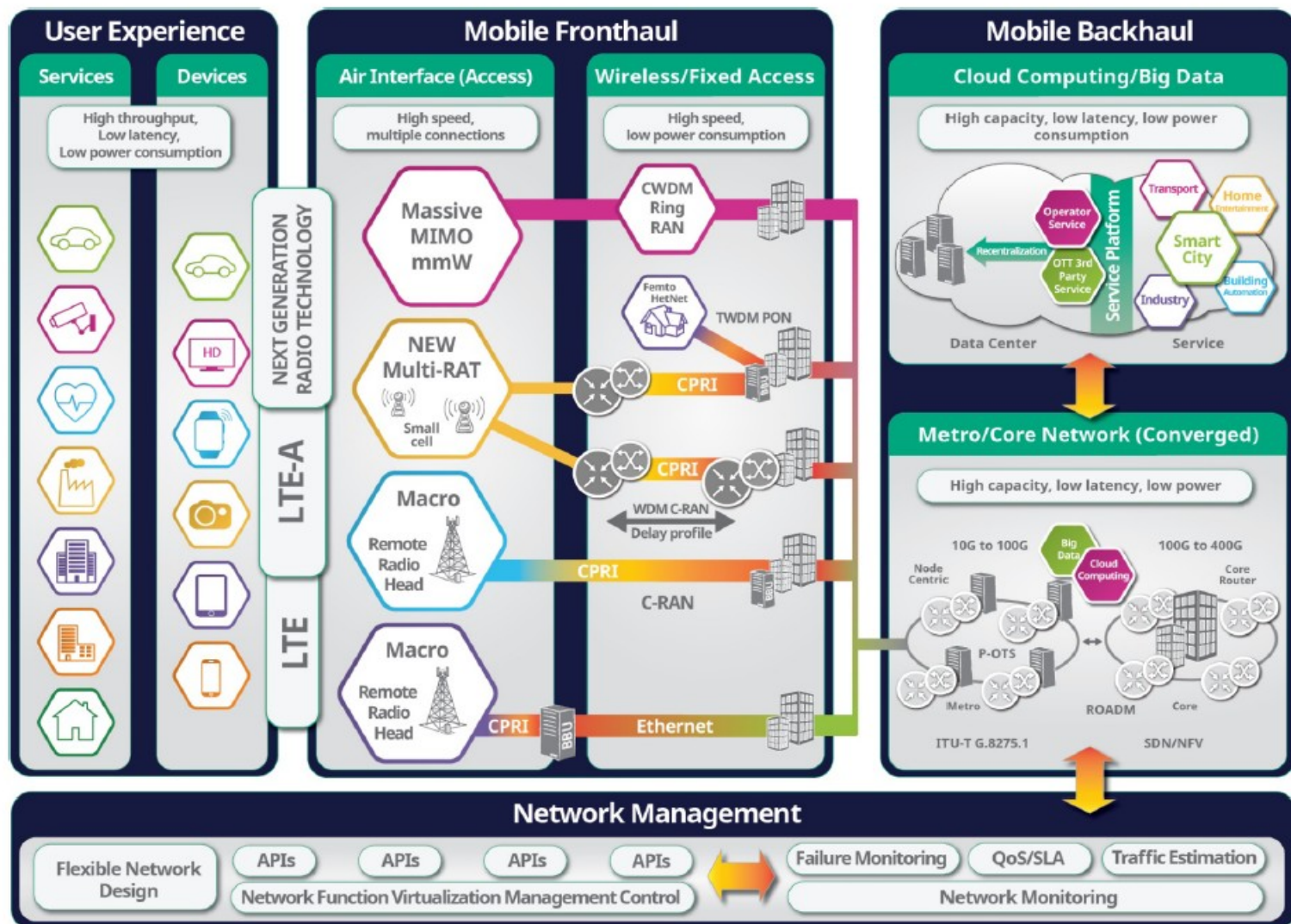point to point links: Active optical networks
Central Office to end users

Star topology: Passive Optical Networks – PON
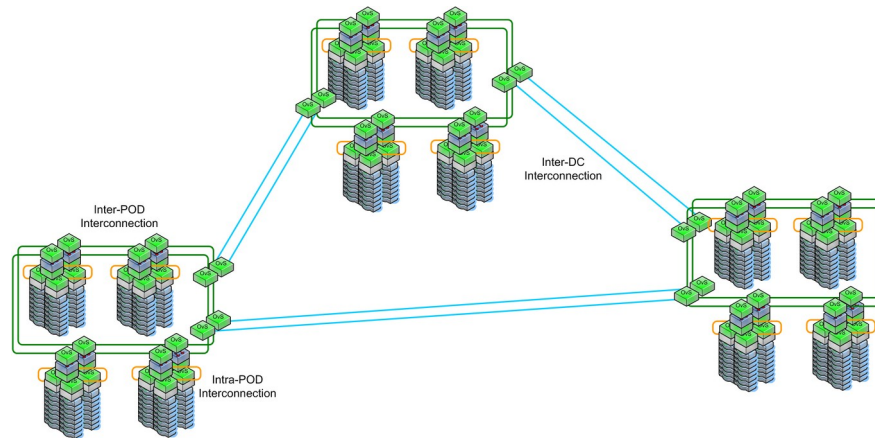Optical Line Terminal - OLT to optical network units - ONU
No active optical devices (switches, amplifiers), only splitters
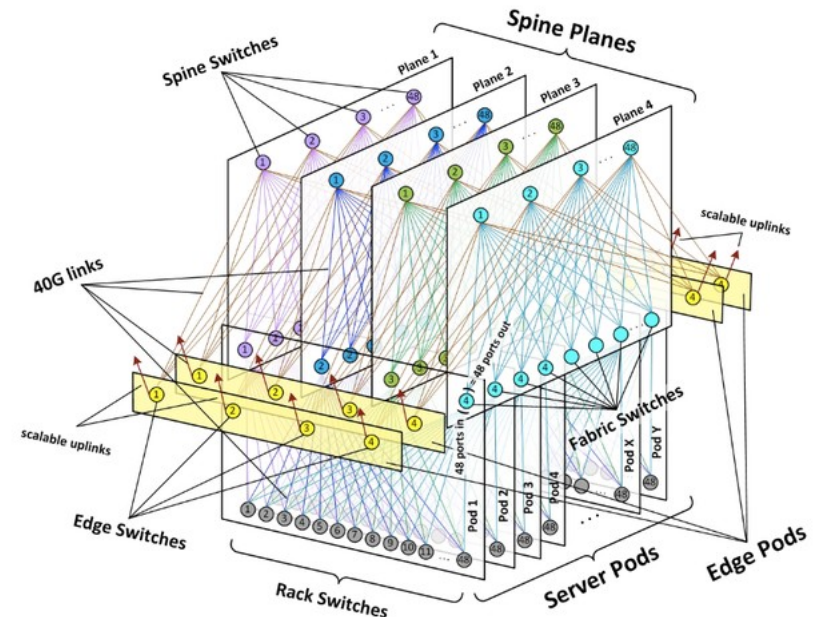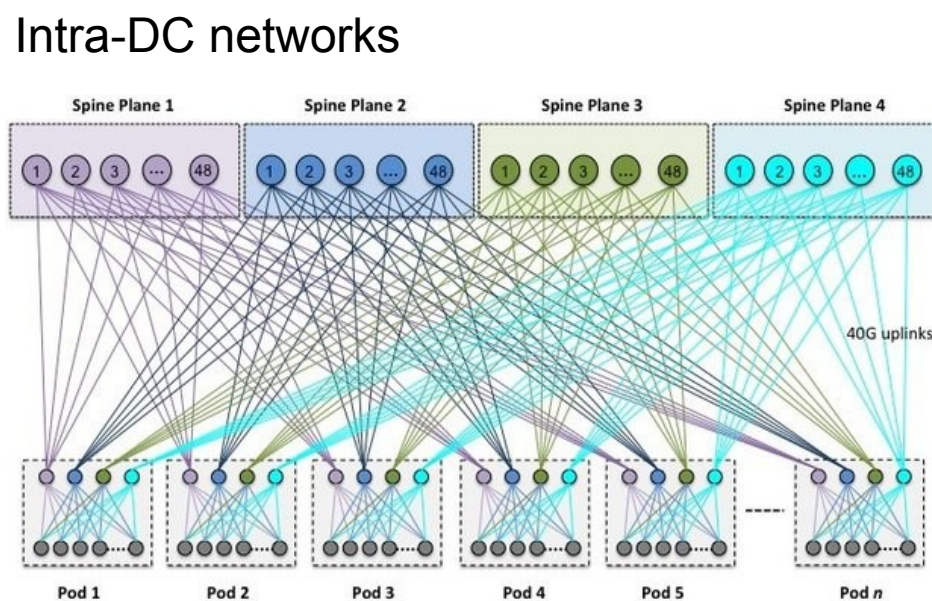
Next Generation Networks

Optical Networks
Electrical and Electronic Engineering

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Data Center Networks

Inter-DC networks

Intra-DC networks

- End of session 1

Any questions?

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