OPTICAL COMMUNICATIONS

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Introduction

➢ Optical Fiber Communication is an important Telecommunication infrastructure for world-wide broadband networks.

➢ Optical Fibers provide enormous and unsurpassed transmission bandwidth with negligible latency.

➢ Optical Fibers are the transmission medium of choice for long distance and high data rate transmission in Telecommunication Networks.
Introduction

➢ An optical fiber is essentially a waveguide for light.
➢ It consists of a core and cladding surrounded with Plastic Jacket.
➢ The index of refraction of the cladding is less than that of the core, causing rays of light leaving the core to be refracted back into the core.
➢ Optical fibers work on the principle of total internal reflection.
The advantages of fiber optic over wire cable

➢ Thinner
➢ Higher carrying capacity
➢ Less signal degradation
➢ Light signal
➢ Low power
➢ Flexible
➢ Non-flammable
➢ Lightweight
Disadvantage of fiber optic over copper wire cable

➢ Optical fiber is more expensive per meter than copper

➢ Optical fiber can not be join together as easily as copper cable. It requires training and expensive splicing and measurement equipment.
Optical Fiber Communication System

(a) Fiber cross section

(b) System
Major Elements of Optical Fiber Communication Link
Optical fiber cable installations

- Aerial-mounted cable
- Fiber cables within buildings
- Directly buried fiber cable
- Fiber cables in underground ducts
- Regenerator
- Undersea regenerator or optical amplifier
- Undersea optical cable
Signal path through an optical link

Electric input pulses

LED or laser transmitter

Optical power pulses

Optical fiber

Attenuated and distorted optical power pulses

$pinc$ or avalanche photodiode

Electric current pulses containing photodetector noise

Amplifier and filter

Voltage pulses and amplifier noise

Decision circuit and pulse regenerator

Regenerated output voltage pulses

Signal-processing equipment

The arrows denote the time slot centers.
Optical Fiber Types

Diagram showing the structure of an optical fiber, including the core, cladding, buffer coating, jacket, buffer, cladding, and core layers.
Types of Fibers

➢ Step-Index Fiber: It is known as step-index fiber because the index of refraction changes radically between the core and the cladding.

➢ The light energy in a single-mode fiber is concentrated in one mode only.

➢ It is basically used in telephone and cable TV.

➢ The Step-Index fibers propagate both single and multimode signals within the fiber core.
Fiber Types

![Fiber Types Diagram]

- **Multimode Graded-Index**
  - Core
  - Cladding
  - Cross Section
  - Refractive Index Profile
  - Light Path

- **Multi-mode Step-Index**
  - Core
  - Cladding
  - Cross Section
  - Refractive Index Profile
  - Light Path

- **Single-mode**
  - Core
  - Refractive Index Profile
  - Light Path
Fiber Types

➢ Graded-Index fiber: It a compromise multimode fiber, but the index of refraction gradually decreases away from the center of the core.

➢ It is basically used in Broadband Multi-media applications.

➢ Graded-Index fiber has less dispersion than a multimode step-index fiber
Optical Sources

➢ They are Two types of practical light sources in fiber communications systems:
➢ Light Emitting Diode: Emits incoherent light through spontaneous emission.
➢ Used for Multimode systems between 100-200 Mb/s rates and basically used in local-area-network applications.
➢ Broad spectral width and wide output pattern.
➢ LEDs are cheaper and more reliable as compared to Laser Diodes (LDs)
➢ LEDs support lower data rates as compared to that of LDs
➢ LEDs support the following Wavelengths: 850nm, 1300–1550nm region
➢ Due to their relatively simple design, LEDs are very useful for low-cost applications.
Surface-emitting LED
Edge-emitting LED

- Light-guiding layers
- Substrate
- Metalization (for electric contact)
- Heat sink
- Stripe contact (defines active area)
- Active area
- Metalization (for electric contact)
- SiO₂ isolation layer
- Double-heterojunction layers
- Incoherent optical output beam

\[ \theta_\parallel \]

\[ \theta_\perp \]
Optical Sources

➢ LASER Diodes: Emits coherent light through stimulated emission
➢ LDs are highly directional sources that have high optical power outputs
➢ broader modulation bandwidths and therefore can support high data rate transmission.
➢ Mainly used in Single Mode Systems
➢ Light Emission range: 5 to 10 degrees
➢ Require Higher complex driver circuitry than LEDs
LASER

Corrugated feedback grating

Active layer

Confinement layers

Substrate

Laser output
Optical Detector

➢ Photo Detector: A fiber optic receiver is an electro-optic device that accepts optical signals from an optical fiber and converts them into electrical signals.

➢ These are transducers that convert optical signals into electrical signals.

➢ An optical detector does so by generating an electrical current proportional to the intensity of the incident optical light.
Block Diagram of Optical Detector
Optical Fiber Losses

- Losses in optical fiber results from attenuation in the material itself and from scattering, which causes some light to strike the cladding at less than the critical angle.
- Bending the optical fiber too sharply can also cause losses by causing some of the light to meet the cladding at less than the critical angle.
- Losses vary greatly depending upon the type of fiber in use.
- Plastic fiber may have losses of several hundred decibels (dB) per kilometer.
- Graded-index multimode glass fiber has a loss of about 2–4 dB per kilometer.
- Single-mode fiber has a loss of 0.4 dB/km or less.
Splices and Connectors

In fiber-optic systems, the losses from splices and connections can be more than in the cable itself

Losses result from:

(i) Axial or angular misalignment
(ii) Air gaps between the fibers
(iii) Rough surfaces at the ends of the fibers
Noise Contribution in Optical Link

- Harmonic distortion
- Intermodulation
- RIN
- Laser clipping
- Modal distortion
- Attenuation
- GVD
- ASE noise
- Shot noise
- Thermal noise
- Amplifier noise
- APD gain noise

Electrical analog input signal → Optical transmitter → Optical fiber channel → Optical amplifier → Optical detector → CNR → Electrical analog output signal to RF receiver
Multiplexing

- Transmitting several signals over a single communications channel
- Multiplexing Technologies
- Frequency Division Multiplexing: Modulating data into different carrier frequencies.
- Wavelength Division Multiplexing: Multiple wavelengths per fiber and Multiple channels per wavelength
- Time division Multiplexing: Dividing available time among various signals
- Statistical Multiplexing: Dynamic allocation of time spaces depending on the traffic pattern

- Statistical Multiplexing
- Requires buffering resulting in variable delay, Many packets will have to be buffered
- Packets will have to be delayed, Some packets may be lost
Multiplexing
Frequency Division Multiplexing (FDM)
Wavelength Division Multiplexing (WDM)

➢ Partitions the optical bandwidth into a large number of channels
➢ Allows multiple data streams to be transferred along the same piece of fiber at the same time
➢ Consists of nodes interconnected by fiber optic links.
WDM

➢ Multiple channels of information carried over the same fiber, each using an individual wavelength
➢ Attractive multiplexing technique
➢ High aggregate bit rate without high speed electronics or modulation
➢ Low dispersion penalty for aggregate bit rate
➢ Very useful for upgrades to installed fibers
WDM
Problems and Solutions

Problem:
Demand for massive increases in capacity

Immediate Solution:
Dense Wavelength Division Multiplexing

Longer term Solution:
Optical Fiber Networks
Dense Wavelength Division Multiplexing (DWDM)

➢ Dense WDM is WDM utilizing closely spaced channels
➢ Channel spacing reduced to 1.6 nm and less
➢ Uses up to 100 wavelengths through a single fiber
➢ Bandwidth up to 1 Tbps (1000 Gbps)
➢ Cost effective way of increasing capacity without replacing fiber
➢ Allows new optical network topologies, for example high speed metropolitan rings
➢ Optical amplifiers are also a key component
DWDM

WDM transmitter shelf

OC-192 TX \( \lambda_1 \) VA

OC-192 TX \( \lambda_2 \) VA

...\( \lambda_{n-1} \) VA

OC-192 TX \( \lambda_n \) VA

Post-amplifier

Optical transmission line with optical amplifiers

WDM receiver shelf

Pre-amplifier

OC-192 RX \( \lambda_1 \)

OC-192 RX \( \lambda_2 \)

...\( \lambda_{n-1} \)

OC-192 RX \( \lambda_n \)

TX: Optical transmitter
RX: Optical receiver
VA: Variable attenuator
DWDM Advantages

➢ Greater fiber capacity

➢ Easier network expansion
  - No new fiber needed
  - Just add a new wavelength
  - Incremental cost for a new channel is low
  - No need to replace many components such as optical amplifiers

➢ DWDM systems capable of longer span lengths
  - TDM approach using STM-64 is more costly and more susceptible to chromatic and polarization mode dispersion

➢ Can move to STM-64 when economics improve
DWDM Disadvantages

➢ Not cost-effective for low channel numbers
  • Fixed cost of Mux/Demux, transponder, other system components

➢ Introduces another element, the frequency domain, to network design and management

➢ SONET/SDH network management systems not well equipped to handle DWDM topologies

➢ DWDM performance monitoring and protection methodologies developing
Optical Networks

➢ Passive Optical Network (PON)
  (i) Fiber-to-the-home (FTTH)
  (ii) Fiber-to-the-curb (FTTC)
  (iii) Fiber-to-the-premise (FTTP)

➢ Metro Networks (SONET)
  (i) Metro access networks
  (ii) Metro core networks

➢ Transport Networks (DWDM)
  (i) Long-haul networks
Optical Network Architecture

- Long Haul Network
- Metro Network
- Access Network

- DWDM
- SONET
- PON

CPE (customer premise)
Passive Optical Network (PON)

➢ Standard: ITU-T G.983
➢ PON is used primarily in two markets: residential and business for very high speed network access.
➢ Passive: no electricity to power or maintain the transmission facility.
   (i) PON is very active in sending and receiving optical signals
➢ The active parts are at both end points.
   (ii) Splitter could be used, but is passive
Passive Optical Network (PON)

OLT: Optical Line Terminal
ONT: Optical Network Terminal
Basic PON Topologies

**BUS**

**RING**

**STAR**
Star, Tree & Bus Networks

➢ Tree networks are widely deployed in the access front

➢ Tree couplers are similar to star couplers (expansion in only one direction; no splitting in the uplink)

➢ Bus networks are widely used in LANs

➢ Ring networks (folded buses with protection) are widely used in MAN

➢ Designing ring & bus networks is similar
Types of PON

➢ ATM-based PON (APON) – The first Passive optical network standard, primarily for business applications

➢ Broadband PON (BPON) – the original PON standard (1995). It used ATM as the bearer protocol, and operated at 155Mbps. It was later enhanced to 622Mbps.
   (i) ITU-T G.983

➢ Ethernet PON (EPON) – standard from IEEE Ethernet for the First Mile (EFM) group. It focuses on standardizing a 1.25 Gb/s symmetrical system for Ethernet transport only
   (i) IEEE 802.3ah (1.25G)
   (ii) IEEE 802.3av (10G EPON)

➢ Gigabit PON (GPON) – offer high bit rate while enabling transport of multiple services, specifically data (IP/Ethernet) and voice (TDM) in their native formats, at an extremely high efficiency
   (i) ITU-T G.984
## xPON Comparison

<table>
<thead>
<tr>
<th></th>
<th>BPON</th>
<th>EPON</th>
<th>GPON</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Standard</strong></td>
<td>ITU-T G.983</td>
<td>IEEE 803.2ah</td>
<td>ITU-T G.984</td>
</tr>
<tr>
<td><strong>Bandwidth</strong></td>
<td>Down: 622M</td>
<td>Symmetric: 1.25G</td>
<td>Down: 2.5G</td>
</tr>
<tr>
<td></td>
<td>Up: 155M</td>
<td></td>
<td>Up: 2.5G</td>
</tr>
<tr>
<td><strong>Downstream λ</strong></td>
<td>1490 &amp; 1550</td>
<td>1550</td>
<td>1490 &amp; 1550</td>
</tr>
<tr>
<td><strong>Upstream λ</strong></td>
<td>1310</td>
<td>1310</td>
<td>1310</td>
</tr>
<tr>
<td><strong>Transmission</strong></td>
<td>ATM</td>
<td>Ethernet</td>
<td>ATM, TDM, Ethernet</td>
</tr>
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</table>
SONET

➢ Synchronous Optical Network (SONET) standard encodes bit streams into optical signals propagated over optical fiber. SONET defines a technology for carrying many signals of different capacities through a synchronous, flexible & optical hierarchy.

➢ SONET topology can be a mesh, but most often it is a dual ring.

➢ De-Multiplexing is easy
SONET in Metro Network

Long Haul (DWDM) Network

Core Router

Metro SONET Ring

Access Ring

Voice Switch

T1

PBX

T1
(a) 

SONET Architecture

STS Line

Section

Section

STS Line

STS-1 Path

STE: Section Terminating Equipment, e.g. a repeater
LTE: Line Terminating Equipment, e.g. a STS-1 to STS-3 multiplexer
PTE: Path Terminating Equipment, e.g. an STS-1 multiplexer

(b)

Path

Line

Section

Optical

Path

Line

Section

Optical
Services

➢ Network characteristics
  (i) Full redundancy
  (ii) Fast restoration
  (iii) High availability (99.999 %)
  (iv) High bandwidth
  (v) Dynamic allocation and high bandwidth efficiency
  (vi) Support various services

➢ More providers and equipment builders (due to Deregulation of the telecom industry)

➢ Providers are expected to provide more services at higher capacity at lower prices!

➢ A positive feedback business model

➢ Need for high capacity network

➢ More users
Service Types

➢ Two basic service types (switching technologies)
  (i) Connection-oriented
  (ii) Connectionless
➢ Connection-oriented
  (i) Based on circuit switching (setup, connect, tear-down)
  (ii) Example: Public Switching Telephone Network (PSTN)
  (iii) Originally only supported voice
  (iv) Not good for bursty traffic
➢ Connectionless
  (i) Based on sending datagrams
  (ii) Examples: Packet, message, burst switching
  (iii) Improves bandwidth and network utilization
Evolution of Optical Networks – First Generation

- Started in 1980
- Limited to fiber optic transmission systems – the rest of the system was electrical
  - Thus, the electronic was the major bottleneck
  - The received optical data had to be dropped and then transmitted – this was a point-to-point system
  - Example: Synchronous Optical Network (SONET) and Synchronous Digital Hierarchy (SDH), Fiber Distributed Data Interface (FDDI), Fiber Channel
First Generation Optical Networks

➢ These systems were based on Optical TDM (10Gb/s and 40Gb/s)

➢ Higher capacity systems were built using WDM technology (1 Tb/s) – remember a single phone line is only 60 Kb/s)
FDDI Ring Structure

- FDDI backbone consists of two separate fiber-optic rings,
  - primary ring: active
  - secondary ring: “on hold,”

- Station Types
  - Class A: dual-attachment stations, Class B: single-attachment station.
FDDI Fiber Specifications

➢ OPTICAL FIBER SUPPORT
  ▪ FDDI can support 62.5/125-, 50/125-, and 100/140(Core/Cladding) -µm multimode fiber sizes. Maximum distance 2 Km.
  ▪ FDDI also supports the use of single-mode fiber,
    • Long-distance transmission (up to 40 Km)
    • FDDI single-mode fiber is commonly specified as 8/125, 9/125, and 10/125.

➢ OPTICAL TRANSMITTER
  ▪ 850, 1300, and 1550 nm
  ▪ 850 and 1300 nm for multimode fiber
  ▪ 1300 and 1500 nm for single-mode fiber
  ▪ For single-mode fiber laser diodes must be used

➢ ATTENUATION
  ▪ For multimode fiber
    • Maximum cable attenuation is 1.5 dB/km at 1300 nm.
  ▪ single-mode fiber
    • power budget extends from 10 to 32 dB
Evolution of Optical Networks – Second Generation

➢ Incoming optical signals could be switched in optical domain (optical switching)
  ▪ No longer limited to point-to-point

➢ Underlying technologies included
  ▪ Optical Add-Drop Multiplexers (OADM)
  ▪ Optical crossconnects (OXC)
  ▪ Optical line terminals (OLT)
  ▪ Wavelength Add/Drop Multiplexer (WADM)
  ▪ Dense WDM (DWDM)

➢ Examples
  ▪ FTTH, FTTC, ROADM
Second Generation Optical Networks

➢ WADM
➢ OXC
Evolution of Optical Networks – Third Generation

➢ All optical packet switching
➢ All packets are processed in optical domain
  ▪ Transparent to the service
  ▪ Handle any arbitrary bit rate
➢ Underlying technologies
  ▪ Optical buffering
  ▪ Fast switching
Applications of Optical Fiber Communications

➢ Telecommunications
➢ The various applications of fiber optics in the telecommunication area in voice telephones, video phones, telegraph services, message services and data networks all transmitted over common carrier links.
➢ The conventional problems of wire systems like those of ringing, cross talk, electromagnetic interference and induced errors, etc., are completely avoided with the use of optical fiber communication methods.
➢ Coaxial undersea cable systems have been used as one of the major transmission systems in international telecommunication networks over the past 25 years.
➢ Its channel capacity has rapidly increased about ten times per decade with the growth in overseas traffic.
Fiber Applications

➢ **Space Applications**

Optical fiber offers the following significant advantages for space environment, namely high bandwidth, noise immunity, inherent radiation hardness, reduced weight, low bit error rate, size, weight and volume reduction.

➢ **Broad-band Communication**

Optical fiber offer many new opportunities to system planners interested in broadband video and other services.

➢ In the private customer application, a coalescence of the existing community antenna television system (CATV) and telecommunications services seems likely, with the development of wide band switched integrated networks.

➢ Primarily providing educational and entertainment TV, but with a capability to provide many other services also.
Information Technology Applications

➢ A modern large computer system is composed of a large number of interconnections ranging in length over 16 orders of magnitude from the micrometer dimensions of the on chip very large scale integration (VLSI) connections to thousands of kilometer for terrestrial links in computer networks.

➢ The transmission line features of fiber optics are potentially attractive for many of these computer connections.
Conclusion

➢ Optical fibres are used as a versatile transmission medium for variety of applications related to transmission of information.

➢ Single mode fibre enjoys lower signal attenuation than multimode and hence, it can be used for longer distances up to 100kms while multimode fibre can be used for smaller distances up to 6 km.

➢ Optical interconnections offer several advantages over metallic interconnections, they include: higher bandwidth, higher interconnection densities, lower crosstalk etc
Conclusion

➢ The applications discussed are numerous and more are still emerging on the horizon that might lead towards a dream Internet made by all-optical WDM network.
➢ The different types of the Multiplexing in all optical networks.
➢ The evolution of Optical networks in the three different generations have been discussed.
➢ PONs with respect to nodes type, data transmission rate and architecture is also discussed.
➢ It is very hard to predict anything for telecom networks during next ten years but optical communication will surely make its place in changing face of telecom infrastructure.
References


References


THANK YOU