EE 443/CS 543 Optical Fiber Communications
Dr. Donald Estreich
Fall Semester

Lecture 2

http://www.wiretechworld.com/the-future-of-optical-fibres/
Highlights from Lecture 1 (Fall Semester 2020) – I

1. Telecommunications purpose is to carry digitized signals around the World. Driving force behind fiber optic communication is to provide telecommunications with capacity necessary to meet needs.

2. Basic elements of an optical fiber link include (1) Transmitter with optical source), (2) Fiber optic cable, (3) Receiver with photo-detector, and (4) Sometimes includes regenerator or optical amplifier in link.


4. Advantages of OFC include (1) Ultrawide bandwidth, (2) Ultralow transmission loss, (3) Higher immunity to interference and cross-talk, (4) Lower weight (compared to copper wire), (5) Lower cost per byte in operation, (6) Better security, (7) Long lifetime, and (8) Resistant to water & many chemicals.
Highlights from Lecture 1 (Fall Semester 2020) – II

4. Disadvantages of OFC include (1) More expensive to install, (2) Fiber is more fragile than copper wire, (3) Difficult to splice, and (4) More difficult to add network nodes after initial installation.

5. Technology generations: First generation used graded-index fibers; Second generation used single-mode fibers; Third generation used single-mode lasers; Fourth generation added optical amplifiers.

6. Waveguides support many modes above their cutoff frequencies. Generally these modes propagate at different velocities.

7. Harmonic waves traveling within an optical fiber cable are of the form $A \cdot \cos(\omega t - kz)$.

8. Optic fibers are cylindrical dielectric waveguides that transport non-TEM waves at frequencies above the cutoff frequency.
Telecommunications Encompasses a Wide Range of Technologies

Perhaps the best definition of telecommunication is

*Telecommunications is the suite of technologies, devices, equipment, facilities, networks, and applications that support communication at a distance.*

The range of telecommunications applications is broad and includes telephony and video conferencing, facsimile, broadcast and interactive television, instant messaging, e-mail, distributed collaboration, a host of Web- and Internet-based communications, and data transmission.

**Telecommunications Trends in 2020**

1. Telecoms working toward 5G
2. Internet of Things (IoT)
3. Incorporating AR and VR technology

https://techimplement.com/4-reasons-why-telecom-industry-needs-a-crm/
Overview: Applications of Networks I

✓ Communications/Data Storage
  Wide use of optical fiber communication systems for data transmission, including long-distance backhauls, computer data communications (LAN, MAN, WAN), voice signals, Internet traffic, and submarine cables for intercontinental communications.

✓ Broadcast/CATV/Cable Television
  Digital video distribution, high-definition broadcast signals, closed circuit television, etc. Passive optical networks: Fiber to the Curb, Fiber to the Home, etc. Most cable television providers use optical fiber networks for content distribution.

✓ Networking
  Interconnection of computers within buildings, across local area networks, metropolitan area networks and wide area networks. Used in a wide variety of networks requiring fast data transport and/or massive data transmission (such as in storage networks).
Overview: Applications of Networks II

✓ Industrial/Commercial
   Used in applications that can’t tolerate electromagnetic interference. Also used in sensor applications, for monitoring places hard to reach or have harsh environments. *Examples*: Communication cabling in automobiles, aircraft and boats; also used in factories, etc.

✓ Military
   Military requires highly secure and hardened fibers for military equipment in combat environments.
A Simplistic View of a Telecommunication Network

A telecommunication network consists of a set of interconnected nodes that exchange data with each other. The links may use a variety of technologies based on the methodologies of circuit switching, message switching, or packet switching, to pass messages and signals.

Channels, or links, may be wire, coaxial cable, optical fiber or wireless.

Obviously, an oversimplified Picture!

https://www.britannica.com/technology/telecommunications-network
Desired Features in Telecommunication Networks

• **High data capacity** (meets customer’s requirements)

• **Scalable** in supporting data traffic
  Today it must support packet switching

• Delivers **new and flexible types of services**
  Such as “Bandwidth on Demand”
  Restorable connections with guaranteed service

• High network **reliability** and **security**

• Customer **affordable** (*i.e.*, cost effective network)
Simplified Public Telecommunication Network

From: Ramaswami, Sivarajan & Sasaki, *Optical Networks: A Practical Perspective*, 3rd edition, Morgan Kaufmann Publishers, Figure 1.1 on page 5; © Elsevier 2010.
Local, Metropolitan and Wide Area Networks

LAN - Local Area Network
A Local Area Network (LAN) is a private network that connects computers and devices within a small area like a residence, an office or a building. On a small scale, LANs are used to connect personal computers to printers. However, LANs can also extend to a few kilometers when used by companies, where many computers share a variety of resources like hardware (e.g., printers, scanners, audiovisual devices, etc.), software and data.

MAN - Metropolitan Area Network
A Metropolitan Area Network (MAN) is a larger network than a LAN. Typically covers multiple cities or towns. It is relatively expensive to operate and multiple organizations often share ownership. Typically tens to hundreds of kilometers in size.

WAN - Wide Area Network
A Wide Area Network (WAN) is typically a much larger network than LAN and MAN. It often covers multiple countries or states. It is expensive and may be owned by multiple corporations or organizations. Often a WAN covers an entire state or nation and they may span the world (such as the Internet does).

In addition, there are Personal Area Networks (PAN), Wireless Local Area Networks (WLAN), Storage Area Networks (SAN), Virtual Private Networks (VPN), etc.
Differentiating Networks by Size

Example: My PAN Network in Sebastopol

Use W-Fi at home [3 computers, 2 printers, 2 cell phones & a router]

First-Generation Optical Networks

First-generation optical networks essentially used optical fiber for point-to-point links where the fiber replaced copper wires or cables. Optical fiber provided lower bit error rates and higher data capacities than copper. All the switching and other intelligent network functions were handled by digital electronics.

Examples of first-generation optical networks are SONET (synchronous optical network) and the essentially similar SDH (synchronous digital hierarchy) network, which form the core of the telecommunications infrastructure in North America and in Europe and Asia, respectively, as well as a variety of enterprise networks such as Fibre Channel.
An Optical Fiber Communication System uses light wave technology to transmit voice, video and data over a fiber by converting electronic signals into light and back to electronic signals.
OFC Link Components & Requirements

1. Optical source (either LED or laser)
   - High optical output power and wavelength stability
   - Fast modulation capability (direct modulation of device or external modulator)
     - Fast electronics to drive modulation of the optical source
   - Efficient method for coupling optical energy into fiber

2. Optical detector (such as PIN or APD diodes)
   - Detector with fast response
     - Fast electronics to capture the detector’s output
   - Low noise in detector itself and related circuitry
   - Efficient method for coupling fiber’s output into the detector device

3. High-quality optical fiber (lightpath or channel)
   - Low attenuation
   - Adequate physical protection for the fiber
Some Examples of Access Networks

- **Ethernet** –
  The most-commonly installed wired LAN technology. Ethernet LAN typically uses coaxial cable or twisted pair wires for connection. Today Optical Ethernet has been added.

- **DSL** –
  Digital Subscriber Line (DSL) is a connection to home through telephone lines and carries both data and voice signals. DSL commonly allows connection to the Internet.

- **FTTH** –
  Fiber to the home (FTTH) uses optical fiber from a central Office (CO) directly to individual buildings and it provides high-speed Internet access. Also, FTTC (curb) and FTTB (business) delivered by passive optical networks (PON).

- **Wireless LANs** –
  It links two or more devices using high-frequency radio waves and often include an access point for connecting to the Internet (typically Wi-Fi is commonly used).

- **2G, 3G and 4G (LTE) Cellular** –
  Cellular telephony to send or receive packets through nearby base stations operated by a cellular network provider. Soon we add 5G cellular networks to the list.

[https://www.geeksforgeeks.org/access-networks/](https://www.geeksforgeeks.org/access-networks/)
Second-Generation Optical Networks

Second-generation optical networks incorporate switching and routing functions into the optical domain instead of the electronics of the network.

This is accomplished by *wavelength routing* in the optical domain.

Key network elements to do switching and routing include:

1. Optical Line Terminals (OLT)
2. Optical add/drop multiplexers (OADM)
3. Optical crossconnects (OXC)
A WDM Wavelength-Routing Network

From: Ramaswami, Sivarajan & Sasaki, *Optical Networks: A Practical Perspective*, 3rd edition, Morgan Kaufmann Publishers, Chapter 1, Figure 1.4 on page 14; © Elsevier 2010.
Multiplexing Techniques

- Frequency-division multiplexing (FDM)
- Wavelength-division multiplexing (WDM)
- Time-division multiplexing (TDM)
  - Synchronous TDM
  - Asynchronous TDM
    - “Statistical TDM”

Example: SONET/SDH, T1 and ISDN

ISDN = Integrated Services Digital Network; T1 line carries 24 digitized voice channels

https://www.javatpoint.com/multiplexing-techniques
Multiplexing Techniques

**Multiplexing** is a method where multiple analog or digital signals are combined into a signal stream over a shared medium. The primary purpose is to share a scarce resource or provide a switching function. **Demultiplexing** is the inverse operation; each signal on the shared medium is split out into individual links or channels.

For increasing the transmission capacity of a link.

This can be more than one link in general
TDM and WDM Multiplexing Techniques

Wavelength Division Multiplexing (WDM) increases the capacity of a fiber link and is complimentary to TDM.

From: Ramaswami, Sivarajan & Sasaki, Optical Networks: A Practical Perspective, 3rd edition, Morgan Kaufmann Publishers, Figure 1.3 on page11; © Elsevier 2010.
Optical Line Terminals (OLT)

An optical line terminal is a device which serves as the service provider endpoint of a passive optical network. It provides two main functions:

1. To perform conversion between the electrical signals used by the service provider's equipment and the fiber optic signals used by the passive optical network.

2. To coordinate the multiplexing between the conversion devices on the other end of that network.

Example: FTTH using a PON


https://en.wikipedia.org/wiki/Optical_line_termination
Specific Example: A Passive Optical Network (PON)

Wavelength Division Multiplexing (WDM) is shown in example.

OLT

Central Office

Passive Remote Node (RN)

FTTH

FTTC

FTTB

VDSL = Very high speed Digital Subscriber Line

Optical Add-Drop Multiplexer (OADM)

Optical add-drop multiplexers (OADM) are the simplest elements to introduce wavelength management capabilities by enabling the selective adding and dropping of optical channels. The OADM is based upon low-loss, low-cost passive devices and does not need a power supply, thus a reliable, cost-effective and scalable network can be constructed with them.

https://community.fs.com/blog/oadm-optical-add-drop-multiplexer-tutorial.html
Reconfigurable Optical Add-Drop Multiplexer (ROADM)

A reconfigurable optical add-drop multiplexer adds the ability to remotely switch traffic in a wavelength-division multiplexing (WDM) system. A ROADM is an all-optical network element that enables dynamic software-driven provisioning of wavelengths in DWDM network services from a remote management system without major network changes or redesign (it is scalable).

Optical Cross-Connect (OXC)

An optical cross-connect (OXC) is a device used by telecommunication carriers to switch high-speed optical signals in a fiber optic network, such as an optical mesh network. ⇒ Connect any node to any node.

https://commons.wikimedia.org/wiki/File:Optical_Cross_Connect,_OXC.png
Wavelength Division Multiplexing

**Wavelength Division Multiplexing** is an analog multiplexing technique where signals of different wavelengths are combined to be transmitted over a single fiber link.

Each channel has its own distinct wavelength.

https://electronicscoach.com/wavelength-division-multiplexing.html
Wavelength Division Multiplexing Operating Wavelengths

https://www.researchgate.net/figure/Fiber-attenuation-contributions-and-operation-bands_fig12_241685732
Course Wavelength Division Multiplexing

See Fig. 12.55, Page 772, in Senior, 3rd ed.

Dense Wavelength Division Multiplexing

With DWDM we need highly stable laser sources.

https://chinafiberoptics.blog.hu/2017/03/04/cwdm_vs_dwdm_952
Networks in General

https://wallpaperplay.com/board/computer-networking-wallpapers
A data communication network is a collection of interconnected nodes (consisting of computers, terminals, or other devices in many locations) connected by data links which are communication channels providing data paths between nodes.

Four Most Common Generic Network Topologies:

- **Bus**
- **Full Mesh**
- **Ring** (can be single or dual)
- **Star**
- **Mesh**
- **Tree**

Reference: Section 15.2.1.1 on Network Topology, page 971, in Senior, 3rd edition.
Most Networks Are Combinations of these Basic Topologies

Example:

http://techgenix.com/network-topology/
Circuit Switching, Message Switching & Packet Switching

https://www.javatpoint.com/computer-network-switching-techniques
Comparing Circuit-Switching, Message-Switching & Packet-Switching

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Message-Switching</th>
<th>Circuit-Switching</th>
<th>Packet-Switching</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td>Telegraph network for telegram transmission</td>
<td>Telephone network for bidirectional, real-time transfer of voice signals and data</td>
<td>Internet for TCP and datagram packets &amp; reliable streaming service</td>
</tr>
<tr>
<td>End terminals</td>
<td>Telegraph key and sounder</td>
<td>Telephones and modems</td>
<td>Computers</td>
</tr>
<tr>
<td>Information type</td>
<td>Morse code; Baudot &amp; ASCII</td>
<td>Analog voice or PCM digital voice</td>
<td>Binary information</td>
</tr>
<tr>
<td>Transmission system</td>
<td>Digital data over variety of transmission media</td>
<td>Analog and digital data over different transmission media</td>
<td>Digital data over different transmission media</td>
</tr>
</tbody>
</table>

https://slideplayer.com/slide/8606235/
Message Switching In Concept (Not Widely Used Today)

Example: Telegraph

Electric telegraph in 1837

https://www.quora.com/What-is-message-switching
Circuit-Switched Network versus Packet-Switched Network

Packet-switched and circuit-switched networks use very different technologies for sending messages and data from point-to-point (node-to-node).

Circuit-switching was first designed in 1878 to send telephone calls over dedicated channels. This was the landline telephone network (POTS) that dominated telecommunications for many decades.

Packet-switching evolved from the Defence Department’s ARPANET network and does not use dedicated connections to route packets over a network. The Internet is a packet-switched network (and obviously the largest of all packet-switched networks).
Circuit-Switched Networks versus Packet-Switched Networks

**Circuit-Switching** originated to build telephone networks. Wires and switches are used to make a dedicated wireline connections, forming a fixed connection from start to finish. The first telephone network was created in 1878.

In **Packet-Switching** the message is broken into limited-size data packets. These packets are sent over the network by special purpose computers called “routers.” Routers send packets over the network seeking the most effective path to travel as data links become available. Packets don’t necessarily travel by the shortest route, rather the paths chosen are the most efficient in terms of network utilization. Since packets often travel over different routes, they must be reassembled in correct order at the destination node.
Many paths are possible, but only one is selected per call. Once a connection is established, this connection is maintained until call is terminated. PSTN = public switched telephone network

The public switched telephone network (PSTN) is the aggregate of the world's circuit-switched telephone networks that are operated by national, regional, or local telephony operators, providing infrastructure and services for public telecommunication. The PSTN now consists of telephone lines, fiber optic cables, microwave transmission links, cellular networks, communications satellites, and undersea telephone cables, all interconnected by switching centers, thus allowing most telephones to communicate with each other.

Before the Internet and other computer networks, telecommunications had a clear meaning: The telephone (and earlier the telegraph) was an application of technology that allowed people to communicate at a distance by voice (using encoded electronic signals). The telephone service was provided by the public switched telephone network (PSTN). Most of the U.S. network was built and operated by American Telephone & Telegraph (AT&T) – that changed in 1984 when the AT&T monopoly was broken up into the seven “Baby Bells.” These were the Regional Bell Operating Companies (RBOC).

https://en.wikipedia.org/wiki/Public_switched_telephone_network
https://www.nap.edu/read/11711/chapter/3
Local Loops in the PSTN

The Local Loop

- Single central office
  - 10,000 telephone lines can be connected
- The two-wire, twisted-pair connection
  - Telephone and central office
    - local loop or subscriber loop.

LEC = local exchange carrier
CO = central office
IXC = Interexchange carrier

© 2008 The McGraw-Hill Companies
Telephone System and Local Loops

Trunk: A communications path between switching facility to switching facility.

Organization of the telephone system in the United States.
Public Switched Telephone Network (PSTN)

Telephone Lines in 1950s

http://www.themontyminute.com/telephone-pole-blight/

Telephone Operators in 1950s


Crossbar-type telephone switching system from the 1960s

https://www.nextiva.com/blog/what-is-pots.html
Local Loop or Subscriber Loop

In telephony, the **local loop** (also called the **local tail**, **subscriber loop**, or in the aggregate the **last mile**) is the physical link that connects from the demarcation point of the customer premises to the edge of the common carrier’s network or the telecommunications service provider's network.

Historically, the local loop was an electrical circuit in the form of a single pair of conductors (usually twisted pair) from the telephone on the customer’s premises to the local telephone exchange. AT&T established the technical jargon used.

A local loop supports voice and/or data communications applications with the following services:

- Analog voice and signaling as used in traditional POTS
- Integrated Services Digital Network (ISDN)
- Variants of digital subscriber line (DSL)

[https://en.wikipedia.org/wiki/Local_loop](https://en.wikipedia.org/wiki/Local_loop)
Optical Fiber in the Telephone Subscriber Loop

Packet-Switching Network Introduction

Packet-switched networks were invented to address the problem of transporting bursty data. Bursty data does not work well with the circuit-switched network due to its inefficiency.

Packet-switching uses methodology called statistical multiplexing. Thus, it is quite likely that not all packets are active at any one time. The bandwidth requirement is therefore much smaller that with a circuit-switched network. However, this results in random delays in the packets for all users.
Packet-Switched Network

Message broken into packets and each addressed

Many paths possible for a single message as packets are routed to the destination.

Sender (source)

Packets are routed according to the best path available at the time.

Large array of routers and data links.

Router or Switch

Packet route

Receiver (destination)

Packets sequentially reassembled to reveal message

## Information in TCP/IP Packet Headers

### TCP/IP Packet

<table>
<thead>
<tr>
<th>0</th>
<th>4</th>
<th>8</th>
<th>16</th>
<th>19</th>
<th>31</th>
</tr>
</thead>
<tbody>
<tr>
<td>Version</td>
<td>Length</td>
<td>Type of Service</td>
<td>Total Length</td>
<td>Identification</td>
<td>Flags</td>
</tr>
<tr>
<td>Time to Live</td>
<td>Protocol</td>
<td>Header Checksum</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### IPv4 Header
- Source Address
- Destination Address
- Options
- Data

#### TCP Header
- Source Port
- Destination Port
- Sequence Number
- Acknowledgment Number
- Offset | Reserved | TCP Flags | Window |
- Checksum | Urgent Pointer |
- TCP Options

## Circuit-Switched Networks versus Packet-Switched Networks

<table>
<thead>
<tr>
<th>Circuit-Switched “Connection-oriented”</th>
<th>Packet-Switched “Connectionless”</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bandwidth</strong> guaranteed once connected</td>
<td><strong>Bandwidth</strong> is dynamically allocated ((aka \ “adaptive routing”))</td>
</tr>
<tr>
<td>Wastes <strong>Network Bandwidth</strong></td>
<td>Better use of <strong>Network Bandwidth</strong></td>
</tr>
<tr>
<td><strong>Network Capacity</strong> not affected by other traffic; but limited # connections</td>
<td><strong>Network Capacity</strong> independent of concurrent transmission of packets</td>
</tr>
<tr>
<td>Each connection is “dedicated”</td>
<td>Packet forwarding can use any route in the network (“store &amp; forward”)</td>
</tr>
<tr>
<td>Switches perform connections to establish dedicated circuit path for each communication session</td>
<td>Routers and protocols determine the packet routes and adjust to network conditions (“forwarding on the fly”)</td>
</tr>
<tr>
<td>If a connection fails a new connection must be re-established to recover</td>
<td>If one router fails the network still functions by bypassing that router</td>
</tr>
<tr>
<td><strong>Cost</strong> by connection time</td>
<td><strong>Cost</strong> by number of packets</td>
</tr>
</tbody>
</table>

Today both network categories now handle both voice and data.
Packet-Switched Networks Now Dominate Data Networks

Modern communication systems today are dominated by packet-switched networks.

The Internet is the ultimate packet-switched network.

https://dlpng.com/png/1365206
Optical Network Architecture

- **Long Haul Network**: 40 – 100 Gbps & > 1000 km
- **Metro or Regional Network**: 1 – 40 Gbps & < 1000 km
- **< 1 Gbps & < 10 km**

- **SONET**: Metro Network
- **PON**: Access Network
- **CPE (customer premise)**

- **DWDM**: Dense wavelength division multiplexing
CenturyLink’s **Long-Haul** Fiber Optic Network

[Map of CenturyLink’s Long-Haul Fiber Optic Network]

World-Wide Google **Long-Haul** Network

The largest cloud network, comprised of more than 100 points of presence

https://www.em360tech.com/tech-news/google-adding-30-billion-infrastructure-investment/
An **access network** is a telecommunications network which connects subscribers to their immediate service provider (for Internet, video, voice, and many other services).

It is contrasted with core networks, which connect local providers to one another. An access network may be further divided into feeder links (networks) and distribution links.
# Five Primary Internet Access Networks

<table>
<thead>
<tr>
<th>Service</th>
<th>Average speed</th>
<th>High-end speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSL Internet</td>
<td>768 kbps – 1.5 Mbps</td>
<td>3 Mbps – 7 Mbps</td>
</tr>
<tr>
<td>Cable modem</td>
<td>4 Mbps – 6 Mbps</td>
<td>10 Mbps – 100+ Mbps</td>
</tr>
<tr>
<td>Satellite</td>
<td>5 Mbps – 10 Mbps</td>
<td>12 Mbps – 25 Mbps</td>
</tr>
<tr>
<td><strong>Fiber Internet</strong></td>
<td><strong>50 Mbps – 100 Mbps</strong></td>
<td><strong>1 Gbps – 10 Gbps</strong></td>
</tr>
<tr>
<td>Cellular Wireless</td>
<td>Depends upon generation</td>
<td>Variable</td>
</tr>
</tbody>
</table>

Comments on Internet over Fiber:

1. You probably don’t need that much speed*
2. Limited availability, but getting better
3. Expensive to install for providers, which is why it is of limited availability today

* But you want it anyway.
According to Nielsen’s Law of Internet Bandwidth, the fastest speeds offered to residential customers rise 40 to 50% every year.

Dial-up is not broadband access.

Maximum Download Rates to Residential Customers in USA

**Internet over Fiber (IOF) – Top Ten Providers**

<table>
<thead>
<tr>
<th>Provider</th>
<th>Population</th>
<th>No. States</th>
<th>Max Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verizon FiOS</td>
<td>34,400,000</td>
<td>10</td>
<td>940 Mbps</td>
</tr>
<tr>
<td>AT&amp;T Fiber</td>
<td>20,400,000</td>
<td>21</td>
<td>1 Gbps</td>
</tr>
<tr>
<td>Frontier Communications</td>
<td>10,920,000</td>
<td>8</td>
<td>100 Mbps</td>
</tr>
<tr>
<td>CenturyLink</td>
<td>8,150,000</td>
<td>50</td>
<td>1 Gbps</td>
</tr>
<tr>
<td>Google Fiber</td>
<td>2,130,000</td>
<td>10</td>
<td>1 Gbps</td>
</tr>
<tr>
<td>Windstream</td>
<td>1,820,000</td>
<td>44</td>
<td>1 Gbps</td>
</tr>
<tr>
<td>Cincinnati Bell</td>
<td>1,335,000</td>
<td>5</td>
<td>1 Gbps</td>
</tr>
<tr>
<td>C Spire Fiber</td>
<td>1,265,000</td>
<td>8</td>
<td>1 Gbps</td>
</tr>
<tr>
<td>Consolidated Communications</td>
<td>1,106,000</td>
<td>14</td>
<td>1 Gbps</td>
</tr>
<tr>
<td>Armstrong</td>
<td>980,000</td>
<td>5</td>
<td>1 Gbps</td>
</tr>
<tr>
<td>Sonic.net (Sonoma County)</td>
<td>398,000</td>
<td>1</td>
<td>1 Gbps</td>
</tr>
</tbody>
</table>

Note: Data dated July 2019; Listed 1,246 providers.

[https://broadbandnow.com/Fiber-Providers](https://broadbandnow.com/Fiber-Providers)
Fiber Optic Broadband Services

Broadband service commonly refers to high-speed Internet access that is always on and faster than the traditional dial-up access. When available to mass markets broadband opens up a wide variety of interactive communications for both consumers and businesses, bringing to reality interactive video networks, interactive banking and shopping from the home, and interactive distance learning, etc.

The “last mile” for optical fiber goes from the curb to the television set top, known as fiber-to-the-curb (FTTC) or sometimes fiber-to-the-home (FTTH). Passive optical networks (PON) are now commonly used to deliver “fiber-to-the-whatever” broadband services.

https://www.fcc.gov/general/types-broadband-connections
Architecture of Fiber Access Networks as Defined by ITU-T

FTTH = Fiber to the home
FTTDp = Fiber to the Distribution Point
FTTN = Fiber to the Node

FTTB = Fiber to the business
FTTC = Fiber to the curb

Basic Variants of FTTX Broadband Access Networks.

- **Twisted pair wire**
- **DSLAM = digital subscriber line access multiplexer**
- **OLT**
- **DSLAM**
- **Switch**
- **NT**
- **ONT**
- **Splitter**
- **Optical Fiber**
- **Access Network**
- **To Metro / Regional Network**
- **Operator Site**
- **Subscriber Premises**
- **max. 5 km**
- **max. 100 m**
- **50~1500 m**

Connections & Wavelengths in FTTH-PON Access Network

PON = Passive Optical Network (Point-to-Multipoint)

**Ethernet**

Ethernet typically connects computers together in a local area network or LAN. It has been the most widely used method of linking computers together in Local Area Networks since the 1980s.

Originally Ethernet speeds clocked at only 10 megabits per second (10 Mbps). Fast Ethernet eventually raised data transfers to 100 Mbps, but after large technological strides, today's Gigabit Ethernet supports speeds of up to 1,000 Mbps and 100 Gigabit Ethernet with speeds of up to 100,000 Mbps, as defined by the IEEE 802.3ba 2010 standard.

IEEE 802.3 was introduced in 1983.
# Ethernet LAN Data Rates by IEEE Standard

## Defining Ethernet LANs: Standard Names

<table>
<thead>
<tr>
<th>Original IEEE</th>
<th>IEEE Shorthand Name</th>
<th>Informal Name(s)</th>
<th>Speed</th>
<th>Typical Cabling</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.3i</td>
<td>10BASE-T</td>
<td>Ethernet</td>
<td>10 Mbps</td>
<td>UTP</td>
</tr>
<tr>
<td>802.3u</td>
<td>100BASE-T</td>
<td>Fast Ethernet (Fast E)</td>
<td>100 Mbps</td>
<td>UTP</td>
</tr>
<tr>
<td>802.3z</td>
<td>1000BASE-X</td>
<td>Gigabit Ethernet (Gig E, GbE)</td>
<td>1000 Mbps</td>
<td>Fiber</td>
</tr>
<tr>
<td>802.3ab</td>
<td>1000BASE-T</td>
<td>Gigabit Ethernet (Gig E, GbE)</td>
<td>1000 Mbps</td>
<td>UTP</td>
</tr>
<tr>
<td>802.3ae</td>
<td>10GBASE-X</td>
<td>10 GbE</td>
<td>10 Gbps</td>
<td>Fiber</td>
</tr>
<tr>
<td>802.3an</td>
<td>10GBASE-T</td>
<td>10 GbE</td>
<td>10 Gbps</td>
<td>UTP</td>
</tr>
<tr>
<td>802.3ba</td>
<td>40GBASE-X</td>
<td>40GbE (40 GigE)</td>
<td>40 Gbps</td>
<td>Fiber</td>
</tr>
<tr>
<td>802.3ba</td>
<td>100GBASE-X</td>
<td>100GbE (100 GigE)</td>
<td>100 Gbps</td>
<td>Fiber</td>
</tr>
</tbody>
</table>

*Ethernet Naming Summary*

https://slideplayer.com/slide/9668432/
What is Synchronous Optical Network (SONET)?

Synchronous Optical NETworking (SONET) and Synchronous Digital Hierarchy (SDH) are standardized protocols that transfer multiple digital bit streams synchronously over optical fiber using lasers or highly coherent light from light-emitting diodes (LEDs). At lower transmission rates data can also be transferred via an electrical interface.

The SONET layer internally routes and switches connections. It incorporates its own physical, data link and network layers.

An Internet Protocol (IP) network treats a SONET network as providing it with point-to-point optical links between IP routers.
SONET/SDH encodes bit streams into optical signals propagated over optical fiber. SONET carries many signals of different bit rate capacities through a synchronous, flexible, optical hierarchy.

• Provides for end-to-end transport of bit streams
• All clocks in the network are locked to a common master clock so that TDM can be used
• Multiplexing is carried out by byte interleaving
• SONET/SDH is backward compatible to DS-1 and E-1
• Manages different data rates between clients

Note: 51.84 Mbps is equivalent to 28 DS-1 lines (or 28 T-1 lines).

https://web.cs.wpi.edu/~rek/Undergrad_Nets/B07/SONET.pdf
Synchronous Optical Network – SONET

The SONET **basic signal rate** is 51.84 Mbps (*aka* STS-1).

Higher-rate signals, namely STS-N signals, are obtained by interleaving the bytes from N frame-aligned STS-1 signals. This is possible because the clocks of the individual signals are synchronized over the entire SONET network.

Lower-speed data streams are easily extracted without performing demultiplexing on the entire STS-N signal.

Note: For SDH the **basic signal rate** is 155.52 Mbps.
Fundamental Elements of a SONET/SDH Network

ADM: Add/drop multiplexer
STS MUX: Synchronous transport signal multiplexer
STS DEMUX: Synchronous transport signal demultiplexer
R: Regenerator
T: Terminal

https://www.ques10.com/p/47691/sonet-architecture-1/
## SONET/SDH Multiplexing Rates

<table>
<thead>
<tr>
<th>SONET</th>
<th>SDH</th>
<th>Data Rate (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Electrical</td>
</tr>
<tr>
<td>STS-1</td>
<td>OC-1</td>
<td>-----</td>
</tr>
<tr>
<td>STS-3</td>
<td>OC-3</td>
<td>STM-1</td>
</tr>
<tr>
<td>STS-9</td>
<td>OC-9</td>
<td>STM-3</td>
</tr>
<tr>
<td>STS-12</td>
<td>OC-12</td>
<td>STM-4</td>
</tr>
<tr>
<td>STS-18</td>
<td>OC-18</td>
<td>STM-6</td>
</tr>
<tr>
<td>STS-24</td>
<td>OC-24</td>
<td>STM-8</td>
</tr>
<tr>
<td>STS-36</td>
<td>OC-36</td>
<td>STM-12</td>
</tr>
<tr>
<td>STS-48</td>
<td>OC-48</td>
<td>STM-16</td>
</tr>
<tr>
<td>STS-192</td>
<td>OC-192</td>
<td>STM-64</td>
</tr>
<tr>
<td>STS-768</td>
<td>OC-768</td>
<td>STM-256</td>
</tr>
</tbody>
</table>

SPE = Synchronous Payload Envelope

[https://web.cs.wpi.edu/~rek/Undergrad_Nets/B07/SONET.pdf](https://web.cs.wpi.edu/~rek/Undergrad_Nets/B07/SONET.pdf)
Metropolitan SONET Ring

FSO = Free Space Optical

https://www.semanticscholar.org/paper/Flexible-and-hybrid-bidirectional-optical-metro-Ziaie-Muga/13a2ed4648e43b80ce42581801a5050d20f37d5a
Example of Today’s Optical Networks

SONET/SDH Rings

Many packet data networks: IP, ATM, Frame Relay, MPLS, etc.

MPLS = Multi-protocol label switching

From: Lillian Goleniewski, Telecommunications Essentials, 2nd ed., Figure 11.1, page 453.

https://flylib.com/books/en/2.566.1/optical_networking_today_and_tomorrow.html
Fibre Channel Uses Optical Fiber

Fibre Channel (FC) is a high-speed data transfer protocol (running at 1, 2, 4, 8, 16, 32, and 128 gigabit per second rates) providing in-order, lossless delivery of raw block data; primarily used to connect computer data storage to servers. Fibre Channel is used in storage area networks (SAN) in commercial data centers. Fibre Channel typically runs on optical fiber cables within and between data centers.

https://en.wikipedia.org/wiki/Fibre_Channel

Uses 8B/10B Coding

http://www.50mu.net/2015/11/05/cisco-smart-zoning-part-ii-examples/

HBA = Host Bus Adapter
Optical Transport Network (OTN) Diagram

ITU-T G.709 OTN standard

OTN is a “digital wrapper” and was designed to transport data packet traffic such as IP and Ethernet over fiber optics, especially SONET/SDH.

GMPLS = Generalized Multiprotocol Label Switching

Ask a Question

Not used in EE 443/CS 543 for the 2020 Fall Semester, but may still be useful to the student.
## Protocols & Services to Open Systems Interconnect (OSI) Model

<table>
<thead>
<tr>
<th>Layer</th>
<th>Function</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 Application</td>
<td>User Interface to the application</td>
<td>Data</td>
</tr>
<tr>
<td>6 Presentation</td>
<td>Data presentation; encryption; compression; encoding</td>
<td>Data</td>
</tr>
<tr>
<td>5 Session</td>
<td>Maintaining Session; interhost communication</td>
<td>Data</td>
</tr>
<tr>
<td>4 Transport</td>
<td>Flow control; assign port numbers; control end-to-end connection</td>
<td>Segments</td>
</tr>
<tr>
<td>3 Network</td>
<td>Logical addressing; routing; datagram encapsulation, etc.</td>
<td>Packets</td>
</tr>
<tr>
<td>2 Data Link</td>
<td>Media access control; data framing; physical addressing; error detection</td>
<td>Frames</td>
</tr>
<tr>
<td>1 Physical</td>
<td>Encoding and signaling; moves bits between hosts (or devices or nodes)</td>
<td>Bits</td>
</tr>
</tbody>
</table>

### Protocols & Services
- **TCP**
- **UDP**
- **MPLS**
- **IP**
- **DHCP**
- **Ethernet**
- **PPP**
- **DSL**
- **SONET**
- **SDH**
- **OTN**

### Media
- **Wireline, optical fiber, wireless**
Different Configurations of Fiber Access (PON) Networks

From: Ramaswami, Sivarajan & Sasaki, *Optical Networks: A Practical Perspective*, 3rd edition, Morgan Kaufmann Publishers, Chapter 11, Figure 11.5 on page 638; © Elsevier 2010.
A Network Interface Unit (NIU) is a device that serves as a demarcation point between the carrier's local loop and the customer's on-premises wiring. This is where the data wires end and a customer's home wiring starts.

An Optical Network Unit (ONU) is a device that terminates the PON and presents customer service interfaces to the user. Some ONUs implement a separate subscriber unit to provide services such as telephony, Ethernet data, or video.

A Remote Node (RN) terminal or computer is located apart from the main network.
Optical Fiber Network Evolution

1st Generation
- SONET/SDH point-to-point
- Late 1980s and 1990s
- "static"

2nd Generation
- WDM
- 2000s
- "static" Routing

3rd Generation
- Optical burst switch
- 2010s and beyond
- "dynamic"

- Optical circuit switch/optical packet switch
- (Optical hybrid switch)

Deployment Time Frame

After John M. Senior, *Optical Fiber Communications*, 3rd Edition, Pearson, 2009; Figure 15.1, page 968.