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
  - Few copies available in Electrical department and main libraries
  - Other useful material sources listed on website
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.)
1.1 Drivers for Networking Evolution

- Dominance of data
  - Internet technologies reversed 80%-to-20 % ratio of voice to data traffic
  - Increased demand for truly 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. Newton)?

  - 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.)

![Diagram showing light ray and plane wavefronts](image)

**Figure 6**

Intensity Distribution of Fringes

**Young's Double Slit Experiment**

- Light Propagation Direction
- Coherent Sunlight From Single Slit
- Destructive Interference
- Constructive Interference
- Screen
- Barrier with Double Slits
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)

<table>
<thead>
<tr>
<th>Less dense medium</th>
<th>More dense medium</th>
<th>Less dense medium</th>
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<tbody>
<tr>
<td><img src="image" alt="Fast moving photon" /></td>
<td><img src="image" alt="Photon slowed down" /></td>
<td><img src="image" alt="Photon speeds up" /></td>
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**Figure 8**

The Photoelectric Effect
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

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

- Copper Links
- Metallic cable
- Electrical repeater

- Terrestrial radio links
- Satellite links
- Orbiting satellite
- Radio relay stations

- Fiber links
- Optical to electrical converter
- Electrical repeater
- Electrical to optical converter
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

![Attenuation vs Wavelength Graph]

- Absorption by residue Hydroxyl (OH-) ions
- Standard fibers
- Zero water-peak fibers
5. Advantages of Fiber

- Larger information carrying capacity

**Data rate**

- **10 Gbps**
  - Visible light communications

- **1 Gbps**
  - UWB 802.15.3

- **100 Mbps**
  - MM wave communication

- **10 Mbps**
  - WLAN 802.11a/b/g

- **1 Mbps**
  - iBurst 802.20

- **100 Kbps**
  - xDSL

**Communication distance**

- **1 m**
  - IrDA 802.11b

- **10 m**
  - Bluetooth 802.15.1

- **100 m**
  - ZigBee 802.15.4

- **1 km**
  - 3G/3.5G

- **10 km**
  - WiMAX 802.16

- **100 km**
  - SATCOM
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 \( n_1 \approx 1.5 \)
  - 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
6.2 Light Transmission in Fiber

- Law of Reflection and Snell’s Law
  - Angle of Incidence $\theta_i = \text{Angle of Reflection} \ \theta_r$
  - Snell’s Law: $n_1 \sin \theta_i = n_2 \sin \theta_t$

![Diagram showing light transmission in fiber with angles and media types]
6.2 Light Transmission in Fiber

As \( \theta_i \) increases... \( \theta_t \) increases... until \( \theta_t = 90^\circ \)

Value of \( \theta_i \) (where \( \theta_t = 90^\circ \)) = “Critical Angle” = \( \theta_{cr} \)

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

\[ \theta_i > \theta_{cr} \]

Virtualy nothing transmitted

Total Internal Reflection
6.2 Light Transmission in Fiber

if $\theta_1 < \text{critical angle } \theta_{cr}$, ray is both reflected and refracted

Light is eventually lost (leaky mode)

if $\theta_1 > \text{critical angle } \theta_{cr}$, ray totally reflected

Light is transmitted (guided mode)
6.3 Modes of a Fiber

What makes a fiber singlemode or multimode?

- Single mode optical fiber
  - dimension of core
  - $n_1$ and $n_2$
  - wavelength

- Multimode optical fiber

$n_1$ and $n_2$ refer to the indices of the core and cladding materials, respectively.
6.4 Key Coupling Parameters

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

Diagram:
- Core
- $\theta_{0\text{max}}$
- Light is transmitted
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 $L$

\[ P_{out} = P_{in} e^{-\alpha L} \]

-fiber attenuation coefficient
6.5 Fiber Attenuation

- Attenuation coefficient $\alpha$ preferably expressed in units of dB/km

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

or

\[
\alpha_{\text{dB}} = (10\log_{10} e)\alpha \approx 4.343\alpha
\]
6.6 Fiber Dispersion

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

![Dispersion Diagram]

As a pulse travels down a fiber, dispersion causes pulse spreading. This limits the distance and the bit rate of data on an optical fiber.
6.7 Fiber Limitations

- Link performance is limited by:
  - Loss
  - Spreading

![Diagram showing the impact of loss and spreading on link performance](image)
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!

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