Elk Technologies
https://elktech.org
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# Module 4: Physical Layer

## Introduction to Networks

Cisco | Networking Academy®
Mind Wide Open™

# Module Objectives

- Module Title: Physical Layer
- Module Objective: Explain how physical layer protocols, services, and network media support communications across data networks.

| Topic Title | Topic Objective |
|---|---|
| 4.1 Purpose of the Physical Layer | Describe the purpose and functions of the physical layer in the network. |
| Physical Layer Characteristics | Describe characteristics of the physical layer. |
| 4.2 Copper Cabling | Identify the basic characteristics of copper cabling. |
| 4.3 UTP Cabling | Explain how UTP cable is used in Ethernet networks. |
| 4.4 Fiber-Optic Cabling | Describe fiber optic cabling and its main advantages over other media. |
| 4.5 Wireless Media | Connect devices using wired and wireless media. |

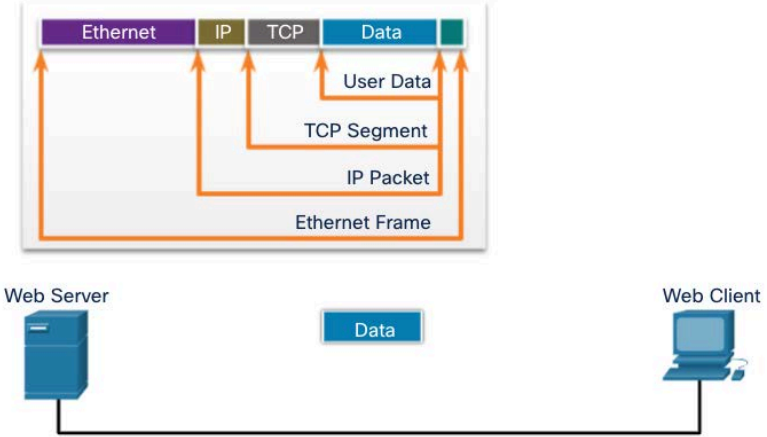
# 4.1 Purpose of the Physical Layer

# The Physical Connection

- Before any network communications can occur, a physical connection to a local network must be established.
- This connection could be wired or wireless, depending on the setup of the network.
- This generally applies whether you are considering a corporate office or a home.
- A **Network Interface Card** (NIC) connects a device to the network.
- Some devices may have just one NIC, while others may have multiple NICs (Wired and/or Wireless, for example).
- Not all physical connections offer the same level of performance.

# The Physical Layer

- Transports bits across the network media.
- Accepts a complete frame from the Data Link Layer and encodes it as a series of signals that are transmitted to the local media.
- The last step in the encapsulation process.
- The next device in the path to the destination:
  - receives the bits
  - re-encapsulates the frame
  - then decides what to do with it



# 4.2 Physical Layer Characteristics

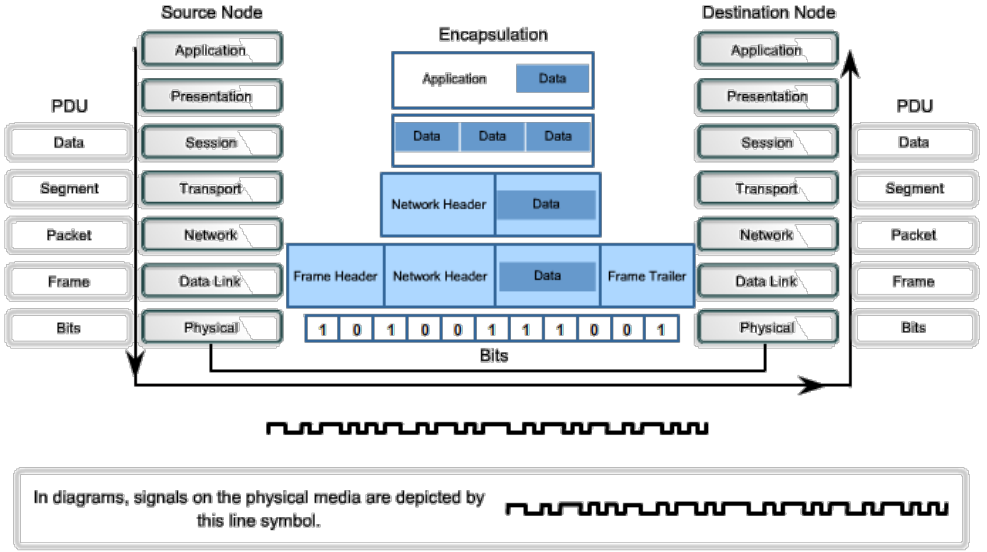
# Physical Layer Standards

- The physical layer standards are implemented in hardware and are governed by many organizations including:
  - International Organization for Standardization (ISO)
  - Telecommunications Industry Association/Electronic Industries Association (TIA/EIA)
  - American National Standards Institute (ANSI)
  - International Telecommunication Union (ITU)
  - Institute of Electrical and Electronics Engineers (IEEE)

| Standard organization | Networking Standards |
|---|---|
| **ISO** | • ISO 8877: Officially adopted the RJ connectors (e.g., RJ-11, RJ-45)<br>• ISO 11801: Network cabling standard similar to EIA/TIA 568. |
| **EIA/TIA** | • TIA-568-C: Telecommunications cabling standards, used by nearly all voice, video and data networks.<br>• TIA-569-B: Commercial Building Standards for Telecommunications Pathways and Spaces<br>• TIA-598-C: Fiber optic color coding<br>• TIA-942: Telecommunications Infrastructure Standard for Data Centers |
| **ANSI** | • 568-C: RJ-45 pinouts. Co-developed with EIA/TIA |
| **ITU-T** | • G.992: ADSL |
| **IEEE** | • 802.3: Ethernet<br>• 802.11: Wireless LAN (WLAN) & Mesh (Wi-Fi certification)<br>• 802.15: Bluetooth |

# Purpose of the Physical Layer

- Provides the means to transport the bits that make up a data link layer frame across the network media.
- Accepts a complete frame from the data link layer and encodes it as a series of signals (bits) that are transmitted onto the local media.
- Encoded bits are received by either an end device or an intermediate device and decoded.
- Functions
  - Physical components
  - Encoding
  - Signaling



# Physical Components

- The Physical Components are the hardware devices, media, and other connectors that transmit the signals that represent the bits.
  - Hardware components like NICs, interfaces and connectors, cable materials, and cable designs are all specified in standards associated with the physical layer.
  - A physical connection can be a wired connection using a cable or a wireless connection using radio waves.
- Signaling methods:
  - **Copper cable** - The signals are patterns of electrical pulses.
  - **Fiber-optic cable** - The signals are patterns of light.
  - **Wireless** - The signals are patterns of microwave transmissions.

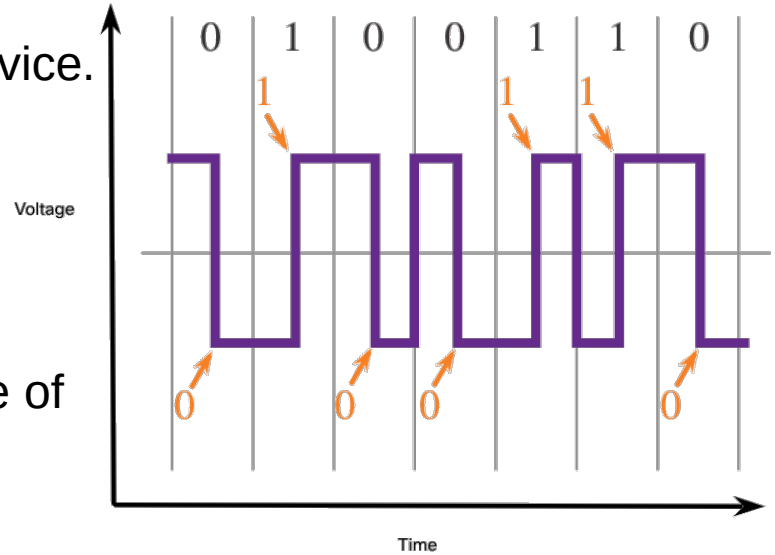
# Physical Layer Fundamental Principles

- Physical layer protocols use frame encoding techniques to:
  - to distinguish data bits from control bits
  - to identify where the frame starts and ends

| Media | Physical Components | Frame Encoding Technique | Signalling Method | Common Uses |
|---|---|---|---|---|
| **Copper cable** | • UTP<br>• Coaxial<br>• Connectors<br>• NICs<br>• Ports<br>• Interfaces | • Manchester Encoding<br>• Non-Return to Zero (NRZ) techniques<br>• 4B/5B codes are used with Multi-Level Transition Level 3 (MLT-3) signaling<br>• 8B/10B<br>• PAM5 | • Changes in the electromagnetic field<br>• Intensity of the electromagnetic field<br>• Phase of the electromagnetic wave | • Horizontal Cabling<br>• Patch Panel Cabling<br>• Cabling to the Desktop |
| **Fiber Optic cable** | • Single-mode Fiber<br>• Multimode Fiber<br>• Connectors<br>• NICs<br>• Interfaces<br>• Lasers and LEDs<br>• Photoreceptors | • Pulses of light<br>• Wavelength multiplexing using different colors | • A pulse equals 1.<br>• No pulse is 0. | • Vertical Cabling<br>• Backbone Cabling<br>• Long-haul Networks<br>• Outdoor Environments |
| **Wireless media** | • Access Points<br>• NICs<br>• Radio<br>• Antennae | • DSSS (direct-sequence spread-spectrum)<br>• OFDM (orthogonal frequency division multiplexing) | • Radio waves | • Open Areas<br>• General Use (coffee shops, hospitals, waiting rooms) |

# Encoding

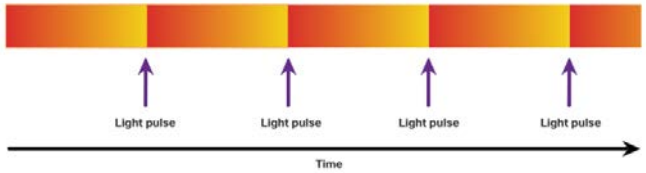
- **Encoding** converts the stream of bits into a format recognizable by the next device in the network path.
- This predefined “coding” provides predictable patterns that can be recognized by the next device.
- Examples of encoding methods include:
  - Manchester (shown in the figure)
  - 4B/5B
  - B/10B
- Physical layer standards must define what type of signal represents a "1" and what type of signal represents a "0”
  - Long pulse might represent a 1 whereas a short pulse represents a 0.



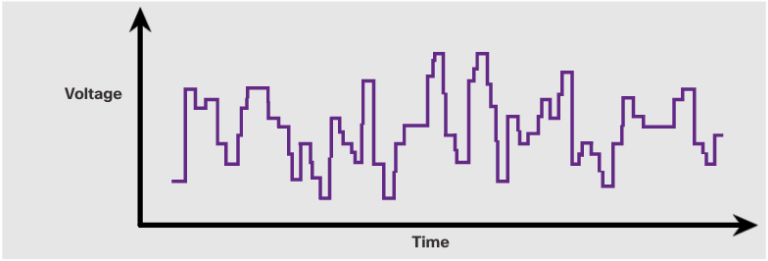

The transition occurs at the middle of each bit period

# Signaling

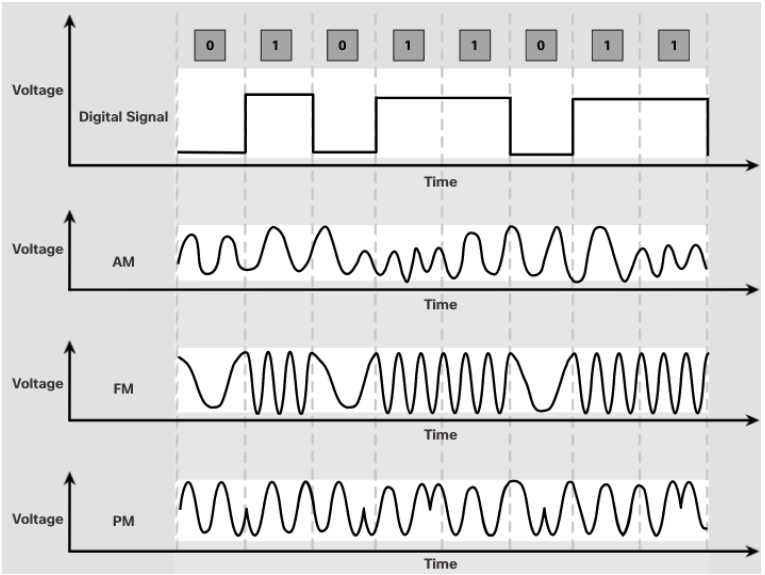
- The **signaling** method is how the bit values, “1” and “0” are represented on the physical medium.
- The method of signaling will vary based on the type of medium being used.




Light Pulses Over Fiber-Optic Cable



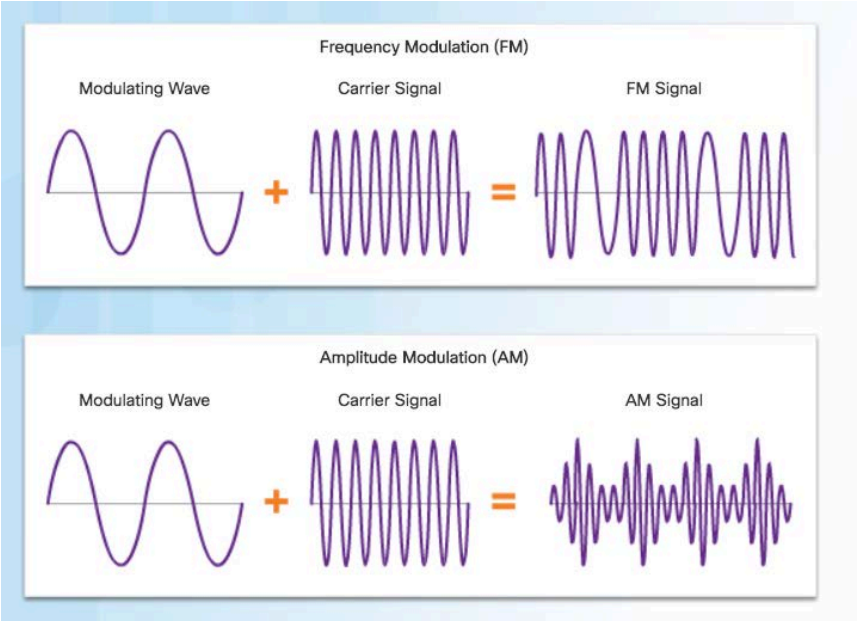

Electrical Signals Over Copper Cable




Microwave Signals Over Wireless (Air)

# Physical Layer Functions

- **Modulation** is the process by which the characteristic of one wave (the signal) modifies another wave (the carrier).



# Bandwidth

- **Bandwidth** is the capacity at which a medium can carry data.
- Digital bandwidth measures the amount of data that can flow from one place to another in a given amount of time; how many bits can be transmitted in a second.
- Physical media properties, current technologies, and the laws of physics play a role in determining available bandwidth.

| Unit of Bandwidth | Abbreviation | Equivalence |
|---|---|---|
| Bits per second | bps | 1 bps = fundamental unit of bandwidth |
| Kilobits per second | Kbps | 1 Kbps = 1,000 bps = $10^3$ bps |
| Megabits per second | Mbps | 1 Mbps = 1,000,000 bps = $10^6$ bps |
| Gigabits per second | Gbps | 1 Gbps – 1,000,000,000 bps = $10^9$ bps |
| Terabits per second | Tbps | 1 Tbps = 1,000,000,000,000 bps = $10^{12}$ bps |

# Bandwidth

- Factors that influence bandwidth:
  - **Amount of traffic** – Data being transferred at a time.
  - **Type of traffic** – High consumption technologies, like video, require more bandwidth than standard text data.
  - **Latency** – Amount of time, including delays, for data to travel from one given point to another and the number of devices crossed.
  - **Throughput** – The measure of the transfer of bits across the media over a given period of time.
  - **Goodput** – The measure of usable data transferred over a given period of time.
    - Goodput = Throughput - traffic overhead

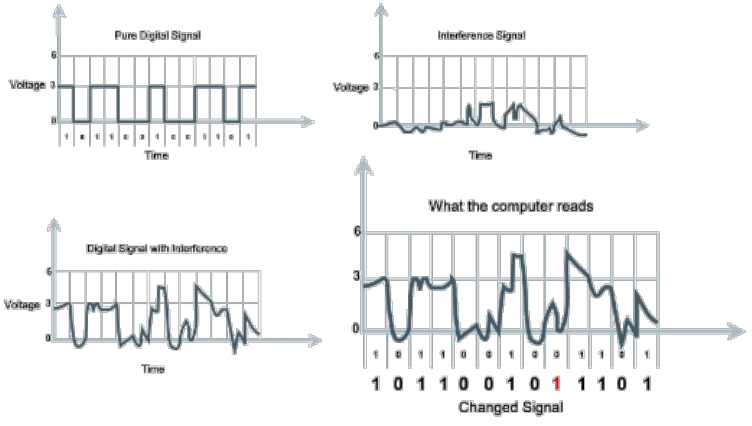
# 4.3 Copper Cabling

# Characteristics of Copper Cabling

- Copper cabling is the most common type of cabling used in networks today.
- Uses electrical pulses to send bits over the cable.
- Advantages:
  - Inexpensive
  - Easy to install
  - Low resistance to electrical current flow
- Limitations:
  - **Attenuation** – the longer the electrical signals have to travel, the weaker they get.
  - **Interference** – The electrical signal is susceptible to interference from two sources, which can distort and corrupt the data signals (Electromagnetic Interference (EMI) and Radio Frequency Interference (RFI) and Crosstalk).

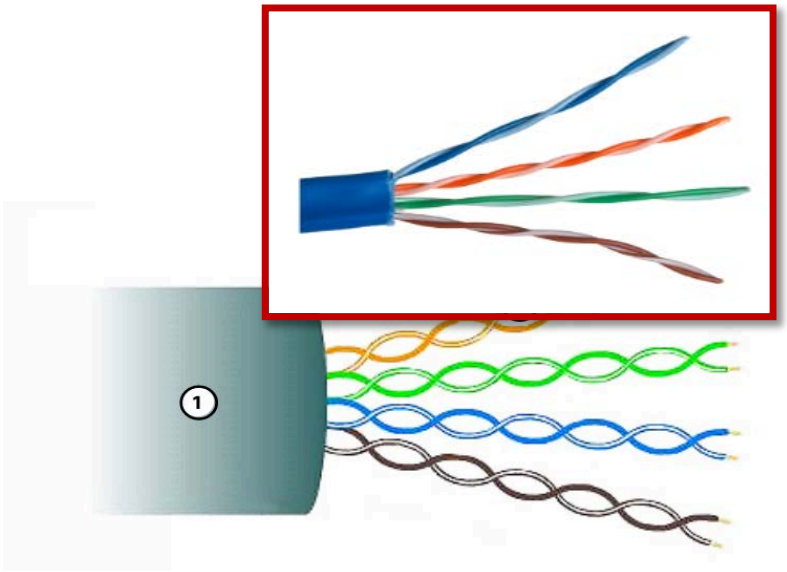
# Characteristics of Copper Media

- Factors that interfere with the copper cabling resulting in signal distortion and data corruption:
  - **Electromagnetic interference** (EMI) or **radio frequency interference** (RFI) - distorts and corrupts the data signals being carried by copper media
    - To counter copper cables wrapped in shielding
  - **Attenuation** – All copper media must follow strict distance limitations.
  - **Crosstalk** – disturbance or distortion caused by the electric or magnetic fields of a signal on one wire to the signal in an adjacent wire
    - To cancel crosstalk opposing circuit wire pairs are twisted together
    - The **magnetic field cancellation effect** is enhanced in UTP cables by increasing and varying the number of twists in each wire pair helping to protect against crosstalk



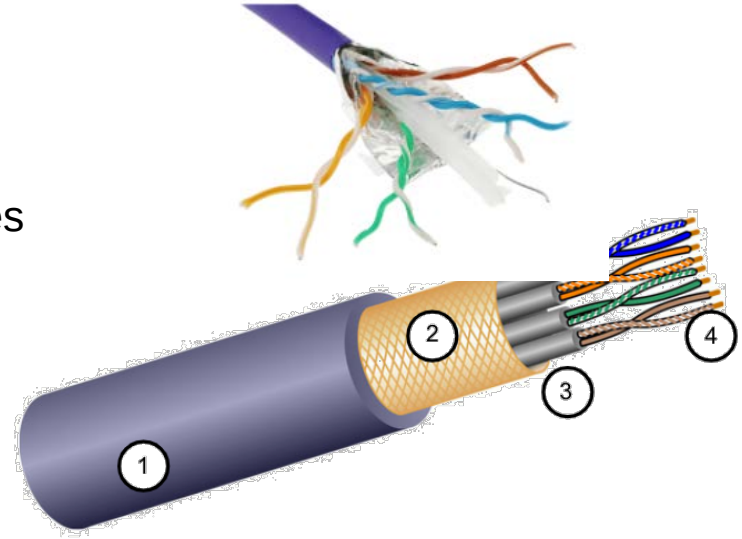
# Unshielded Twisted Pair (UTP)

- UTP is the most common networking media.
- Terminated with RJ-45 connectors.
- Interconnects hosts with intermediary network devices.
- Key Characteristics of UTP:
  1. The outer jacket protects the copper wires from physical damage.
  2. Twisted pairs protect the signal from interference.
  3. Color-coded plastic insulation electrically isolates the wires from each other and identifies each pair.



# Shielded Twisted Pair (STP)

- Better noise protection than UTP
- More expensive than UTP
- Harder to install than UTP
- Terminated with RJ-45 connectors
- Interconnects hosts with intermediary network devices
- Key Characteristics of STP:
  1. The outer jacket protects the copper wires from physical damage.
  2. Braided or foil shield provides EMI/RFI protection.
  3. Foil shield for each pair of wires provides EMI/RFI protection.
  4. Color-coded plastic insulation electrically isolates the wires from each other and identifies each pair.



# Coaxial Cable

- Consists of the following:
  1. Outer cable jacket to prevent minor physical damage
  2. A woven copper braid, or metallic foil, acts as the second wire in the circuit and as a shield for the inr conductor.
  3. A layer of flexible plastic insulation
  4. A copper conductor is used to transmit the electror signals.
- There are different types of connectors used with coa cable.
- Commonly used in the following situations:
  - Wireless installations - attach antennas to wireless devices.
  - Cable internet installations - customer premises wiring.

# 4.4 UTP Cabling

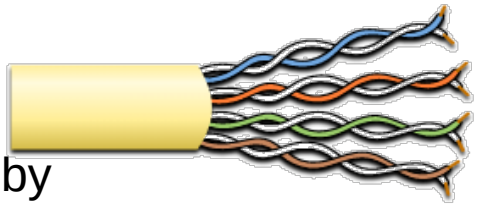
# Properties of UTP Cabling

- UTP has four pairs of color-coded copper wires twisted together and encased in a flexible plastic sheath.
- No shielding is used.
- **Crosstalk** – Caused by the magnetic field of one pair of wires effecting the other pairs.
- UTP relies on the following properties to limit crosstalk:
  - **Cancellation** - Each wire in a pair of wires uses opposite polarity. One wire is negative, the other wire is positive. They are twisted together and the magnetic fields effectively cancel each other and outside EMI/RFI.
  - **Variation in twists** per foot in each wire - Each wire is twisted a different amount, which helps prevent crosstalk amongst the wires in the cable.

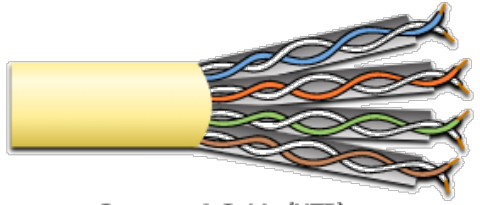
# UTP Cabling Standards and Connectors

- Standards for UTP are established by the TIA/EIA. TIA/EIA-568 standardizes elements like:
  - Cable Types
  - Cable Lengths
  - Connectors
  - Cable Termination
  - Testing Methods
- Electrical standards for copper cabling are established by the IEEE, which rates cable according to its performance. Examples include:
  - Category 3
  - Category 5 and 5e
  - Category 6

Category 3 Cable (UTP)



Category 5 and 5e Cable (UTP)



Category 6 Cable (UTP)

# UTP Cabling Standards and Connectors

- UTP cable terminated with an RJ-45 connector.
- TIA/EIA-568 standard describes the wire color codes to pin assignments (pinouts) for Ethernet cables.
- RJ-45 connector or plug is the male component, crimped at the end of the cable.
- Socket or jack is the female component of a network device, wall, cubicle partition outlet, or patch panel.
- Essential that all copper media terminations be of high quality to ensure optimum performance with current and future network technologies.
- Good termination:
  - Jacket under connector
  - Untwist 3/8”
  - Wires to end of jack
  - Crimp

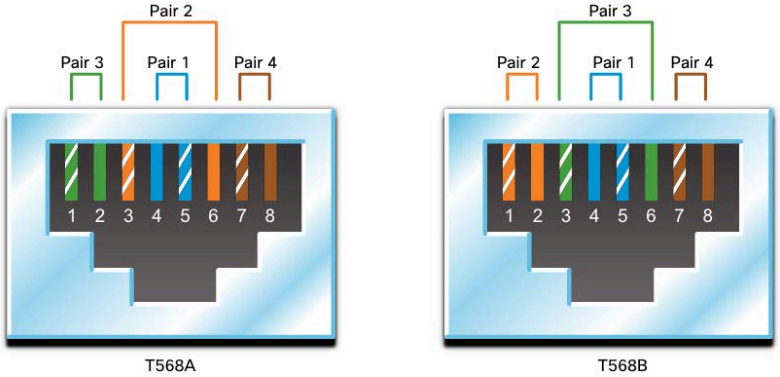

RJ-45 Connector or Plug


RJ-45 Socket or Jack

Poorly terminated UTP cable

Properly terminated UTP cable

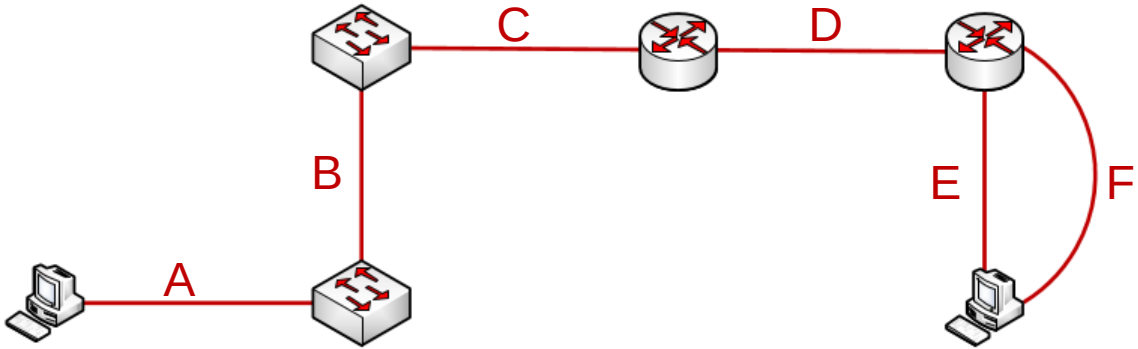
# Straight-through and Crossover UTP Cables




| Cable Type | Standard | Application |
|---|---|---|
| **Straight-through** | Both ends T568A or T568B | Host to Network Device (Unlike devices) |
| **Crossover** * | One end T568A, other end T568B | Host-to-Host, Switch-to-Switch, Router-to-Router (Like devices) |
| * Considered Legacy due to most NICs using Auto-MDIX to sense cable type and complete connection | | |
| **Rollover** | Cisco Proprietary | Host serial port to Router or Switch Console Port, using an adapter |

# Types of UTP Cable

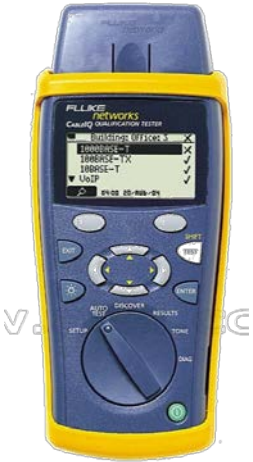
- What types of cables are needed?




- A – **Straight-through Cable**
- B – **Crossover Cable**
- C – **Straight-through Cable**
- D – **Crossover Cable or Serial Cable**
- E – **Crossover Cable**
- F – **Rollover or Console Cable**

# Testing UTP Cables

- UTP Testing Parameters:
  - Wire map
  - Cable length
  - Signal loss due to attenuation
  - Crosstalk




# 4.5 Fiber-Optic Cabling

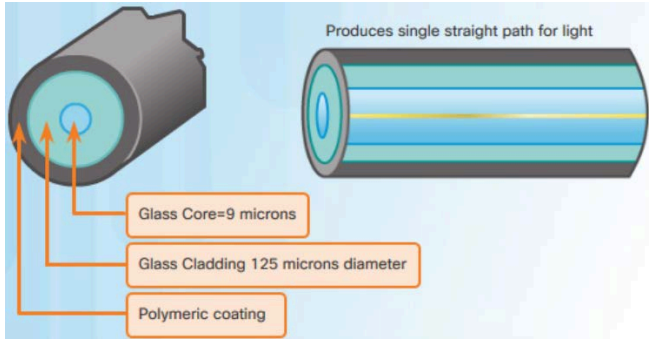
# Properties of Fiber-Optic Cabling

- Not as common as UTP because of the expense involved.
- Uses light (laser or LED) to send bits over the cable.
- Transmits data over longer distances and at higher bandwidths.
- Transmits signals with less attenuation and is completely immune to EMI and RFI.
- Transmits with greater bandwidth potential.
- Used to interconnect network devices and buildings.
- Flexible, but extremely thin, transparent strand of very pure glass, not much bigger than a human hair.
- Bits are encoded on the fiber as light pulses.
- Uses a laser or LED to encode bits as pulses of light.
- The fiber-optic cable acts as a wave guide to transmit light between the two ends with minimal signal loss.

# Types of Fiber Media

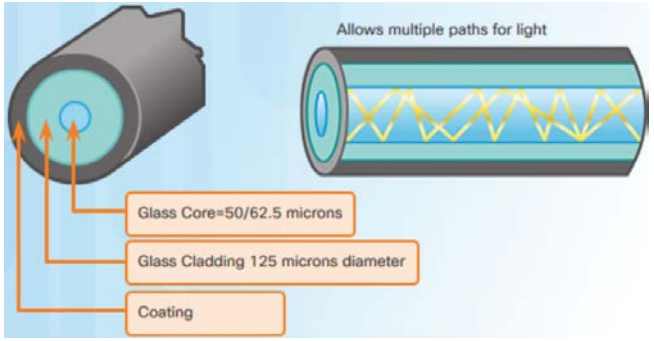
- **Dispersion** refers to the spreading out of a light pulse over time.
- Increased dispersion means increased loss of signal strength.
- MMF has greater dispersion than SMF.

**Single-Mode Fiber**




- Very small core
- Uses expensive lasers
- Long-distance applications

**Multimode Fiber**



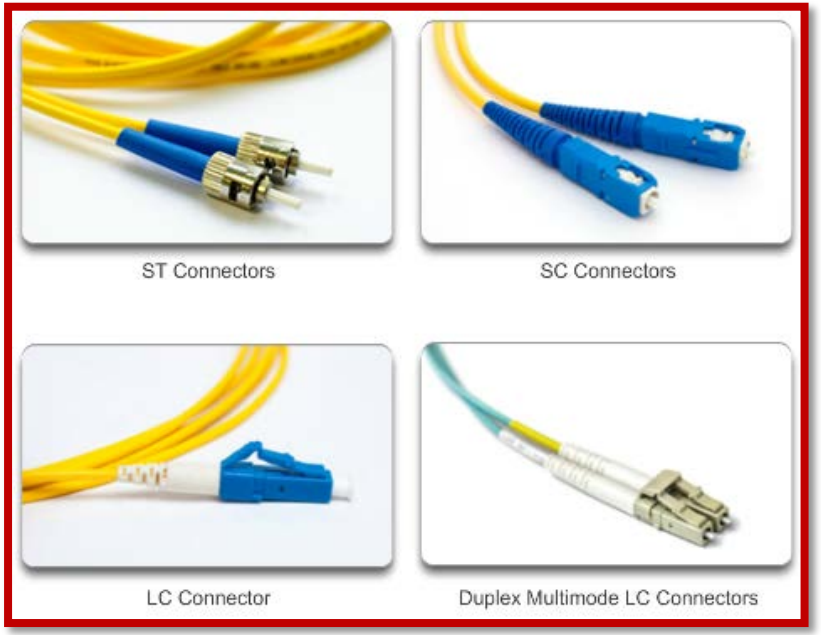

- Larger core
- Uses less expensive LEDs
- LEDs transmit at different angles
- Up to 10 Gbps over 550 meters

# Fiber-Optic Cabling Usage

- Fiber-optic cabling is now being used in four types of industry:
  - **Enterprise Networks** - Used for backbone cabling applications and interconnecting infrastructure devices
  - **Fiber-to-the-Home** (FTTH) - Used to provide always-on broadband services to homes and small businesses
  - **Long-Haul Networks** - Used by service providers to connect countries and cities
  - **Submarine Cable Networks** - Used to provide reliable high-speed, high-capacity solutions capable of surviving in harsh undersea environments at up to transoceanic distances.
- Our focus in this course is the use of fiber within the enterprise.

# Fiber-Optic Connectors

- Most common fiber-optic connectors:
  - **Straight-Tip** (ST) Connectors
    - One of the first connector types used
    - Locks securely with a “twist-on/twist-off”
  - **Subscriber Connector** (SC) Connectors
    - Referred to as square or standard connector
    - Uses a push-pull mechanism to ensure positive insertion.
    - Used with multimode and single-mode fiber
  - **Lucent Connector** (LC) Simplex Connectors
    - Smaller version of SC
    - Popular due to size
  - **Duplex Multimode LC** Connectors
    - Similar to LC but using a duplex connector



# Fiber Patch Cords

- A yellow jacket is for single-mode fiber cables and orange (or aqua) for multimode fiber cables.
- Light can only travel in one direction over optical fiber, two fibers are required to support the full duplex operation.

SC-SC MM Patch Cord

LC-LC SM Patch Cord

ST-LC MM Patch Cord

ST-SC SM Patch Cord

# Fiber versus Copper

- Optical fiber is primarily used as backbone cabling for high-traffic, point-to-point connections between data distribution facilities and for the interconnection of buildings in multi-building campuses.

| Implementation Issues | UTP Cabling | Fiber-Optic Cabling |
|---|---|---|
| Bandwidth supported | 10 Mb/s - 10 Gb/s | 10 Mb/s - 100 Gb/s |
| Distance | Relatively short (1 - 100 meters) | Relatively long ( 1 - 100,000 meters) |
| Immunity to EMI and RFI | Low | High (Completely immune) |
| Immunity to electrical hazards | Low | High (Completely immune) |
| Media and connector costs | Lowest | Highest |
| Installation skills required | Lowest | Highest |
| Safety precautions | Lowest | Highest |

# Testing Fiber Cables

- Terminating and splicing fiber-optic cabling requires special training and equipment
- Three common types of fiber-optic termination and splicing errors are:
  - **Misalignment**: The fiber-optic media are not precisely aligned to one another when joined
  - **End gap**: The media does not completely touch at the splice or connection
  - **End finish**: The media ends are not well polished, or dirt is present at the termination
- Can be field tested by shining a bright flashlight into one end of the fiber while observing the other end

Optical Time Domain Reflectometer (OTDR) can be used to test each fiber-optic cable segment

# 4.6 Wireless Media

# Properties of Wireless Media

- It carries electromagnetic signals representing binary digits using radio or microwave frequencies. This provides the greatest mobility option. Wireless connection numbers continue to increase.
- Some of the limitations of wireless:
  - **Coverage area** - Effective coverage can be significantly impacted by the physical characteristics of the deployment location.
  - **Interference** - Wireless is susceptible to interference and can be disrupted by many common devices (cordless phones, microwaves).
  - **Security** - Wireless communication coverage requires no access to a physical strand of media, so anyone can gain access to the transmission.
  - **Shared medium** - WLANs operate in half-duplex, which means only one device can send or receive at a time. Many users accessing the WLAN simultaneously results in reduced bandwidth for each user.

# Types of Wireless Media

- The IEEE and telecommunications industry standards for wireless data communications cover both the data link and physical layers. In each of these standards, physical layer specifications dictate:
  - Data to radio signal encoding methods
  - Frequency and power of transmission
  - Signal reception and decoding requirements
  - Antenna design and construction
- Uses CSMA/CA technology
  - Collisions can exist in the networks but should be avoided.

# Types of Wireless Media

- Wireless Standards:
  - **Wi-Fi** (IEEE 802.11) - Wireless LAN (WLAN) technology.
  - **Bluetooth** (IEEE 802.15) - Wireless Personal Area network (WPAN) standard.
  - **WiMAX** (IEEE 802.16) - Uses a point-to-multipoint topology to provide broadband wireless access.
  - **Zigbee** (IEEE 802.15.4) - Low data-rate, low power-consumption communications, primarily for Internet of Things (IoT) applications.

| | |
|---|---|
| Wi Fi | • IEEE 802.11 standards<br>• Commonly referred to as Wi-Fi<br>• Uses CSMA/CA – Wireless NIC must wait till channel is clear<br>• Variations include:<br>  • 802.11a: 54 Mbps, 5 GHz<br>  • 802.11b: 11 Mbps, 2.4 GHz<br>  • 802.11g: 54 Mbps, 2.4 GHz<br>  • 802.11n: 600 Mbps, 2.4 and 5 GHz<br>  • 802.11ac: 1 Gbps, 5 GHz<br>  • 802.11ad: 7 Gbps, 2.4 GHz, 5 GHz, and 60 GHz |
| Bluetooth® | • IEEE 802.15 standard<br>• Wireless Personal Area Network (WPAN)<br>• Supports speeds up to 3 Mbps<br>• Provides device pairing over distances from 1 to 100 meters. |
| WiMAX | • IEEE 802.16 standard<br>• Worldwide Interoperability for Microwave Access<br>• Provides speeds up to 1 Gbps<br>• Uses a point-to-multipoint topology to provide wireless broadband access. |

# Wireless LAN

- In general, a Wireless LAN (WLAN) requires the following devices:
  - **Wireless Access Point** (AP) - Concentrate wireless signals from users and connect to the existing copper-based network infrastructure
  - **Wireless NIC Adapters** - Provide wireless communications capability to network hosts
- There are a number of WLAN standards. When purchasing WLAN equipment, ensure compatibility, and interoperability.
- Network Administrators must develop and apply stringent security policies and processes to protect WLANs from unauthorized access and damage.


Home and small business wireless routers integrate the functions of a router, switch, and access point into one device.

# 802.11 Wi-Fi Standards

| Standard | Maximum Speed | Frequency | Backwards compatible |
|---|---|---|---|
| 802.11a | 54 Mbps | 5 GHz | No |
| 802.11b | 11 Mbps | 2.4 GHz | No |
| 802.11g | 54 Mbps | 2.4 GHz | 802.11b |
| 802.11n | 600 Mbps | 2.4 GHz or 5 GHz | 802.11b/g |
| 802.11ac | 1.3 Gbps (1300 Mbps) | 2.4 GHz and 5 GHz | 802.11b/g/n |
| 802.11ad | 7 Gbps (7000 Mbps) | 2.4 GHz, 5 GHz and 60 GHz | 802.11b/g/n/ac |
| 802.11ax (Wi-Fi 6) | 14 Gbps (14,000 Mbps) | 2.4 GHz, 5 GHz, and 60 GHz | 802.1b/g/n/ac |

# 4.7 Module Practice and Quiz

# What did I learn in this module?

- Before any network communications can occur, a physical connection to a local network, either wired or wireless, must be established.
- The physical layer consists of electronic circuitry, media, and connectors developed by engineers.
- The physical layer standards address three functional areas: physical components, encoding, and signaling.
- Three types of copper cabling are: UTP, STP, and coaxial cable (coax).
- UTP cabling conforms to the standards established jointly by the TIA/EIA. The electrical characteristics of copper cabling are defined by the Institute of Electrical and Electronics Engineers (IEEE).
- The main cable types that are obtained by using specific wiring conventions are Ethernet Straight-through and Ethernet Crossover.

# What did I learn in this module?

- Optical fiber cable transmits data over longer distances and at higher bandwidths than any other networking media.
- There are four types of fiber-optic connectors: ST, SC, LC, and duplex multimode LC.
- Fiber-optic patch cords include SC-SC multimode, LC-LC single-mode, ST-LC multimode, and SC-ST single-mode.
- Wireless media carry electromagnetic signals that represent the binary digits of data communications using radio or microwave frequencies. Wireless does have some limitations, including coverage area, interference, security, and the problems that occur with any shared medium.
- Wireless standards include the following: Wi-Fi (IEEE 802.11), Bluetooth (IEEE 802.15), WiMAX (IEEE 802.16), and Zigbee (IEEE 802.15.4).
- Wireless LAN (WLAN) requires a wireless AP and wireless NIC adapters.

# New Terms and Commands

- Telecommunications Industry Association/Electronic Industries Association (TIA/EIA)
- latency
- throughput
- goodput
- Electromagnetic interference (EMI)
- Radio frequency interference (RFI)
- Crosstalk
- Unshielded Twisted Pair (UTP)
- Shielded Twisted Pair (STP)
- Coaxial cable
- RJ-45
- Cancellation
- TIA/EIA-568
- Ethernet Straight-through
- Ethernet crossover
- Rollover
- Single-Mode Fiber (SMF)
- Multimode (MMF)
- Straight-tip (ST) Connectors
- Subscriber Connector (SC) Connectors
- Lucent Connector (LC) Simplex Connectors
- Duplex Multimode LC Connectors
- Bluetooth (IEEE 802.15)
- WiMAX (IEEE 802.16)
- Zigbee (IEEE 802.15.4)
- Wireless Access Point (AP)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