S-72.3340 Optical Networks Course

Lecture 1: Introduction to Fiber-optic Communications

Edward Mutafungwa
Communications Laboratory, Helsinki University of Technology,
P. O. Box 2300,
FIN-02015 TKK, Finland
Tel: +358 9 451 2318, E-mail: edward.mutafungwa@tkk.fi

Lecture Highlights

- Course Description
  - Reference materials, timetables, content etc.
- Lecture 1
  - Introduction
  - Telecommunications network architecture
  - Review of service demand
  - Fiber transmission media
  - Wavelength-division multiplexing
  - Basics of fiber propagation

Course Description

- Lecturer ⇒ Edward
  - edward.mutafungwa@tkk.fi
  - Responsible for lecture presentations and lab works
  - Convenient contact by email if not at lectures

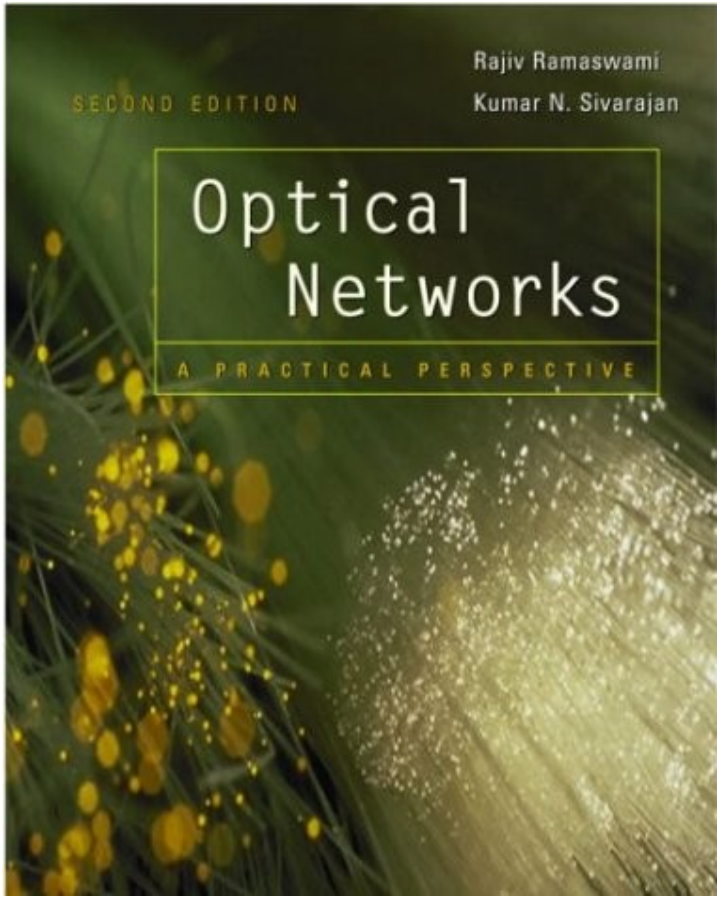
- Course Assistant ⇒ Naser
  - naser.tarhuni@hut.fi
  - Responsible for theoretical exercises/tutorials

Course Description

- Course website
  http://www.comlab.hut.fi/studies/3340/Index.htm
  - Updated regularly for the duration of the course
  - Keep checking for announcements, course material, timetable changes etc.

Course Description

- Recommended course book
  - R. Ramaswami and S. N. Kumar, Optical Networks: A Practical Perspective, 2 nd edition, **ISBN:** 1-55860-655-6, Morgan Kaufmann, San Francisco, 2002.
  - Few copies available in Electrical department and main libraries
  - Other useful material sources listed on website http://www.comlab.hut.fi/studies/334(



Course Description

- Course prerequisites include:
  - S-72.1130 Telecommunication Systems
  - S-72.1140 Transmission Methods in Telecommunication Systems
  - S-38.2121 Routing in Communication Networks
  - S-108.3110 Tietoliikenteen optiikka
  - Understanding of any of following:
    - Optoelectronics
    - Network design
    - Probability theory
    - Telecommunications Network Management
    - Network Protocols

Course Description

- Lectures
  - Lectures 1-2 ⇒ Optical fiber and device technologies
  - Lectures 3-4 ⇒ Physical layer impairments and engineering solutions for network implementation
  - Lectures 5-6 ⇒ Optical transmission standards
  - Lectures 7-8 ⇒ Network design and management
  - Lectures 9-12 ⇒ Practical design considerations and future directions
- Lecture handouts
  - Uploaded a day or two before the lecture

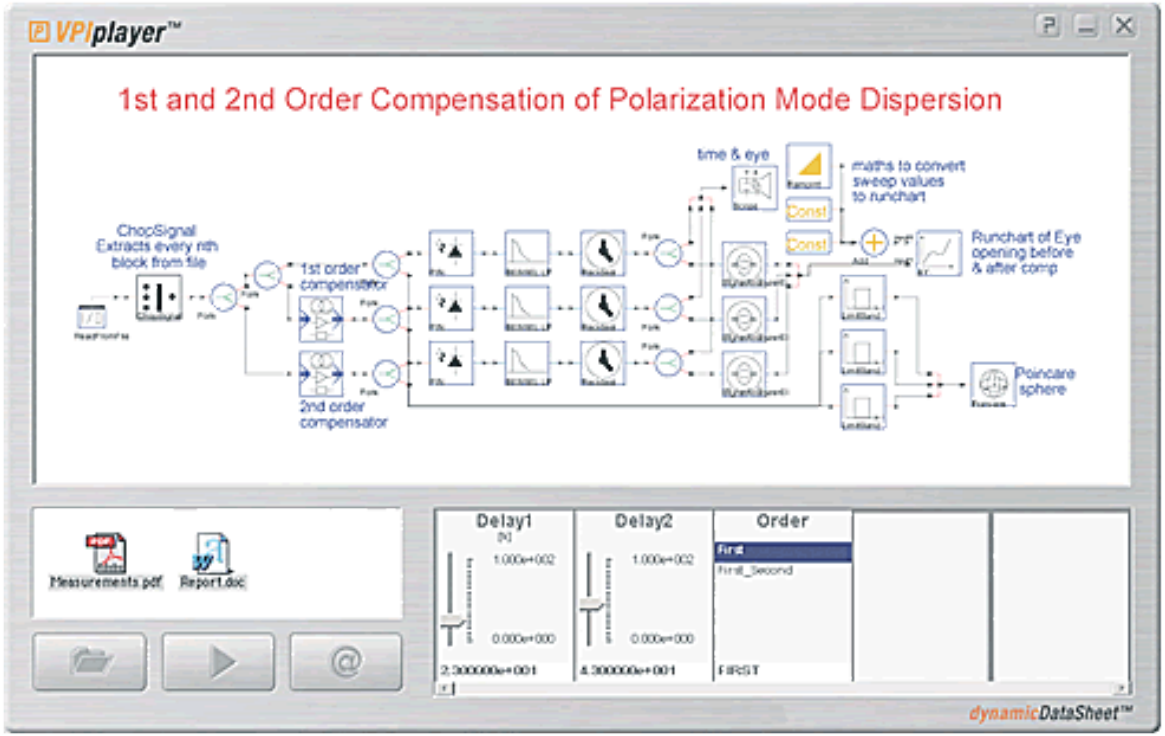
    http://www.comlab.hut.fi/studies/3340/LectureOutline.html

Course Description

- Exercises
  - A few selected theoretical problems taken mostly from the recommended course book
  - Exam questions have almost similar structure!
  - Time and venue: Needs to be decided??
  - First solved independently (1-1½ hour) and then together with the course assistant (½ hour)
  - Solutions also posted on course website afterwards

Course Description

- Simulations
  - Download VPIplayer to play VPItransmissionMaker schematics on your PC/laptop
  - Change schematic parameters, run and interpret results



Course Description

- Lab works
  - Comm. Lab. E wing, 3rd floor, Otakaari 5A.
  - Network setup and configuration done in pairs (3 hours)

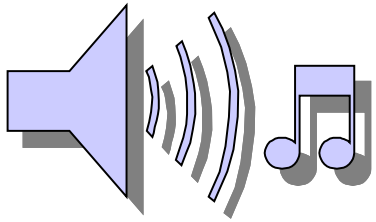
Course Description

- **3 credits** awarded

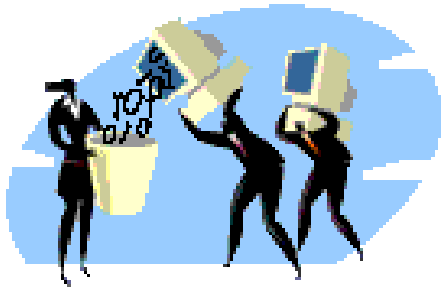
- Basis for Grading
  - 1) Simulations (20% of the final grade)
  - 2) Lab experiment work (20% of the final grade)
  - 3) Final Exam (60% of the final grade)

1. Introduction

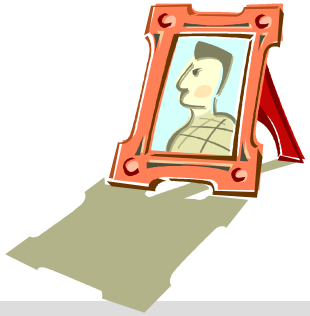
- Information=power in this ”information age”
  - Audio/voice



  - Alphanumeric (data)



  - Visual (still pictures or video)



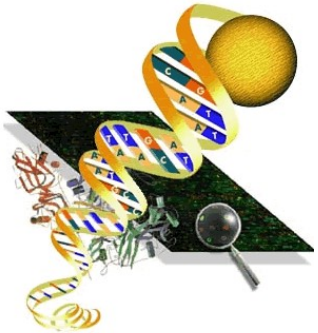
1. Introduction

- Current undisputed growth industries
  - Information transfer, processing, display and storage



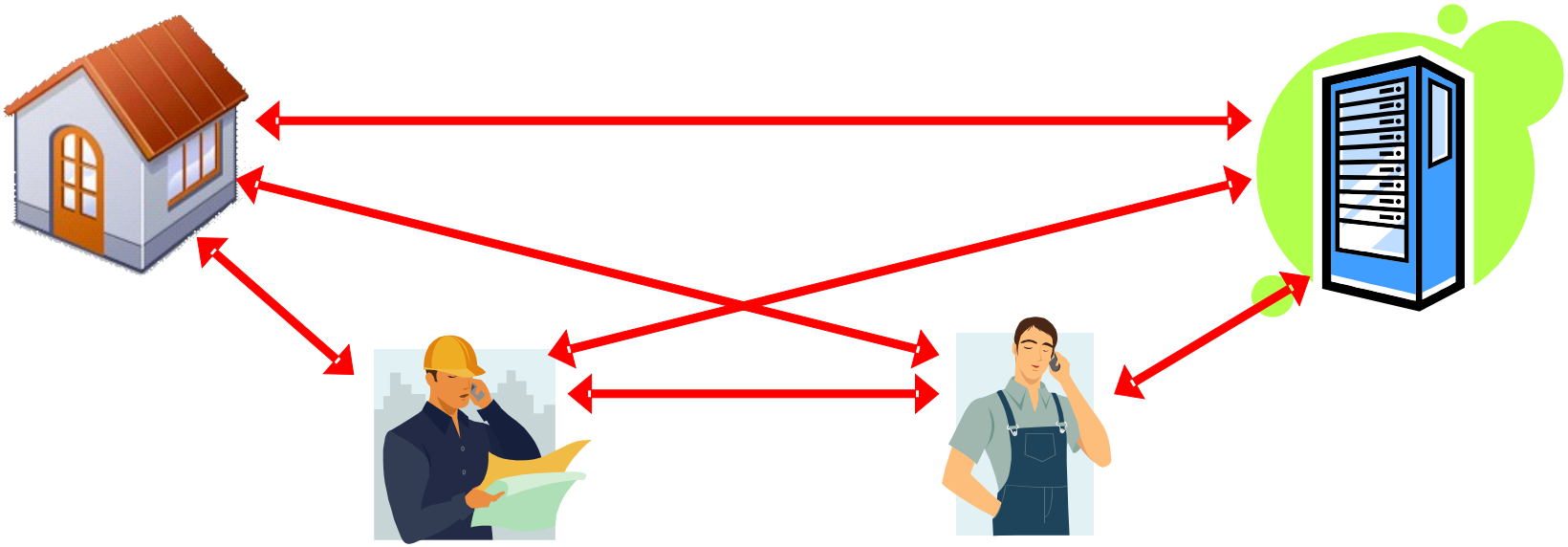






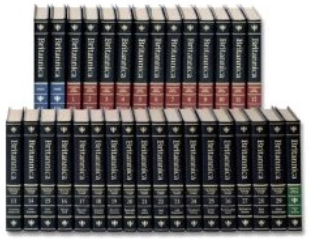
1. Introduction

- Information transfer typically between two or more locations and/or people



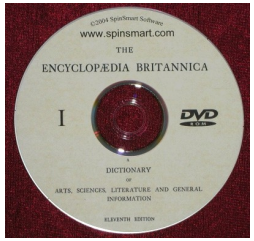
1. Introduction

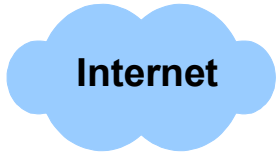
- Telecommunication networks ease and expedite information transfer





Delivering encyclopedia Brittanica (>30 Volumes) to doorstep via DHL couriers using various modes of transport



Delivering encyclopedia Brittanica (1 DVD-ROM) to desktop via the Internet based on advanced telecommunication technologies

1. Introduction

- Design and evolution of telecommunications networks
  - Type of information e.g. videos, data files
  - Quantity of information e.g. latest DVD movie (4.7 GB), contents of Hitachi's new HDD (1 TB or 213 DVDs)

1.1 Drivers for Networking Evolution

- Rising power and reduced cost of computing

IBM PC model 5150

- Year 1981
- 16-655 kB RAM
- 5 MHz processor (Intel 8088)
- About US$ 3000 (= € 5400 today after inflation)

Acer Aspire T180

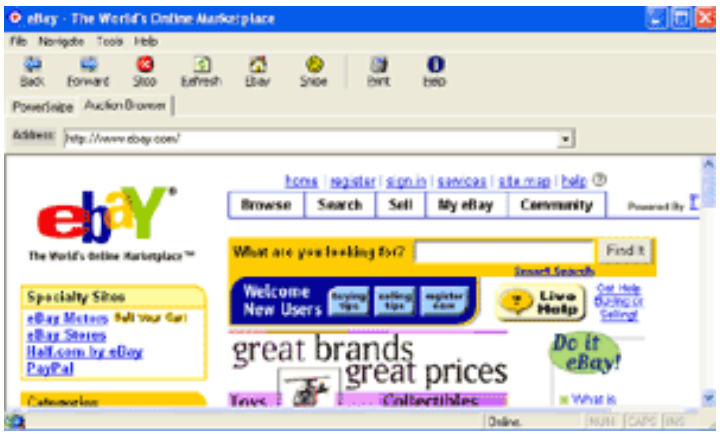
- Year 2007
- 1024 MB RAM
- 1.8 GHz processor (AMD Sempron)
- € 799 (Hobbyhall, Finland)

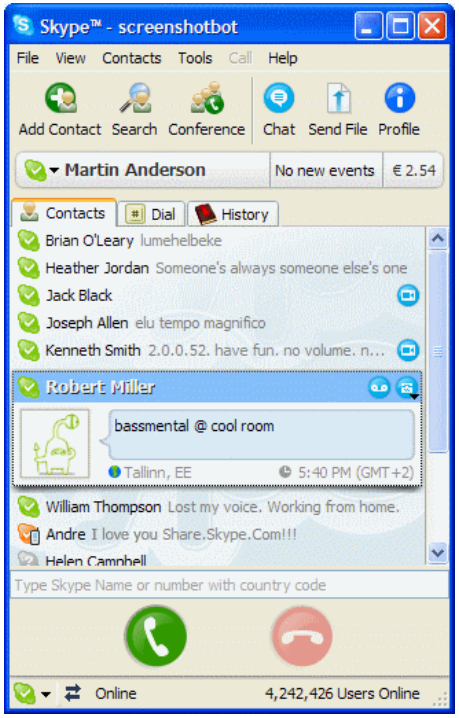
1.1 Drivers for Networking Evolution

- Service pull of the Internet
  - Traditional service boundary between service providers (content, apps, communications etc.) and users blurred
  - User behavioral change (way we learn, work, play etc.)

BitTorrent

Jamba





YouTube™
Broadcast Yourself

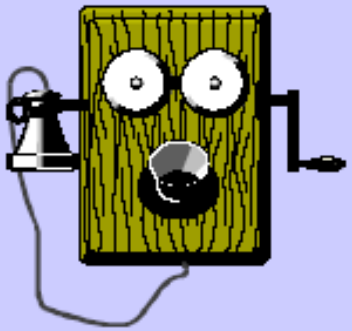
1.1 Drivers for Networking Evolution

- Dominance of data
  - Internet technologies reversed 80%-to-20 % ratio of voice to data traffic
  - Increased demand for trully broadband connectivity

1.1 Drivers for Networking Evolution

- Deregulation of the telecom sector

Past



monopoly positions
long term investment
social considerations

Present

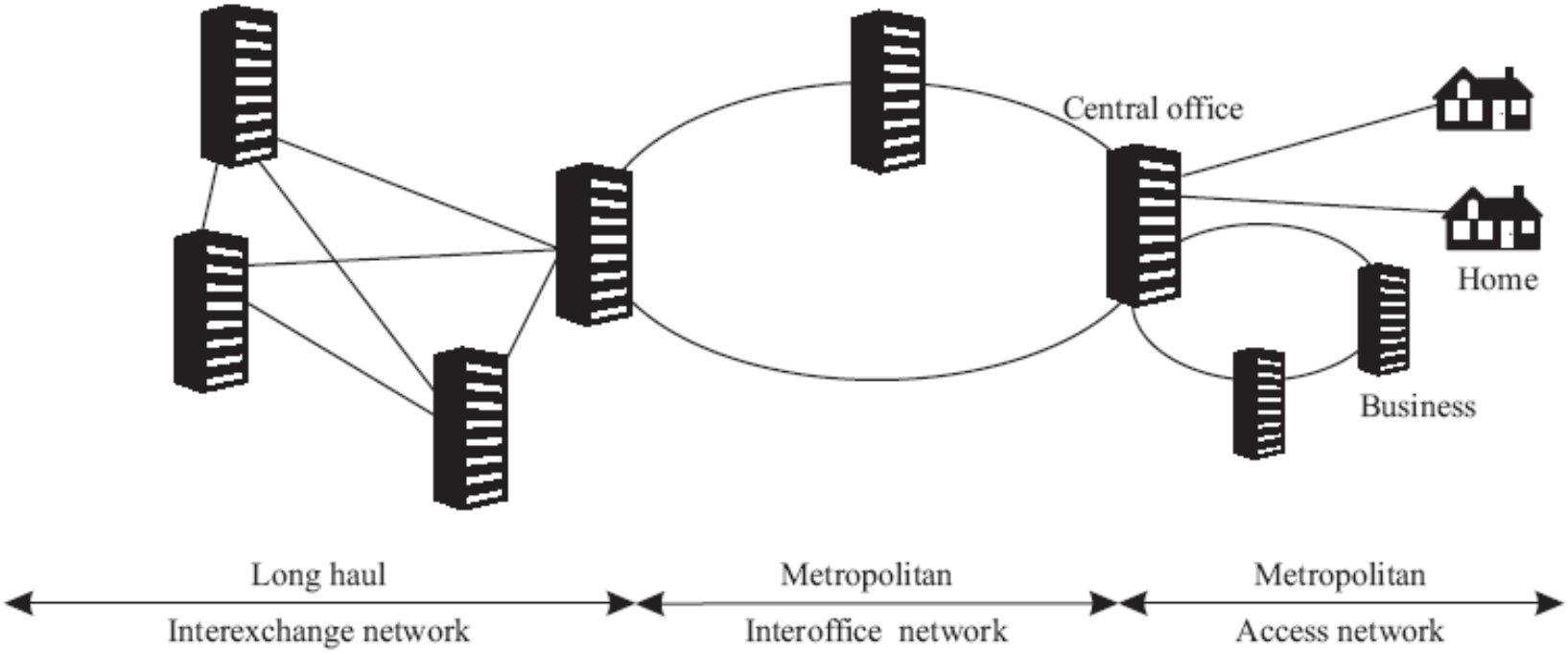
liberalisation & competition
short term return on investment
increased pace of change

1.2 Current Technology Must-Haves

- Internet Protocol (IP)
  - Inherently connectionless and distributed
  - Seamless flow across multiple transmission media
  - IP-based service offerings
  - All-IP, everything over IP etc.
- Wireless mobility
  - The Internet comes to you, any time and any place
- Fiber-optic communications
  - Optical networks at the epicenter of the Internet

2. Telecom Network Architecture

- Different parts of the public network
  - Metro: part of the network within a large city or a region
    - Metro core/interoffice and metro edge/access network
  - Long haul: between national or international cities

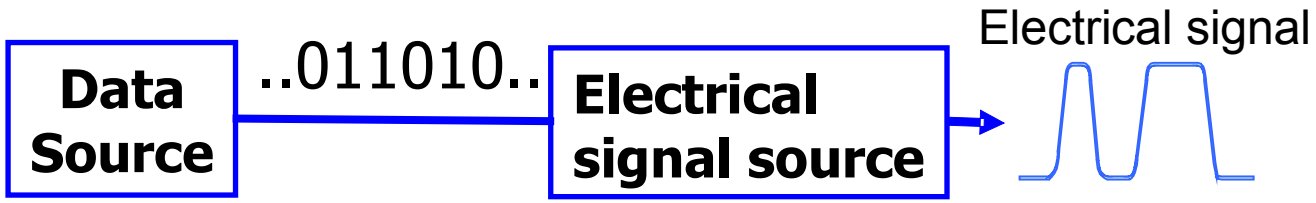


2. Telecom Network Architecture

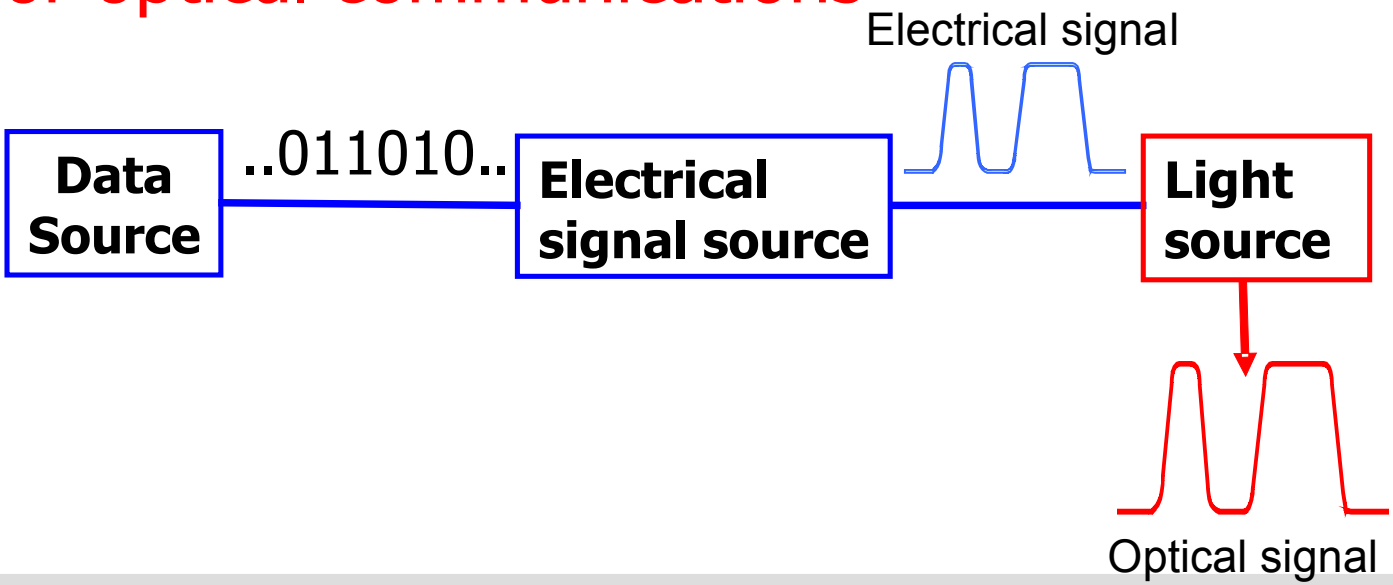
- Private networks owned and operated by enterprises or public institutions for internal use
  - Local area networks (LANs): in building to few km
  - Metropolitan area networks (MANs): tens to a few hundred kilometers
  - Wide area networks (WANs): several hundred to thousands of kilometers
- Corporations usually rely on capacity provided by public networks to implement their MANs/WANs

3. Communication by Light Signals

- Electrical communications



- Light or optical communications



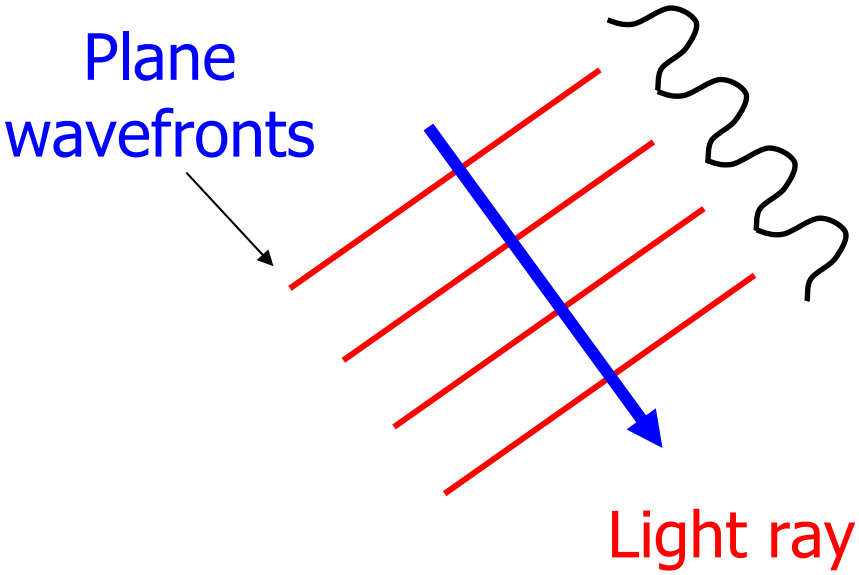
3.1 What is Light?

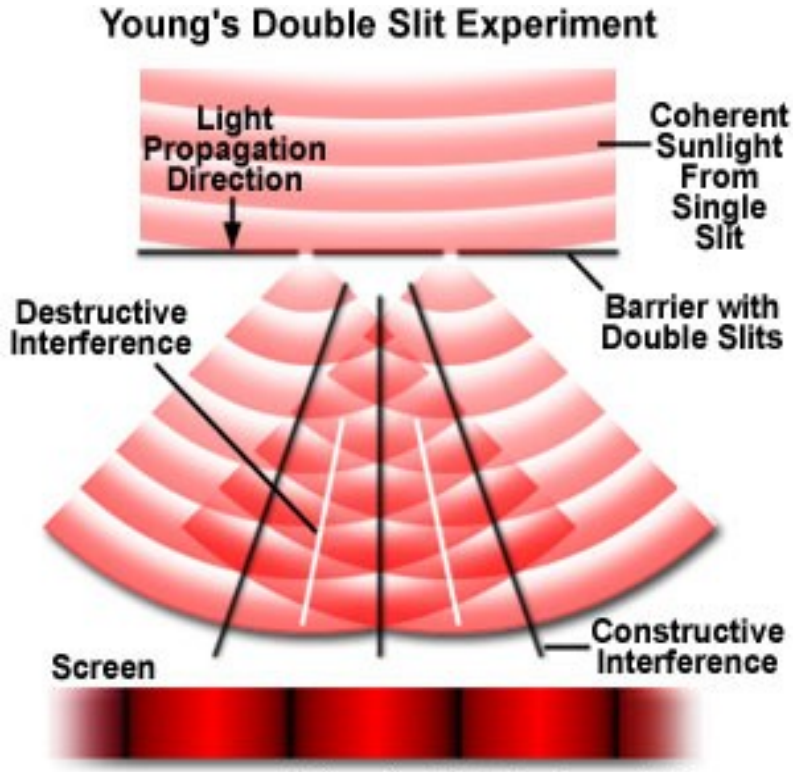
- 17th century debate on light. Is it:
  - a wave (C. Huygens) or a particle stream (I. Newtown)?

  - Light signal exhibits behaviours of both
    - Propagating wave
    - Stream of discrete particles or energy bundles (photons)
  - Wave-particle duality
- Key to understanding important mechanisms in optical communication systems

3.2 Light as a Wave

- Wave-like behaviour (refraction, diffraction, Doppler effect etc.)



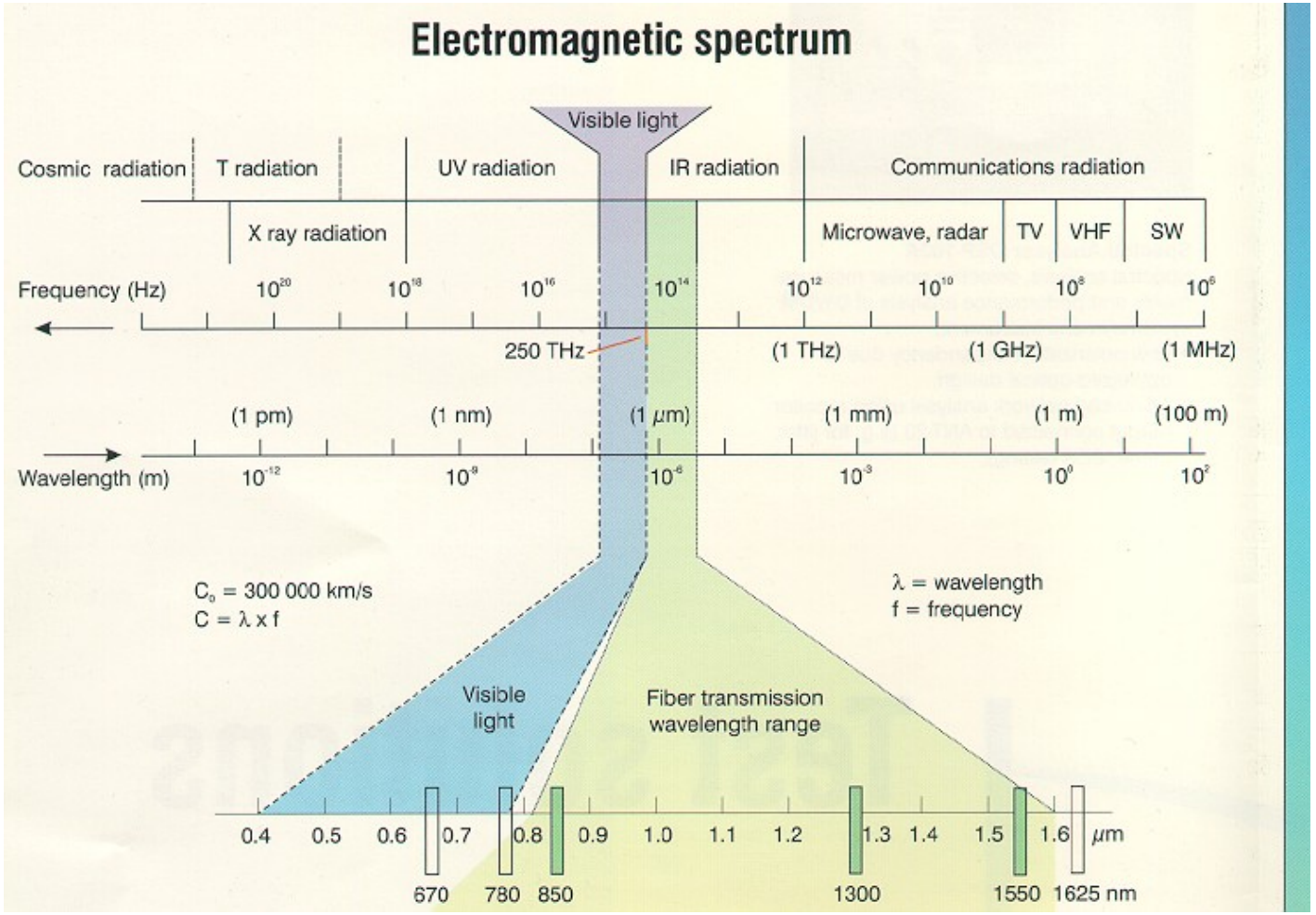


OLYMPUS

Figure 6

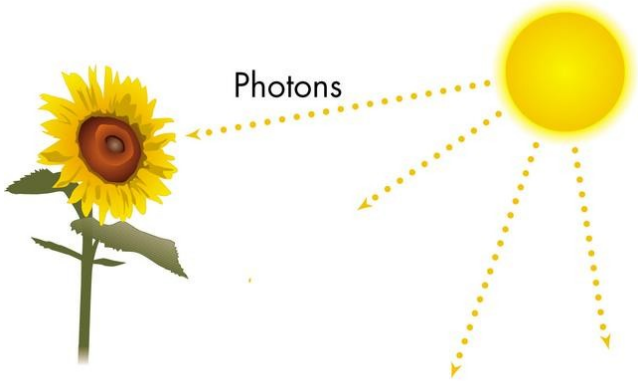
3.2 Light as a Wave

- As a wave characterised by wavelength, velocity, frequency



3.2 Light as a Particle Stream

- Particle-like behaviour (e.g. varying intensity by changing particle number, photoelectric effect)



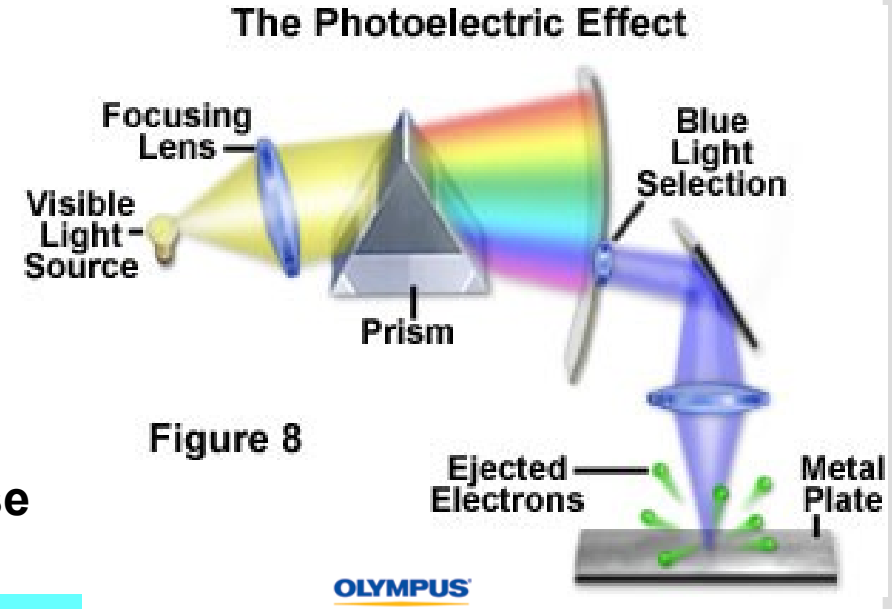


Figure 8

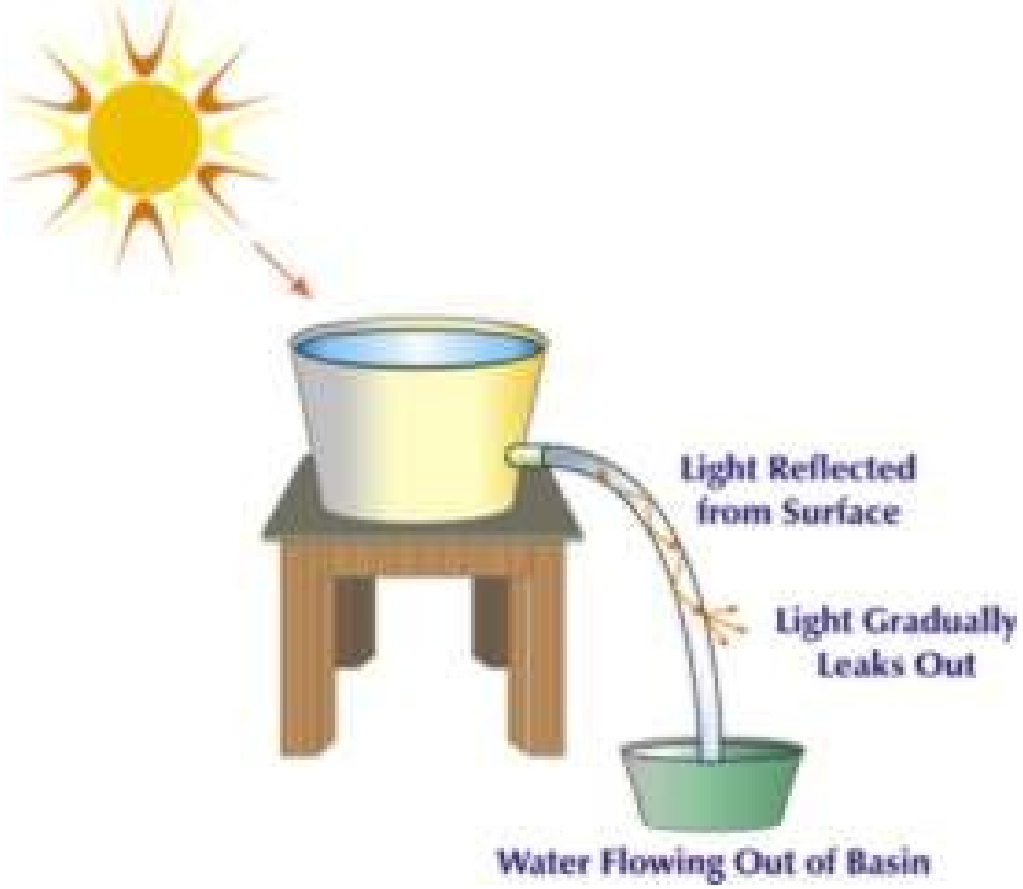
Less dense medium	More dense medium	Less dense medium
Fast moving photon	Photon slowed down	Photon speeds up

4. Fiber Transmission Media

- Earliest form of optical communications
  - Ancient (800BC) Greek and Roman fire beacons
  - Faster than homing pigeons or messengers on horseback!

4. Fiber Transmission Media

- John Tyndall's experiment in 1870
  - Demonstrated "zigzag" flow of light in a confined medium

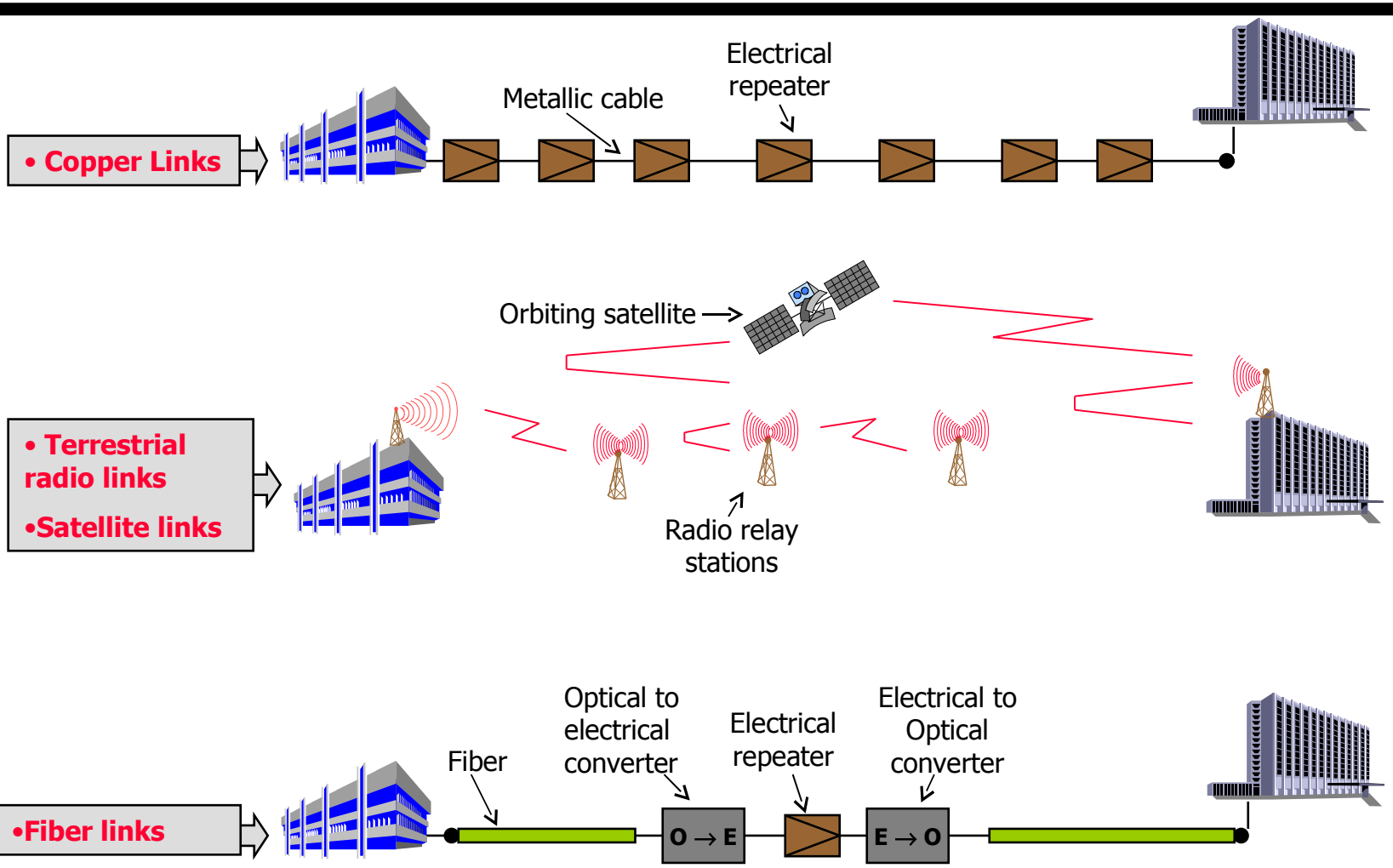


Source: D. Goff, Fiber Optic Ref Guide, 3rd ed., 2002.

4. Fiber Transmission Media

- Modern (post 1960s) optical communications
  - Advent of fibers for guiding light
  - Advent of lasers as an optical signal sources

4. Fiber Transmission Media

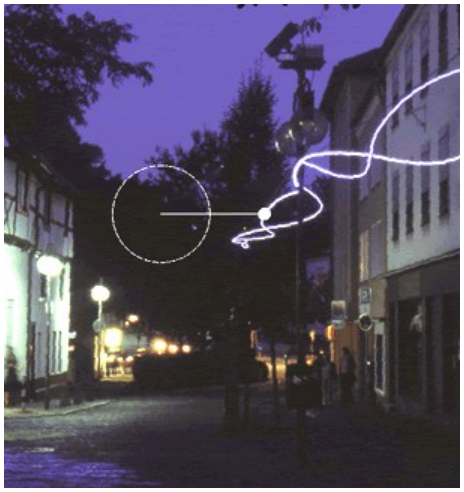


4. Fiber Transmission Media

- Other applications of fibers
  - Remote Sensing
    - Detecting, measuring & characterizing electromagnetic (EM) energy coming from distant objects
    - This EM energy may be collected and transported on fibers
    - Geologic, agriculture, land use, meteorology etc.

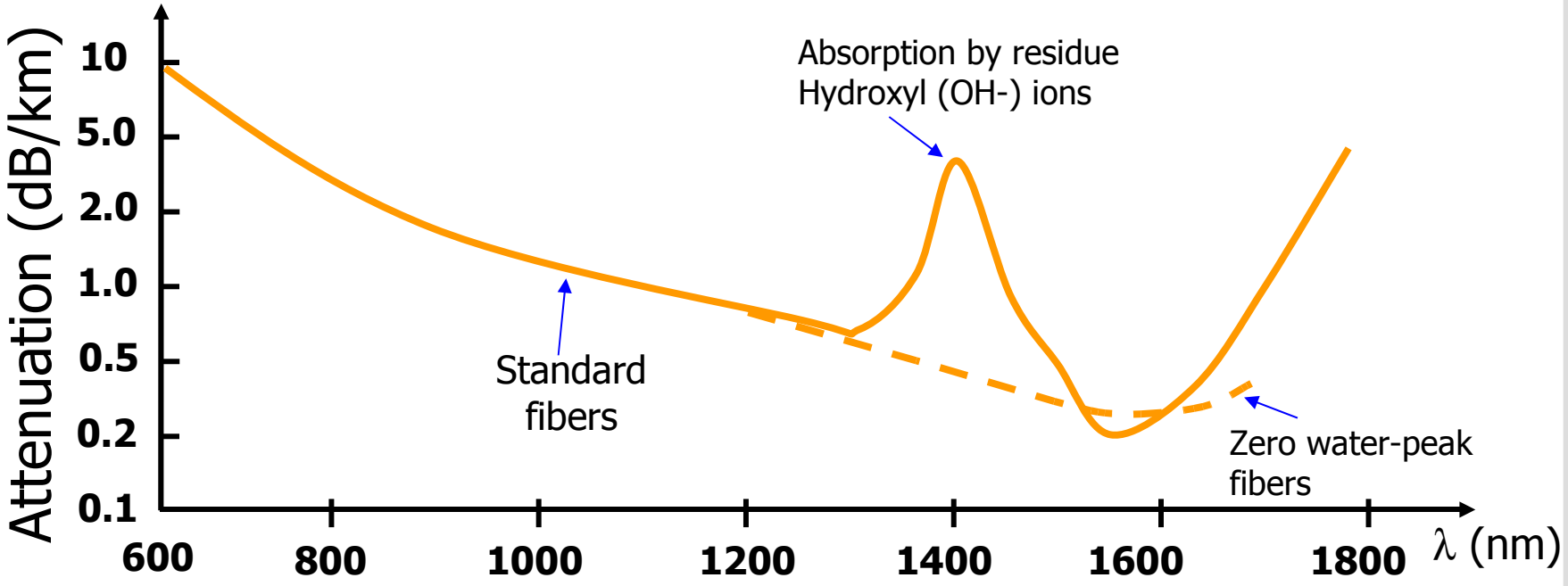
4. Fiber Transmission Media

- Fiber-optic displays, signs and lighting
  - Energy efficient e.g. compared to neon lights/signs
  - No annoying flickering or buzz noise due to interference from other EM sources
  - Safe and withstands extreme weather conditions
  - Easily programmable



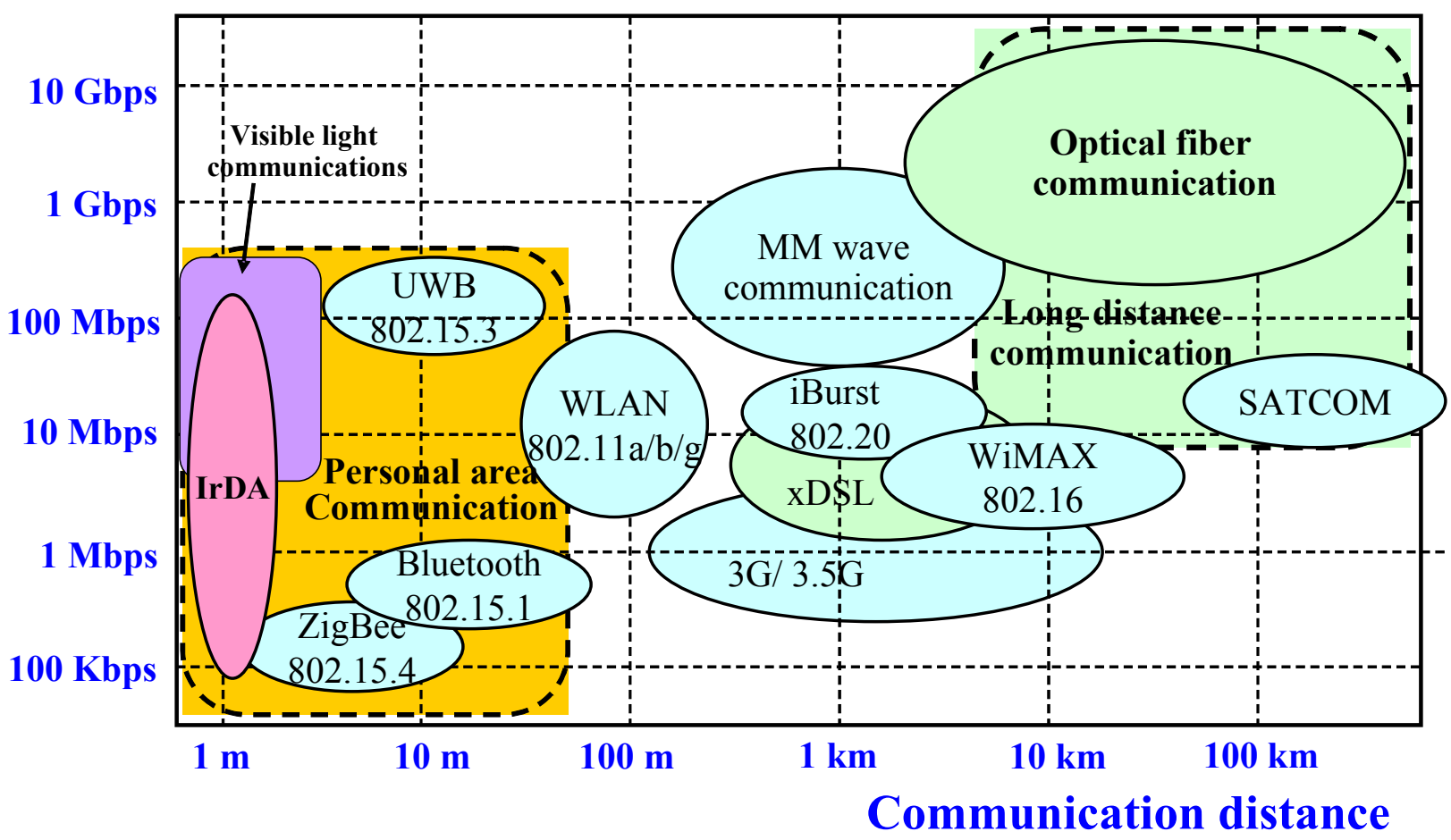
5. Advantages of Fiber

- Advantages of the fiber transmission media
  - Low transmission loss (typically 0.2-0.5 dB/km)
    - Allows longer distances between repeaters or amplifiers
    - By comparison, Cat. 5 UTP (copper pairs) have loss of 7 dB/km to 220 dB/km in 64 KHz-100 MHz range



5. Advantages of Fiber

- Larger information carrying capacity



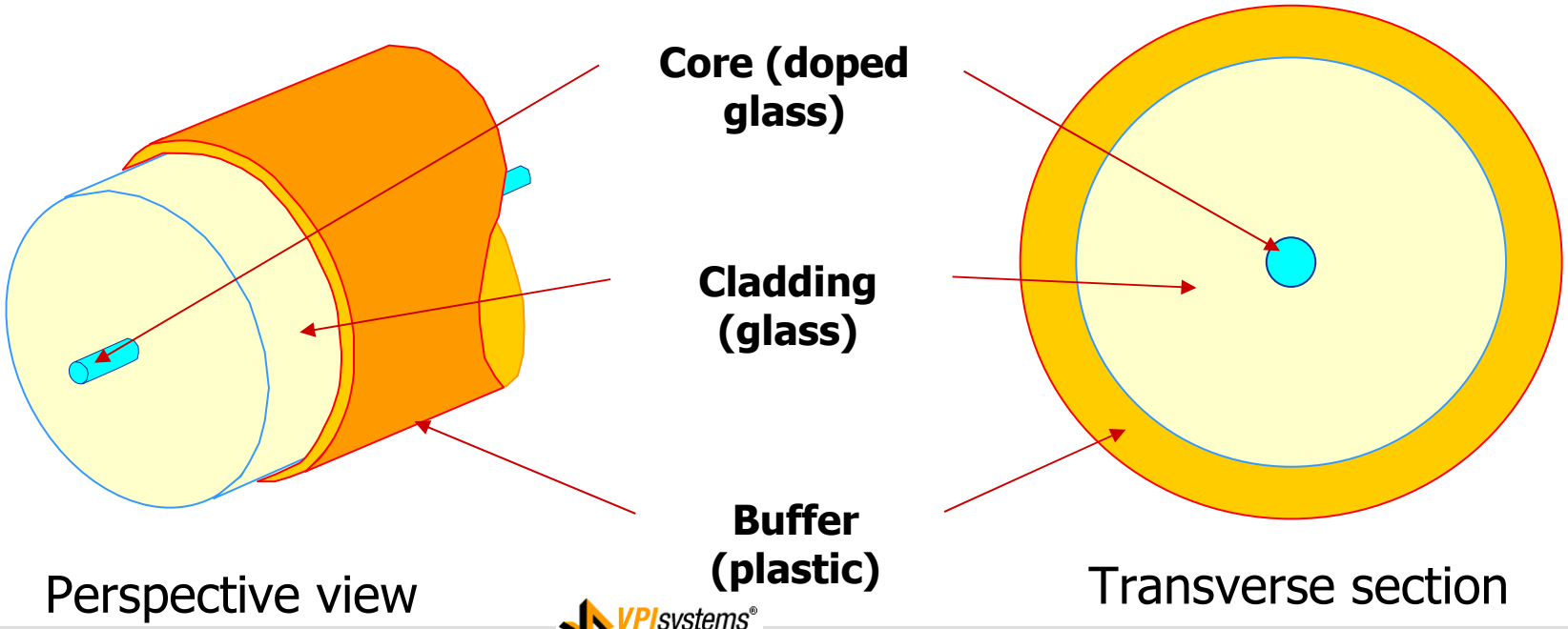
5. Advantages of Fiber

- Immunity to electromagnetic interference
  - Can be placed alongside powerlines or close to radiative equipment e.g. CAT scanners

- More secure to eavesdropping or wiretapping
- Smaller size and weight
  - Example: 700 km of copper cabling weighs 20 tonnes, while same cable run with fiber weighs 7 kg

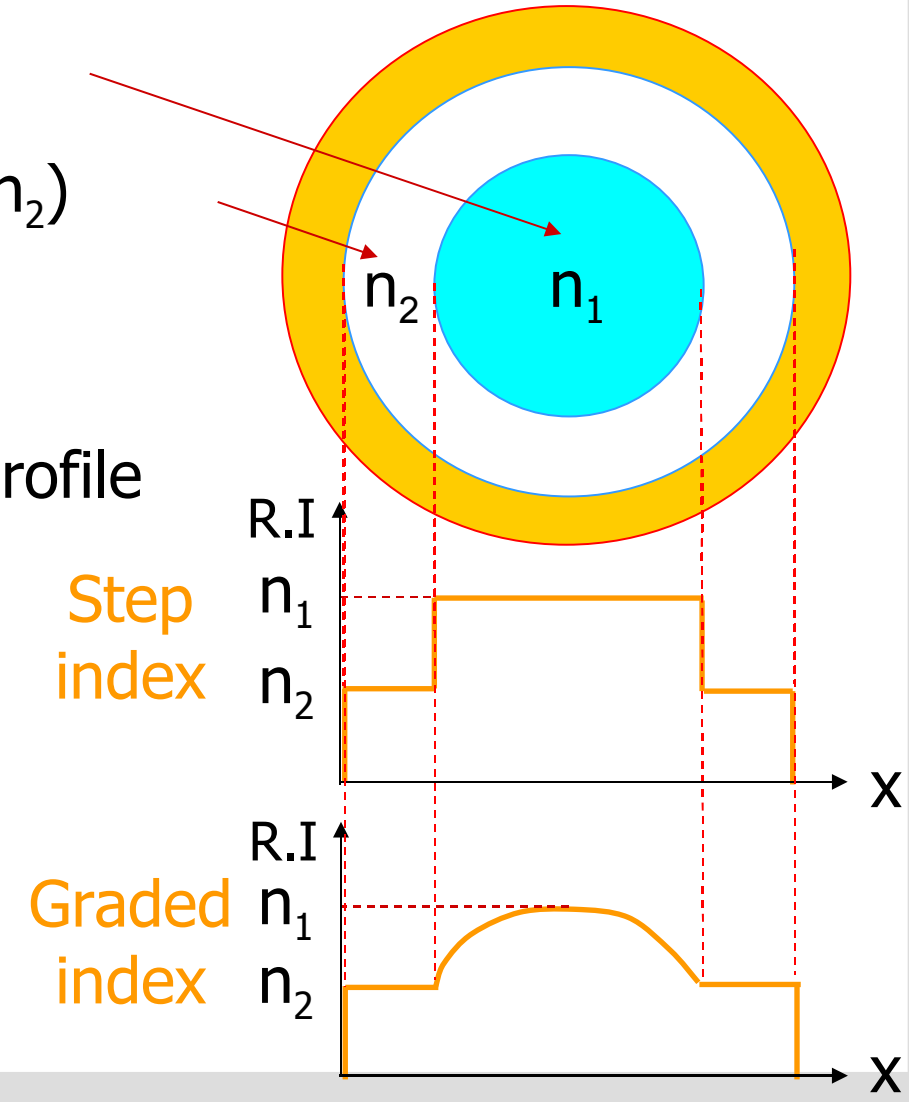
6. Basics of Fiber Propagation

- An optical fiber is composed of:
  - Cylindrical core: refractive index $n_1 \cong 1.5$
  - Cladding: refractive index $n_2 < n_1$
  - Buffer (or primary coating): protects fiber from damage



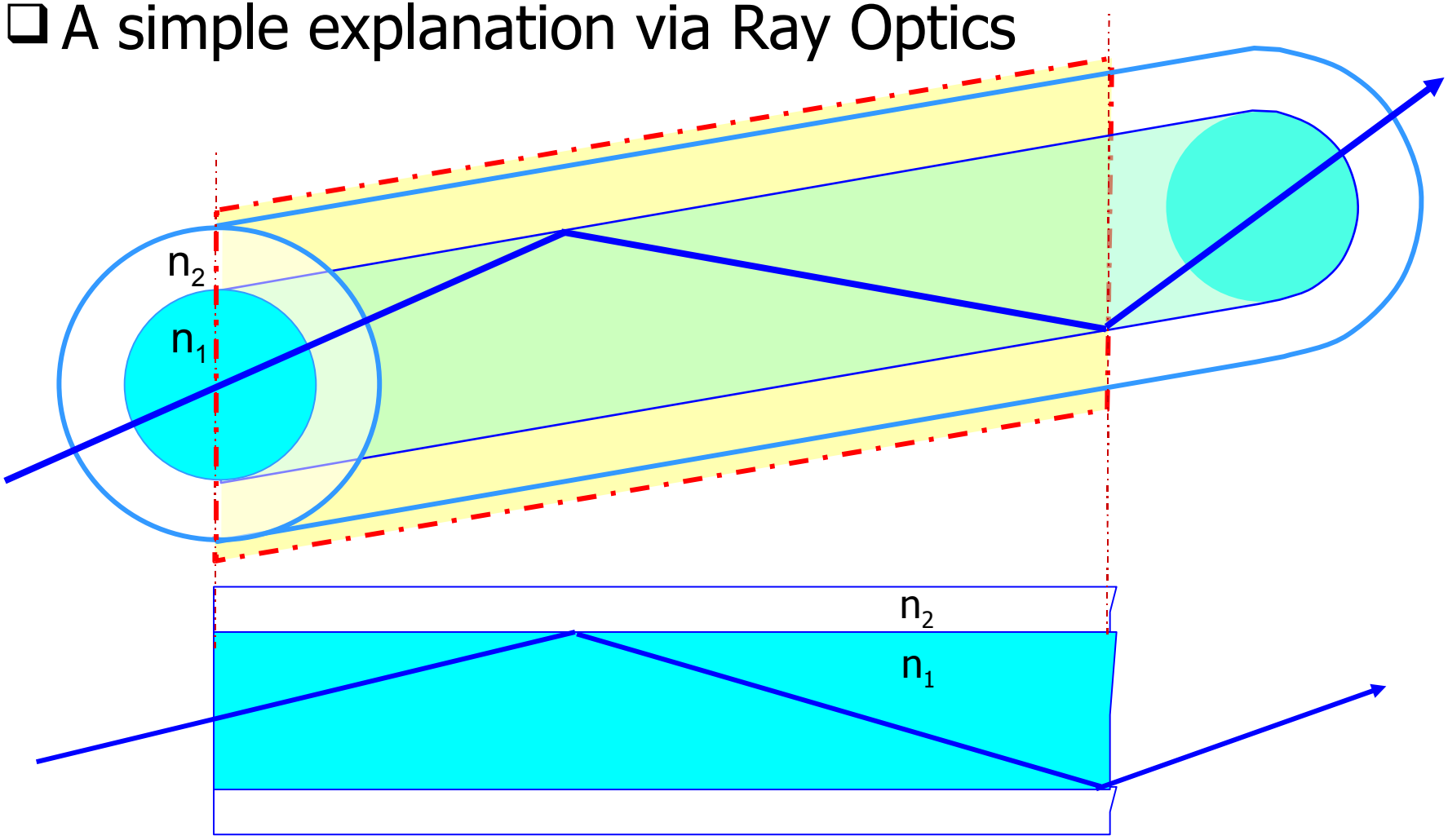
6.1 Fiber Refractive Index Profile

- Core Refractive Index (n_1)
- Cladding Refractive Index (n_2)
- Step Index Profile
- Graded (Quadratic) Index Profile



6.2 Light Transmission in Fiber

- A simple explanation via Ray Optics



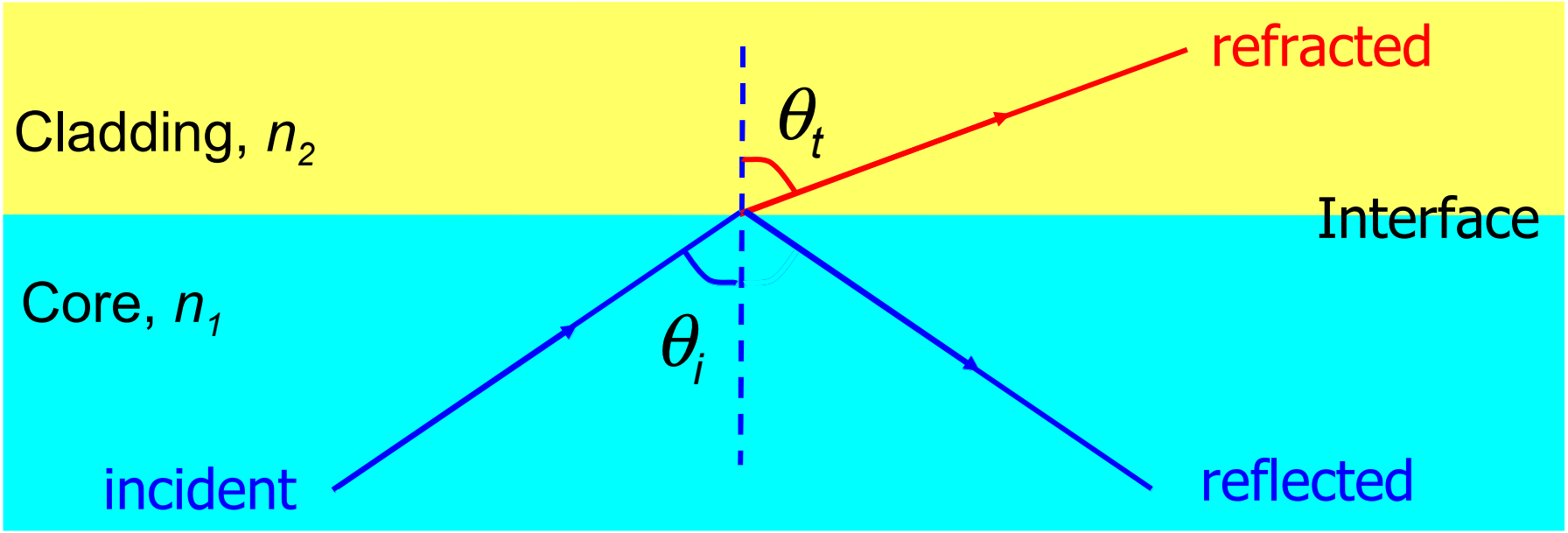
Longitudinal Section

6.2 Light Transmission in Fiber

- Law of Reflection and Snell's Law

  Angle of Incidence θ_i = Angle of Reflection θ_r

  Snell's Law: $n_1 \sin\theta_i = n_2 \sin\theta_t$

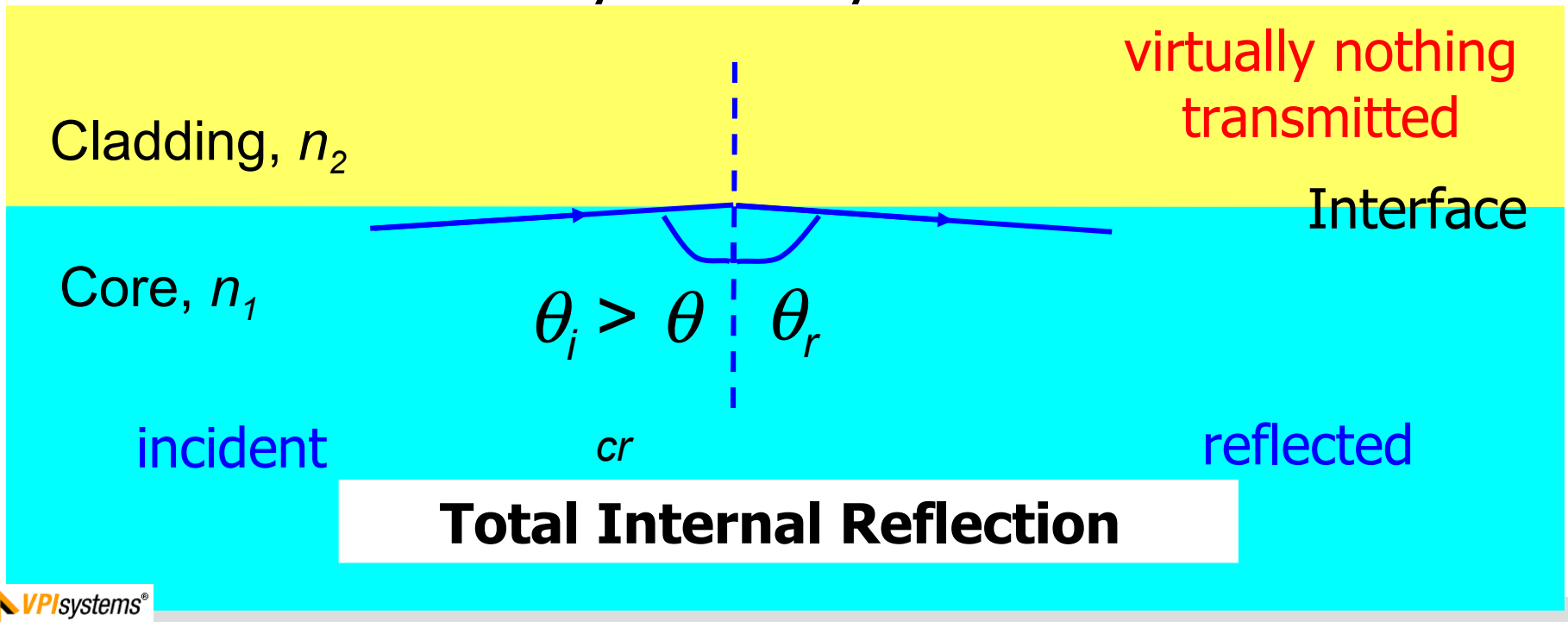


6.2 Light Transmission in Fiber

As θ_i *increases…* θ_t increases… until $\theta_t = 90^o$

Value of θ_i (where $\theta_t = 90^o$) = "Critical Angle" = θ_{cr}

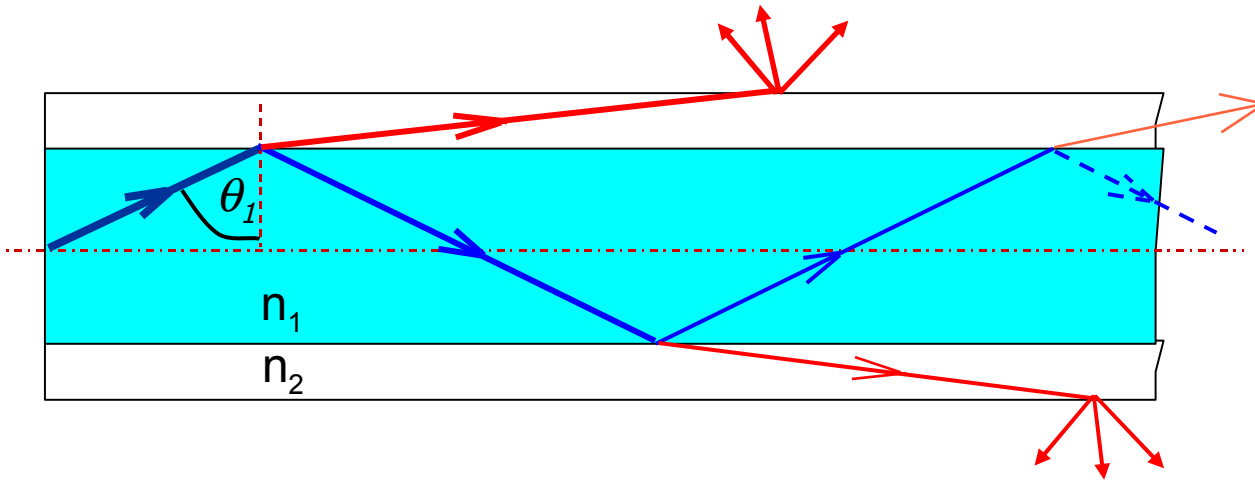
For $\theta_i > \theta_{cr}$, the ray is totally reflected



Total Internal Reflection

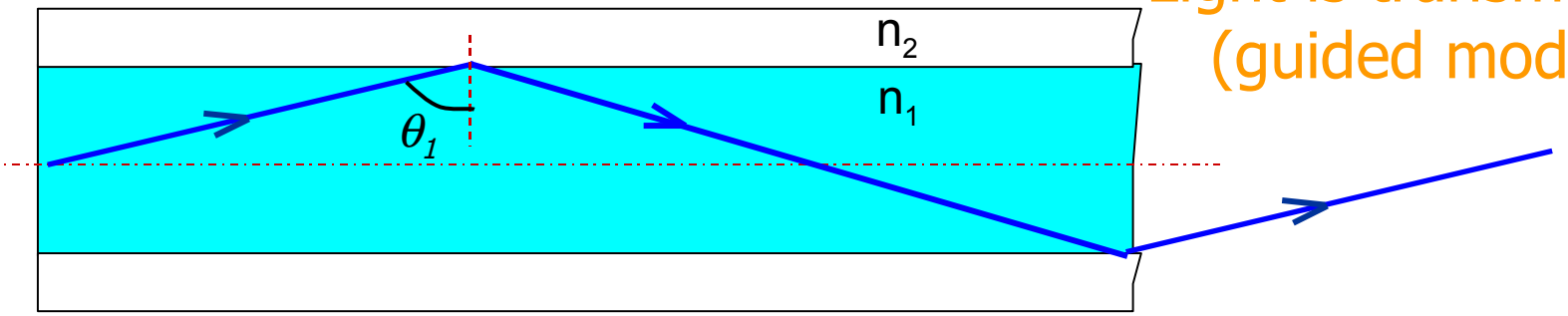
6.2 Light Transmission in Fiber

if θ_1 < critical angle θ_{cr}, ray is both reflected and refracted



Light is eventually lost (leaky mode)

if θ_1 > critical angle θ_{cr}, ray totally reflected

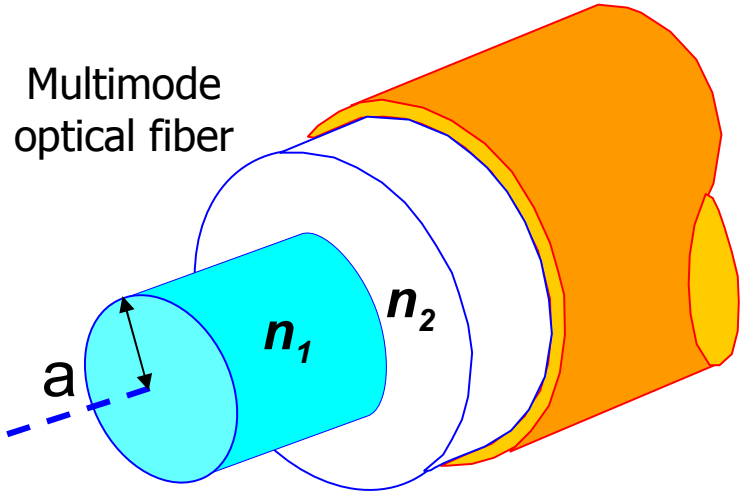


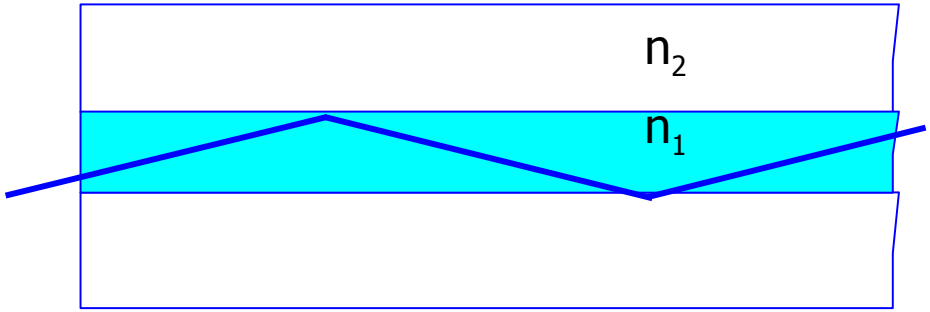
Light is transmitted (guided mode)

6.3 Modes of a Fiber

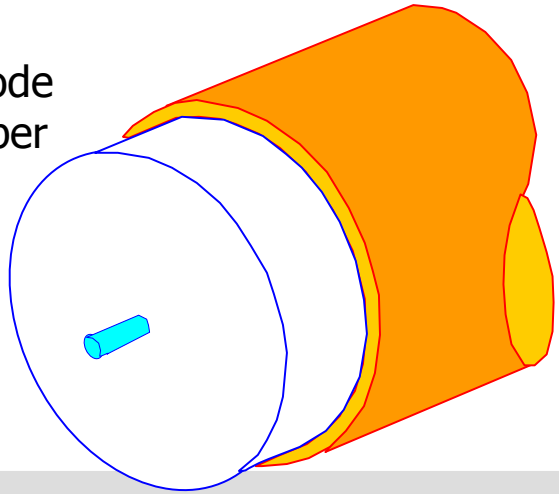
- What makes a fiber singlemode or multimode?

Multimode optical fiber





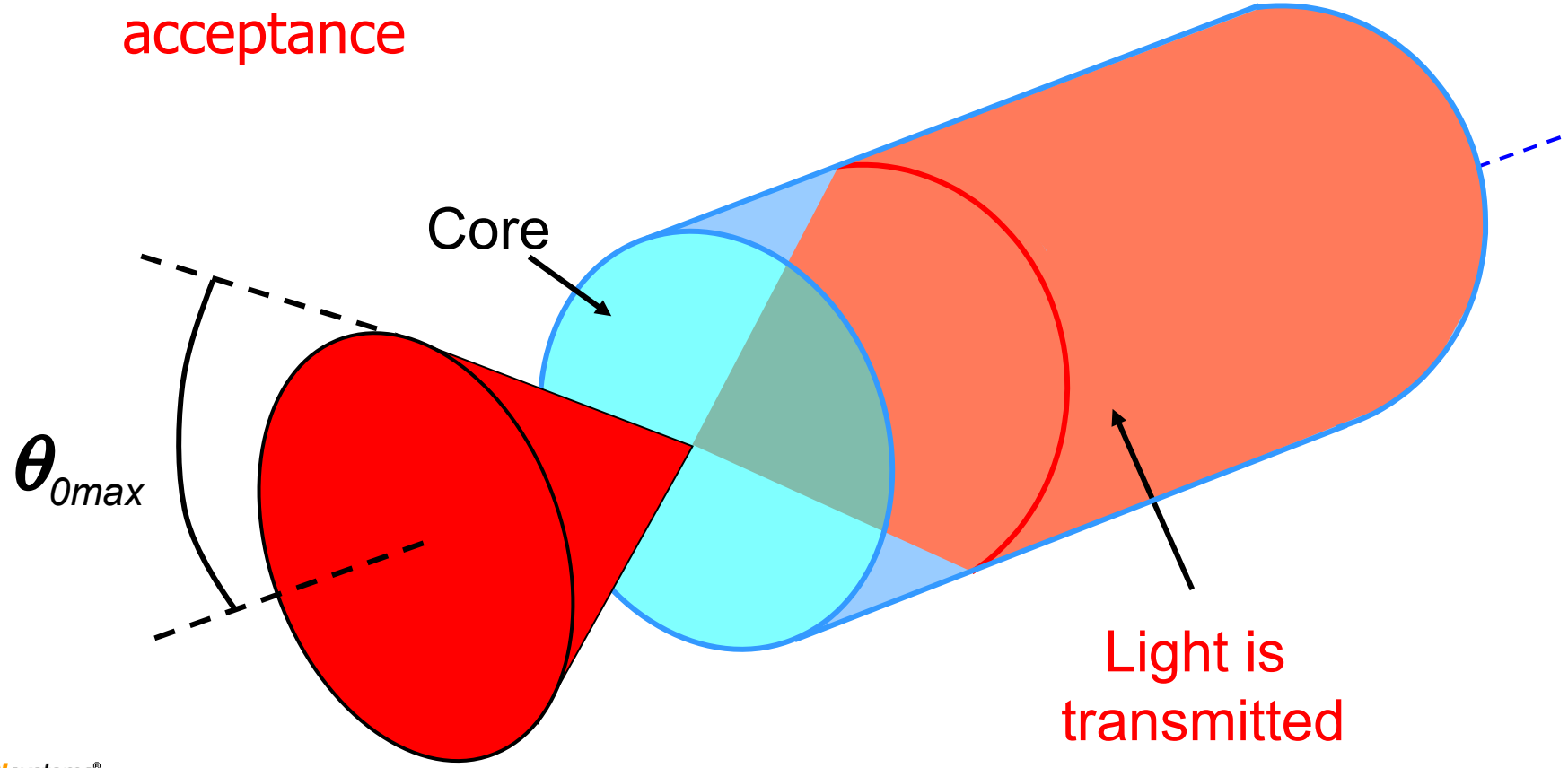
Single mode optical fiber



- dimension of core
- n_1 and n_2
- wavelength

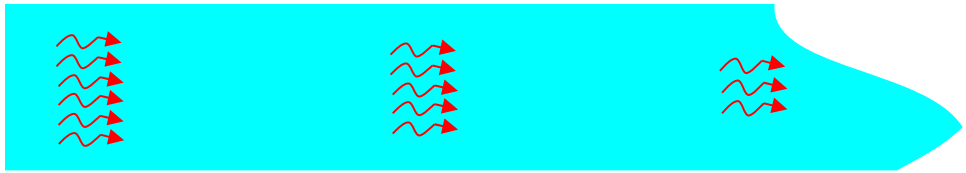
6.4 Key Coupling Parameters

- How much light can be captured by the fiber core?
  - Depends on the acceptance angle $\theta_{0max} \Rightarrow$ cone of acceptance

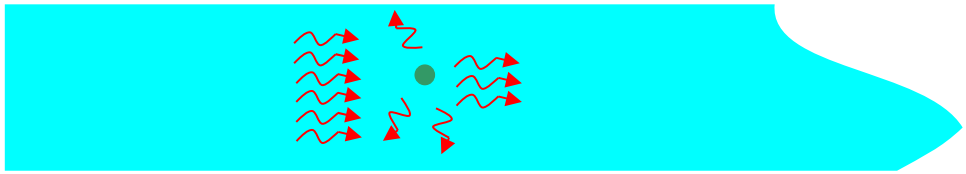


6.5 Fiber Attenuation

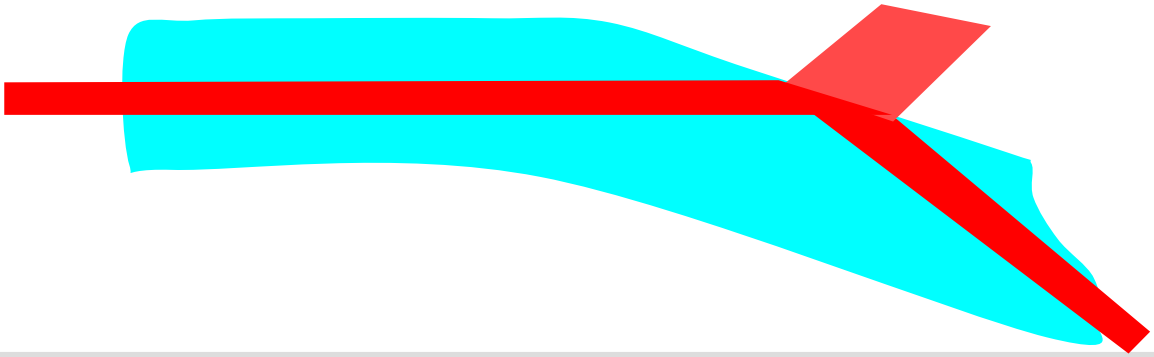
- What causes fiber loss?
  - Absorption



  - Scattering

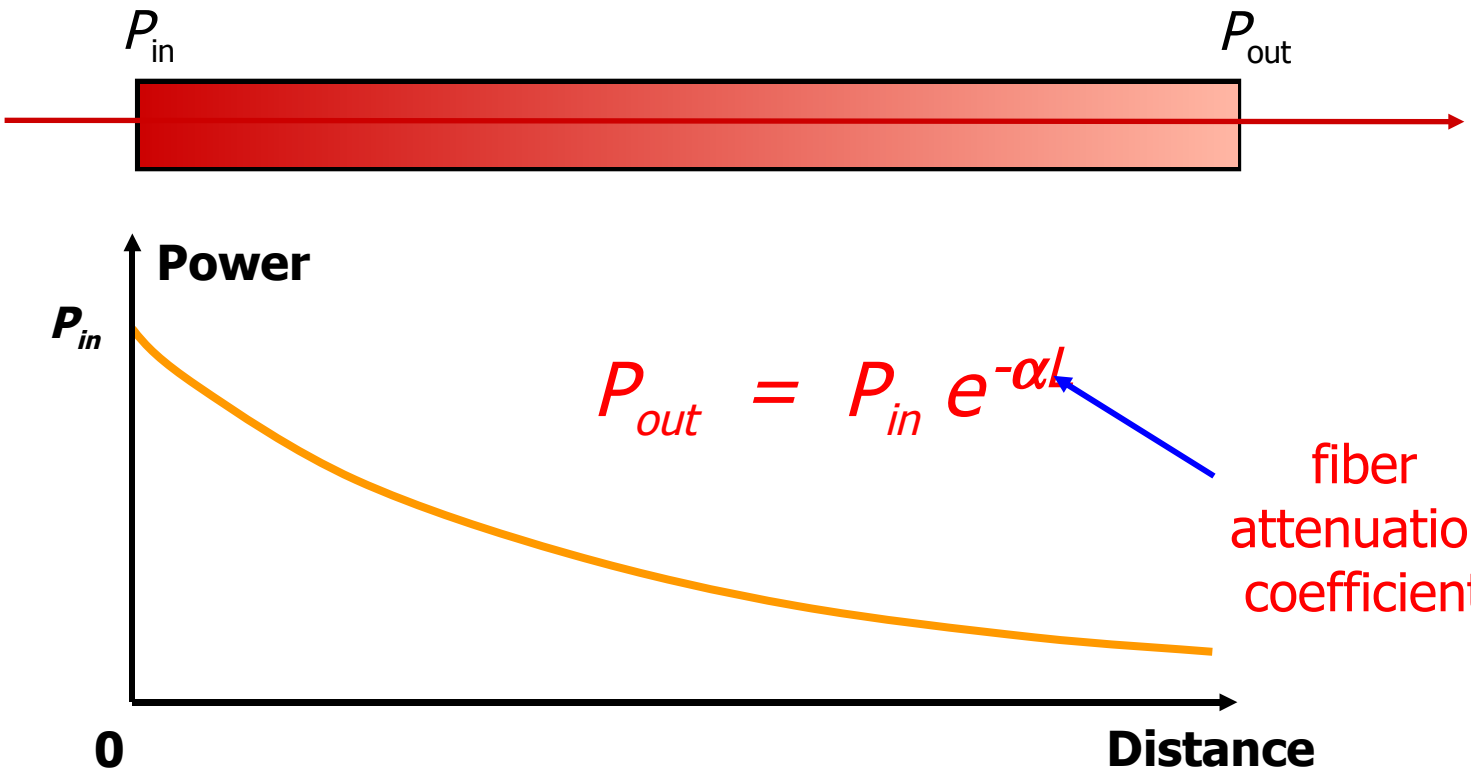


  - Bending



6.5 Fiber Attenuation

- As light travels along a fiber, its power decreases exponentially with distance L



6.5 Fiber Attenuation

- Attenuation coefficient α preferably expressed in units of dB/km

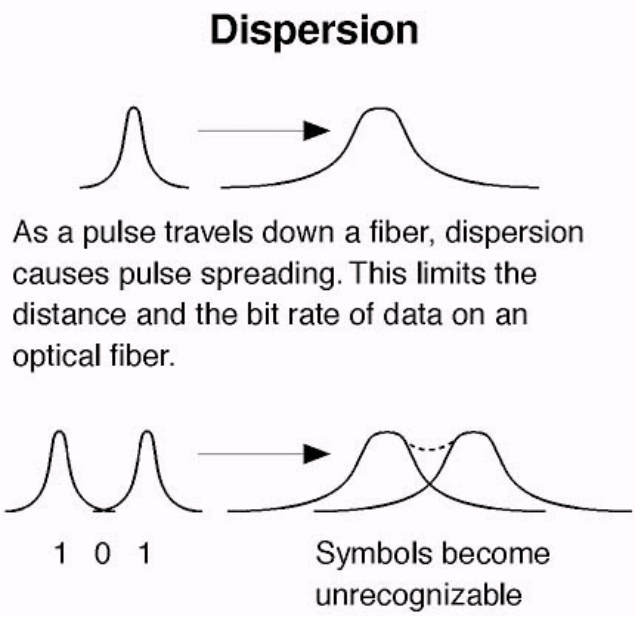
$$\alpha_{dB} = \frac{\left| P_{out}(\text{dBm}) - P_{in}(\text{dBm}) \right|}{L(\text{km})} \text{ (dB/km)}$$

or

$$\alpha_{dB} = (10\log_{10} e)\alpha \approx 4.343\alpha$$

6.6 Fiber Dispersion

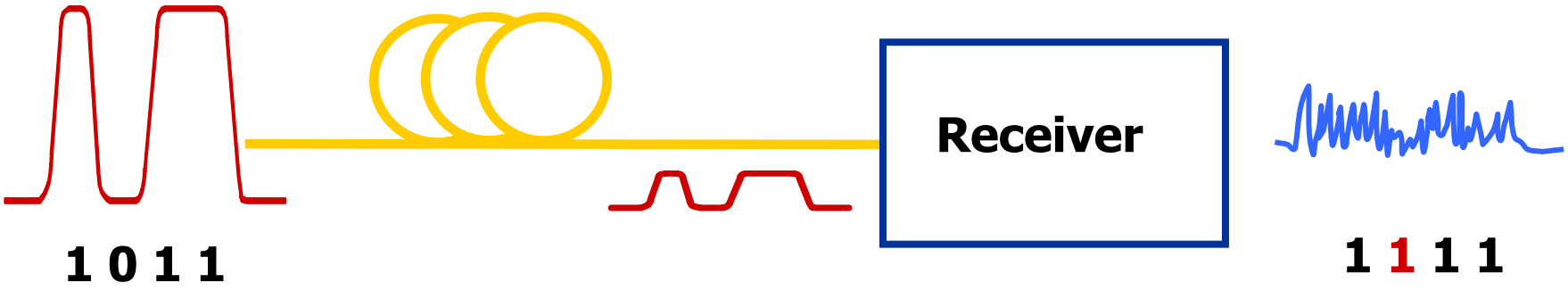
- Dispersion ⇨ different components of the signal travel at different velocities
  - Pulses spread in time
  - Causes intersymbol interference (ISI) ⇨ more errors
  - Limits possible distance and bit rate



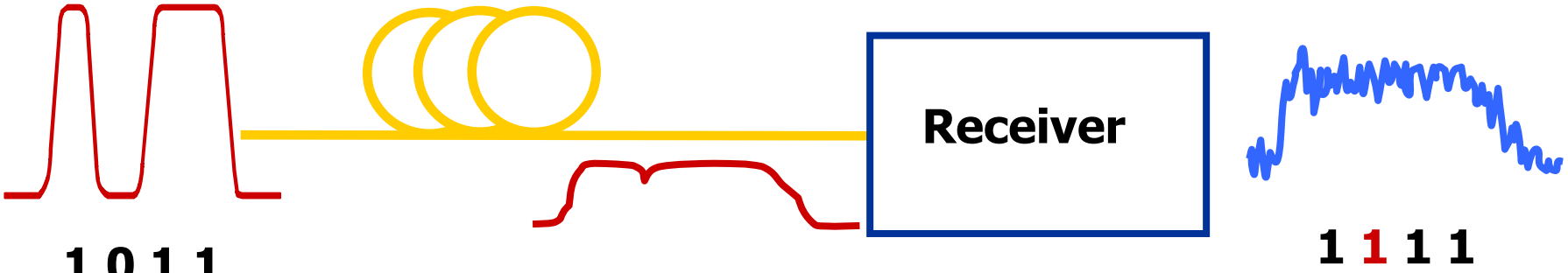
6.7 Fiber Limitations

- Link performance is limited by:

Loss

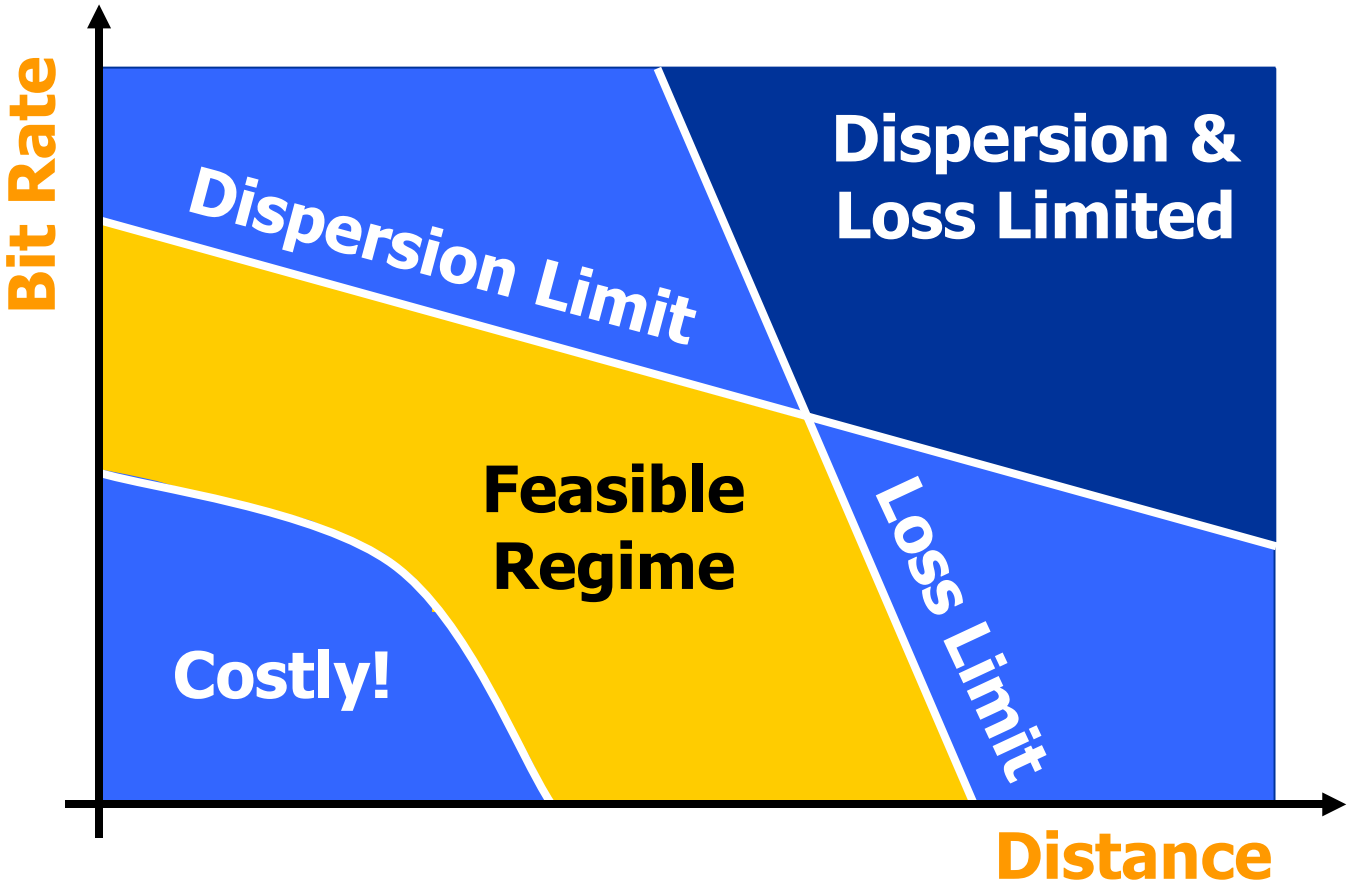


Spreading



6.7 Fiber Limitations

- Graphical representation of fiber limitations



7. Conclusions

- The role of telecommunications networks in the information age
- The fiber transmission medium
  - Nature of light
  - Mechanisms and limitations
  - Advantages over other media
- Next lecture focuses on important building blocks
  - Transmitters, receivers, amplifiers, filters

Thank You!