IE 2004 Computer Networks

03 – Physical Layer

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Lesson outline

- Physical layer functions and components
- Digital signals – Encoding
- Analog signals – Modulation
- Transmission media
  - Copper: UTP
  - Copper: Coaxial
  - Fiber
  - Wireless (free space)
- Transmission impairments
  - Attenuation
  - Interference
  - Crosstalk

Key terms and concepts

- Analog and digital signals
- Encoding
- Modulation
- Attenuation
- Interference
- Twisted Pair cable
- Single-mode and Multi-mode fiber
- Wireless media
- Transmission frequencies

What is the Physical Layer

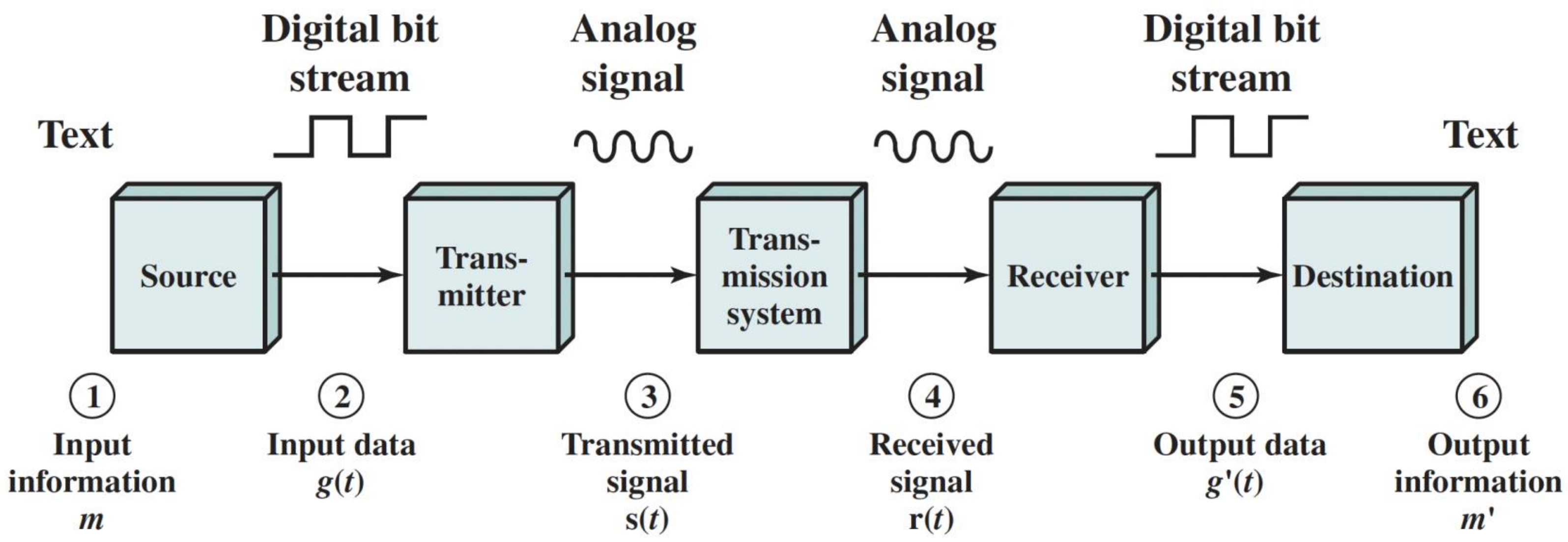
- Lowest layer of the TCP/IP model
- Handles physical transmission of data (1s and 0s)
- Deals with hardware elements and physical connections
- Encompasses cables, connectors, network interface cards, etc.
- Responsible for transmitting signals that represent data over the communication medium
- Physical Layer Standards address three functional areas:
  - Physical Components
  - Encoding / Modulation – Representing 1s and 0s with an electrical or an electromagnetic signal

Physical Components

- 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
- 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
- Hardware components like NICs, interfaces and connectors, cable materials, and cable designs are all specified in the physical layer standards

Communication model

- Data: Entities that convey information
- Signals: Electric or electromagnetic representations of data
- Transmission: Communication of data by the propagation and processing of signals

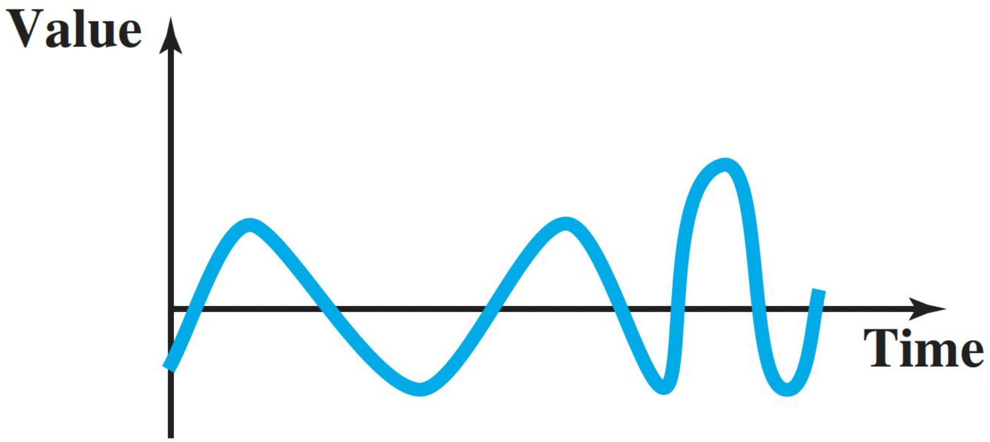


Definition of signals in communication

- Signals are representations of data (1s and 0s)
- Signals carry information from one point to another
- Signals can be in different forms:
  - Electrical (voltage, current)
  - Electromagnetic
    - Includes Optical (light)
- Signal transmitted over the transmission medium can be
  - Digital signal – created by encoding the data
  - Analog signal – created using modulating a carrier signal using data

Analog signals

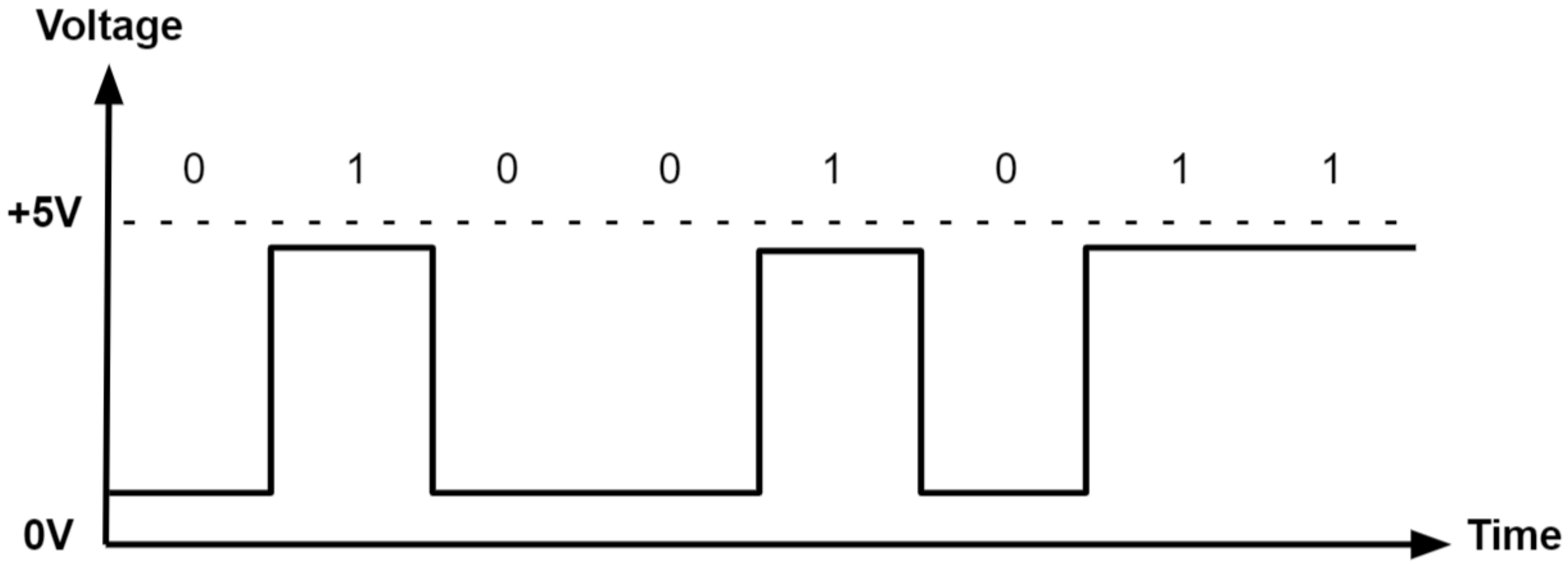
- An analog signal is something that is varying continuously in time and amplitude
- The amplitude refers to the strength of the signal
- The amplitude varies continuously (can take any value between an upper limit and a lower limit)



a. Analog signal

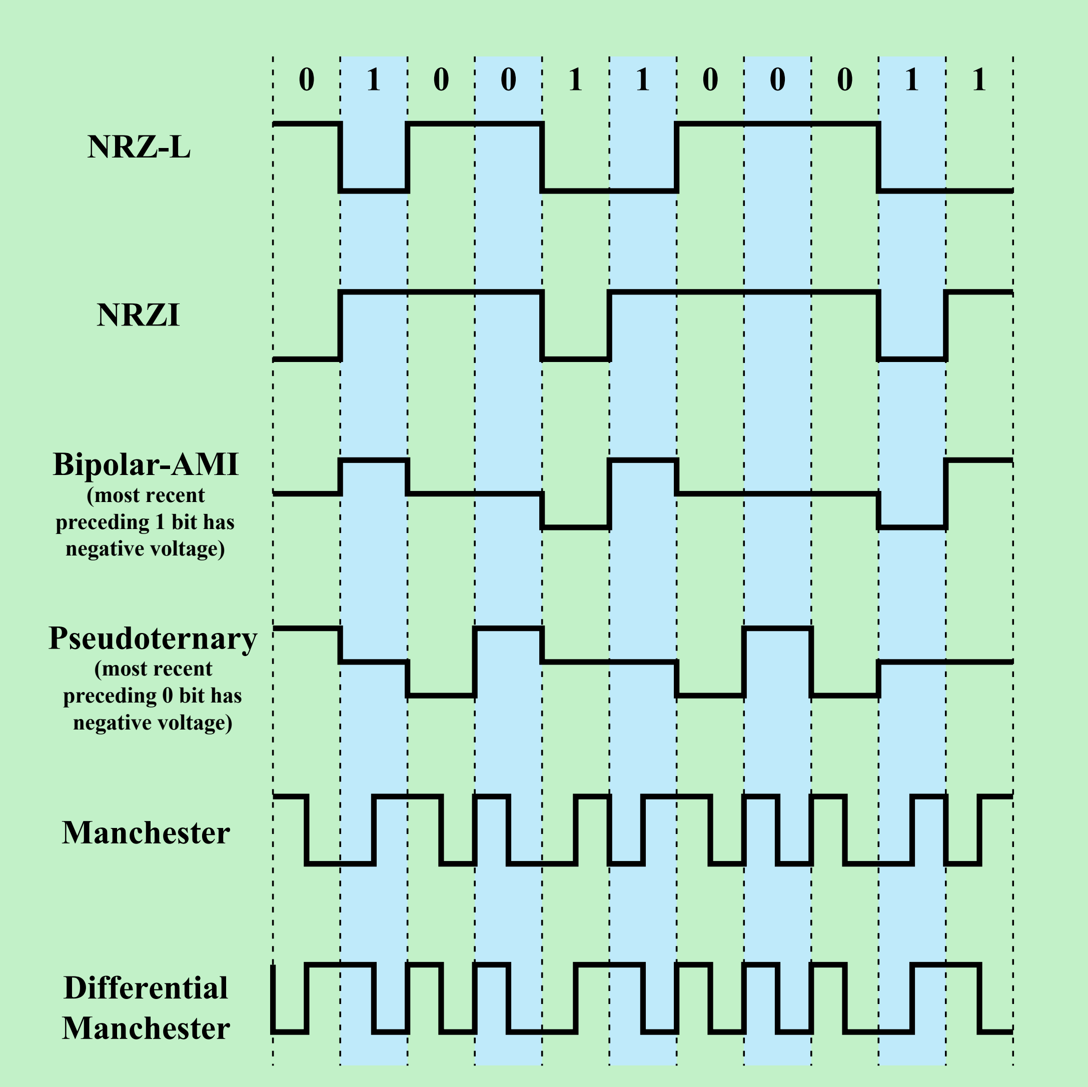
Digital Signals

- Digital signals represent data using discrete values or symbols
- Sequence of discrete voltage pulses
- Each pulse/voltage level is a signal element
- Binary data are transmitted by encoding each data bit into signal elements
- Example:
  binary 0 –> 0V
  binary 1 –> +5V



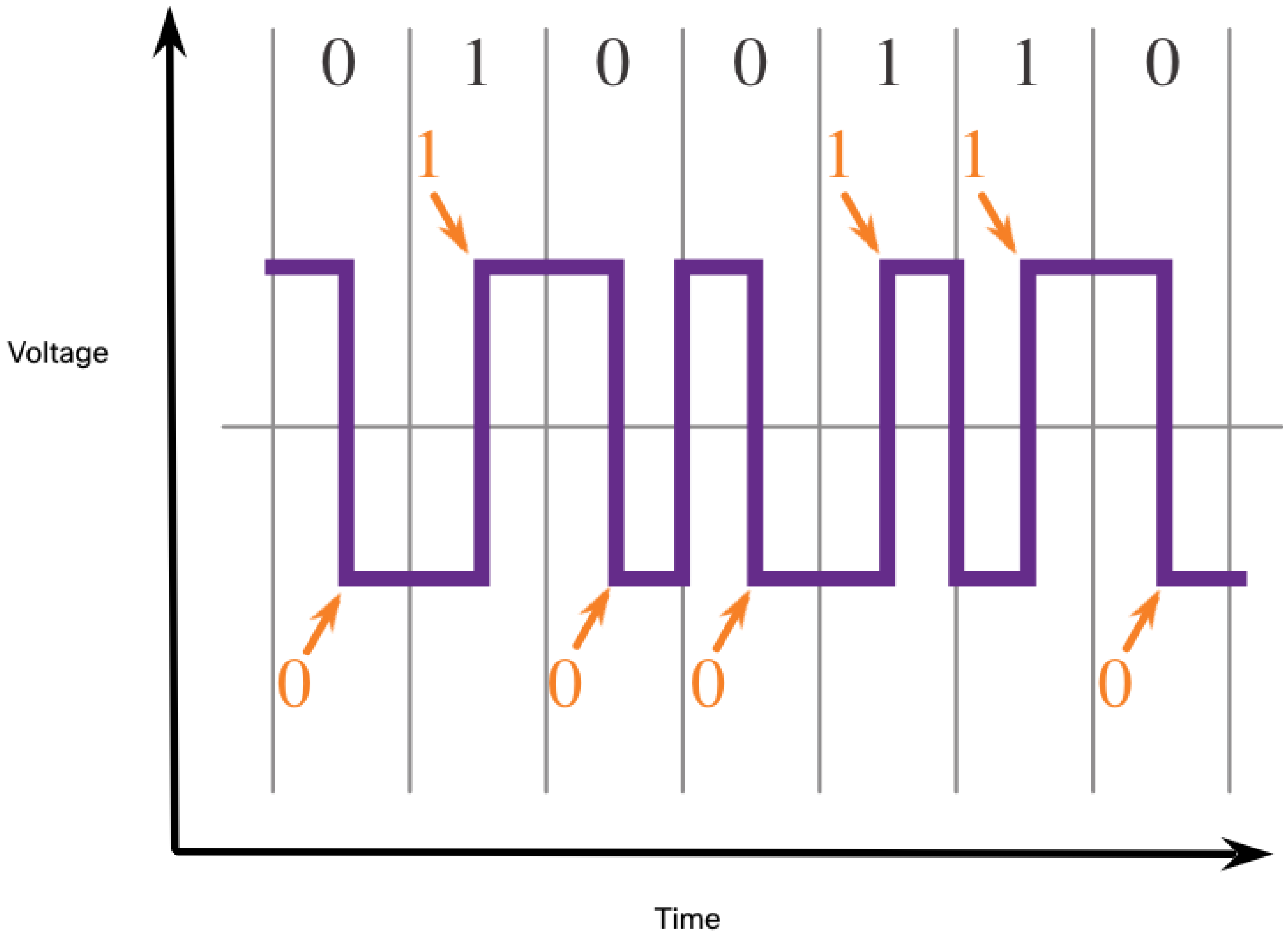
Digital signals: Encoding

- Consider the data stream 0 1 0 0 1 1 0 0 0 1 1
- This data can be encoded using a number of encoding schemes
  - Some have two voltage levels (binary)
  - Some have three voltage levels (ternary)
  - Some have positive and negative voltages (bipolar)
  - Some have only 0 and positive voltages (unipolar)



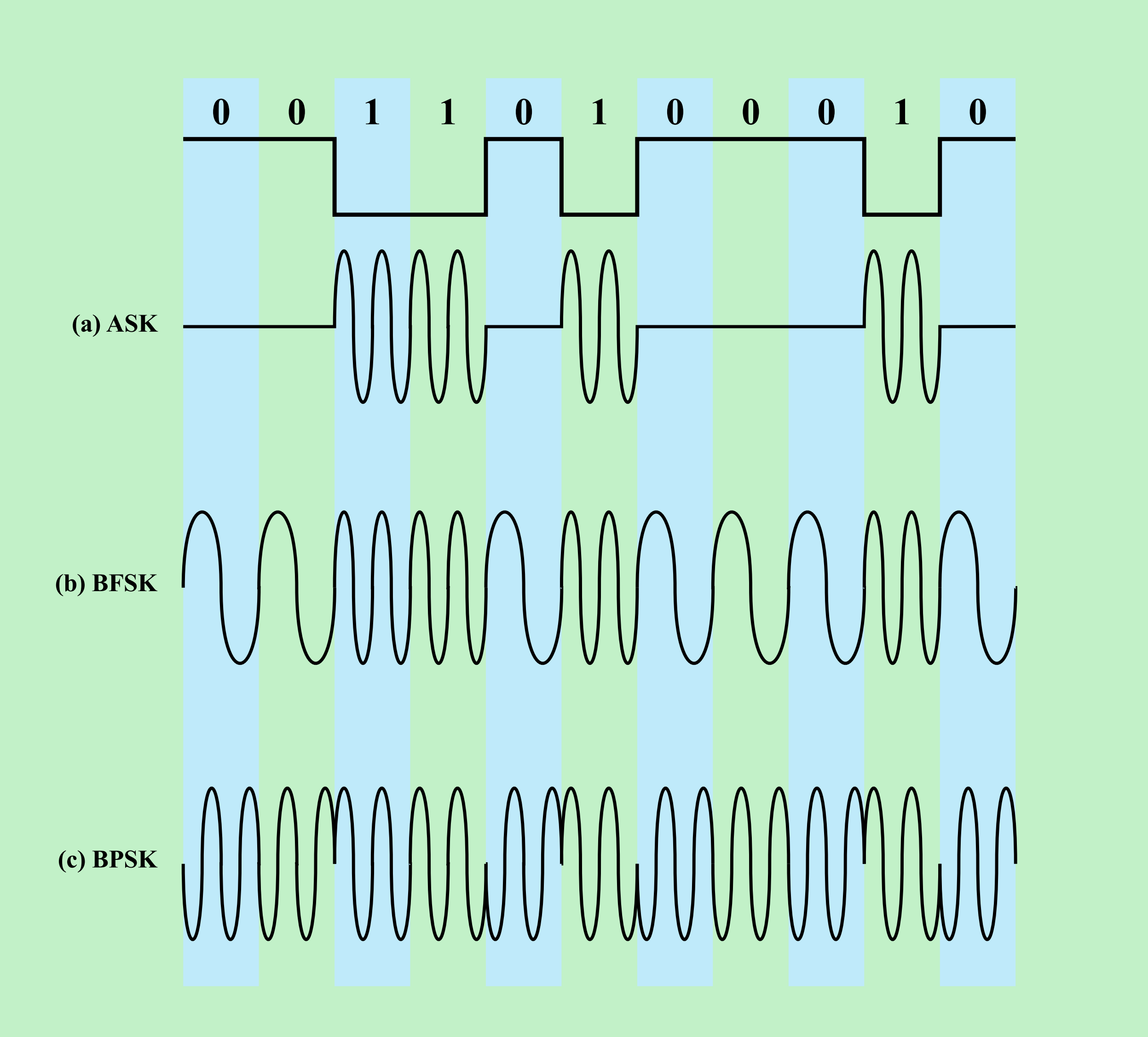
Manchester Encoding

- Used in Ethernet networks at low speeds (10 Mbps)
- 0 represented using a transition from high to low
- 1 represented using a transition from low to high
- Transition occurs at the middle of the bit period



Analog signals: Modulation

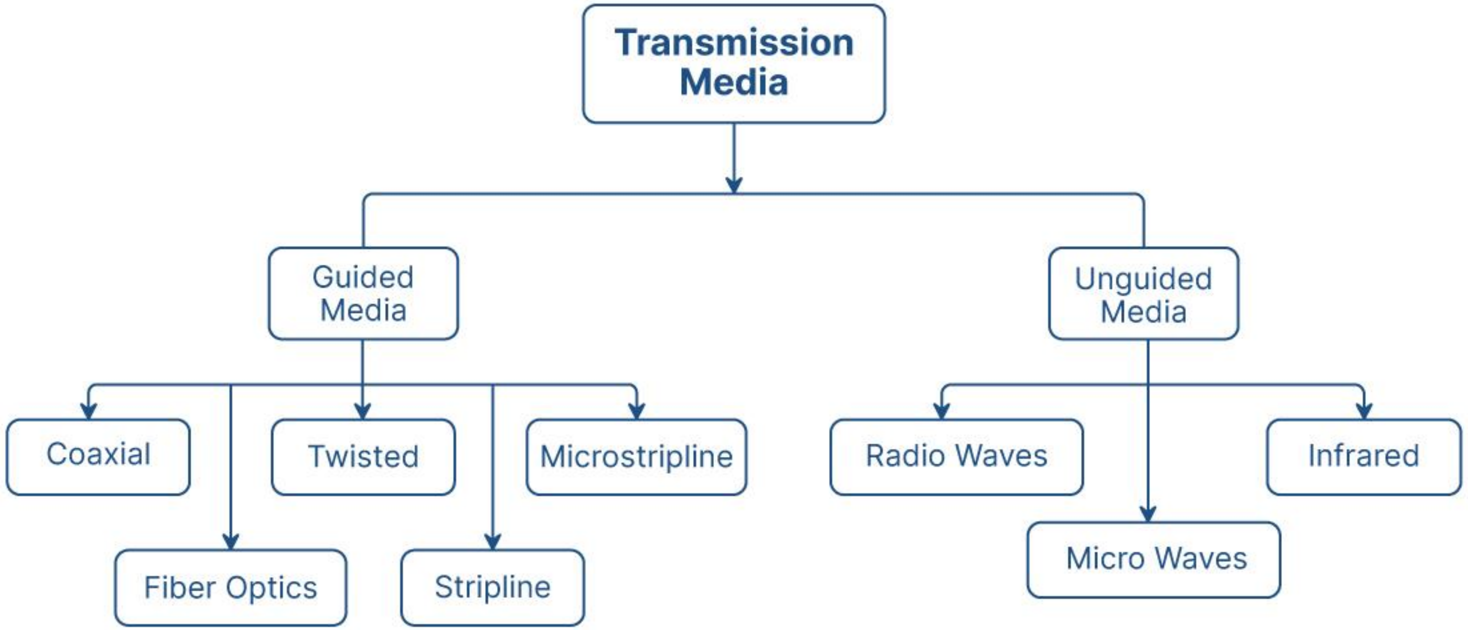
- Consider the data stream
  0 0 1 1 0 1 0 0 0 1 0
- An analog signal is created using a modulation scheme
  - Amplitude modulation (ASK)
    - 1 and 0 represented using two different amplitude levels
  - Frequency modulation (BFSK)
    - 1 and 0 represented using two different frequencies
  - Phase modulation (BPSK)
    - 1 and 0 represented using two different phases (0 and +180)



Review questions

- What is the main function or responsibility of the physical layer?
- What is the relationship between data and signals?
- What are the two types of signals?
- What is encoding?
- What is modulation?
- The following waveform shows the signal on an Ethernet link. It has been encoded using Manchester encoding. Identify the bit periods and determine the data sequence.

Transmission Media



Design Factors Determining Data Rate and Distance

- Bandwidth
  - Higher bandwidth gives higher data rate
- Transmission impairments
  - Impairments, such as attenuation, limit the distance
- Interference
  - Overlapping frequency bands can distort or wipe out a signal
- Number of receivers
  - More receivers introduces more attenuation (in guided media)

Transmission Characteristics of Guided Media

	Frequency Range	Typical Attenuation	Typical Delay	Repeater Spacing
Twisted pair (with loading)	0 to 3.5 kHz	0.2 dB/km @ 1 kHz	50 µs/km	2 km
Twisted pairs (multipair cables)	0 to 1 MHz	0.7 dB/km @ 1 kHz	5 µs/km	2 km
Coaxial cable	0 to 500 MHz	7 dB/km @ 10 MHz	4 µs/km	1 to 9 km
Optical fiber	186 to 370 THz	0.2 to 0.5 dB/km	5 µs/km	40 km

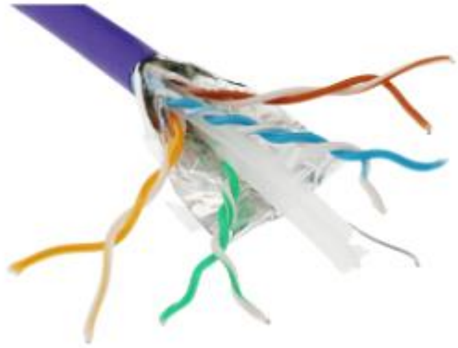
Characteristics of Copper Cabling

- Copper cabling is the most common type of cabling used in networks today. It is inexpensive, easy to install, and has low resistance to electrical current flow.
- Limitations:
  - Attenuation – the signal becomes weaker as it travels away from the source
  - Interference – the electrical signal is susceptible to electromagnetic interference (EMI) from external signals
  - Crosstalk – coupling of signal from one pair of conductors to another
- Mitigation:
  - Strict adherence to cable length limits will mitigate attenuation
  - Some types of copper cable mitigate EMI using metallic shielding and grounding
  - Some types of copper cable mitigate crosstalk by twisting opposing circuit pair wires together

Types of Copper Cabling

- Unshielded Twisted Pair (UTP)
- Shielded Twisted Pair (STP)
- Coaxial cable

Unshielded Twisted-Pair (UTP) Cable

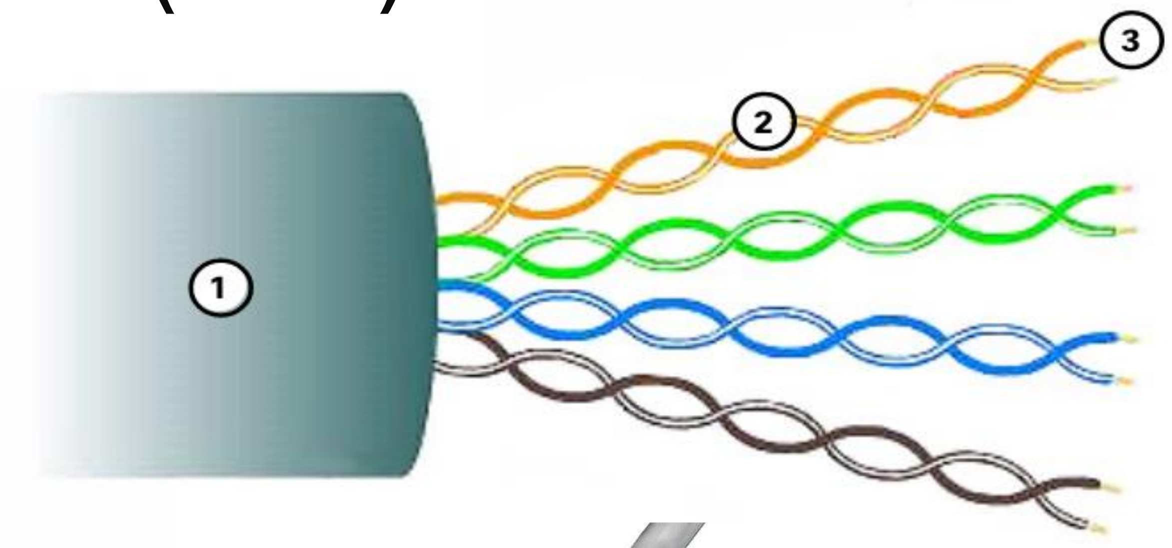


Shielded Twisted-Pair (STP) Cable

Coaxial Cable

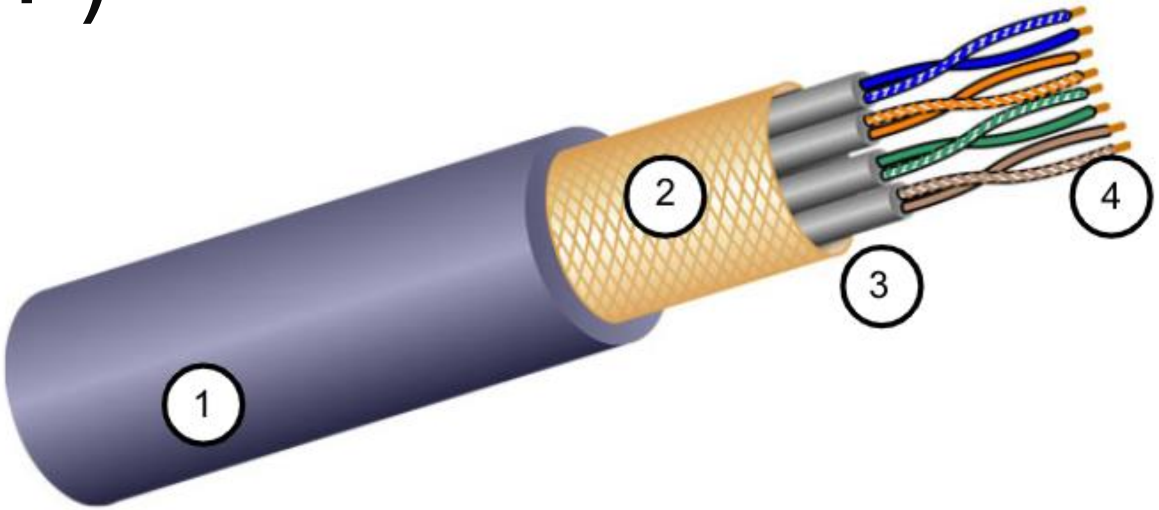
Unshielded twisted pair (UTP)

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



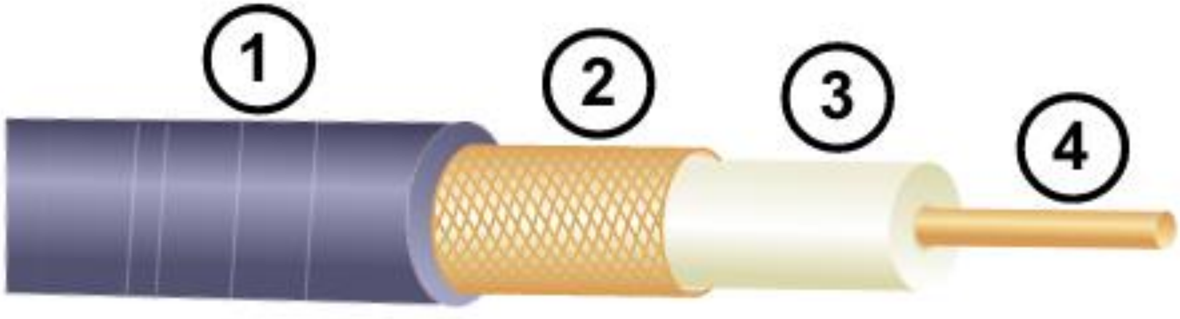
Shielded twisted pair (STP)

- 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
  - The outer jacket protects the copper wires from physical damage
  - Braided or foil shield provides EMI/RFI protection
  - Foil shield for each pair of wires provides EMI/RFI protection
  - Color-coded plastic insulation electrically isolates the wires from each other and identifies each pair



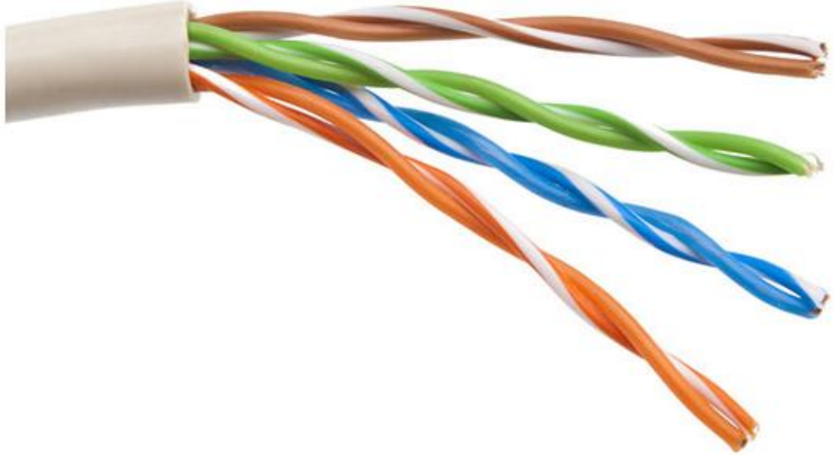
Coaxial cable

- 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 inner conductor.
    3. A layer of flexible plastic insulation
    4. A copper conductor is used to transmit the electronic signals.
- There are different types of connectors used with coax cable.
- Commonly used in wireless installations - attach antennas to wireless devices



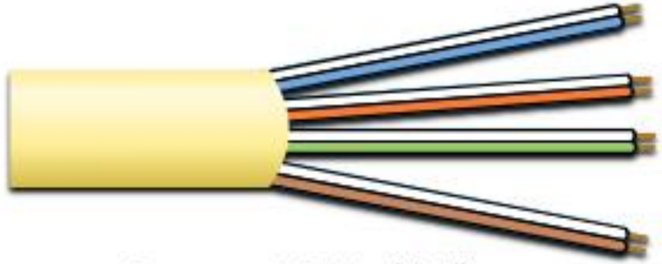
Properties of UTP Cabling

- UTP has four pairs of color-coded copper wires twisted together and encased in a flexible plastic sheath
- No shielding is used
- 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
- Variation in twists per foot in each wire
    - Each wire is twisted a different amount
    - This helps prevent crosstalk amongst the wires in the cable

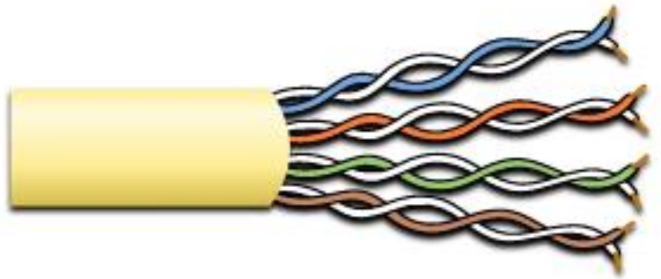


UTP cable standards

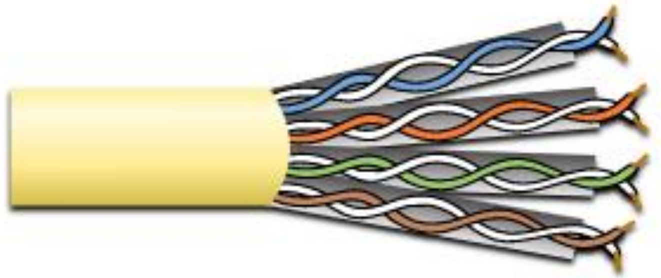
- Standards for UTP are established by the TIA/EIA. TIA/EIA-568 standardizes elements like:
  - Cable Types
  - Cable Lengths
  - Connectors
  - Cable Termination
  - Testing Methods
- Electrical standards for copper cabling are established by the IEEE, which rates cable according to its performance.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



Category 3 Cable (UTP)



Category 5 and 5e Cable (UTP)



Category 6 Cable (UTP)

Twisted pair categories and classes

UTP = Unshielded twisted pair
FTP = Foil twisted pair
S/FTP = Shielded/foil twisted pair

ACR = Attenuation to crosstalk ratio

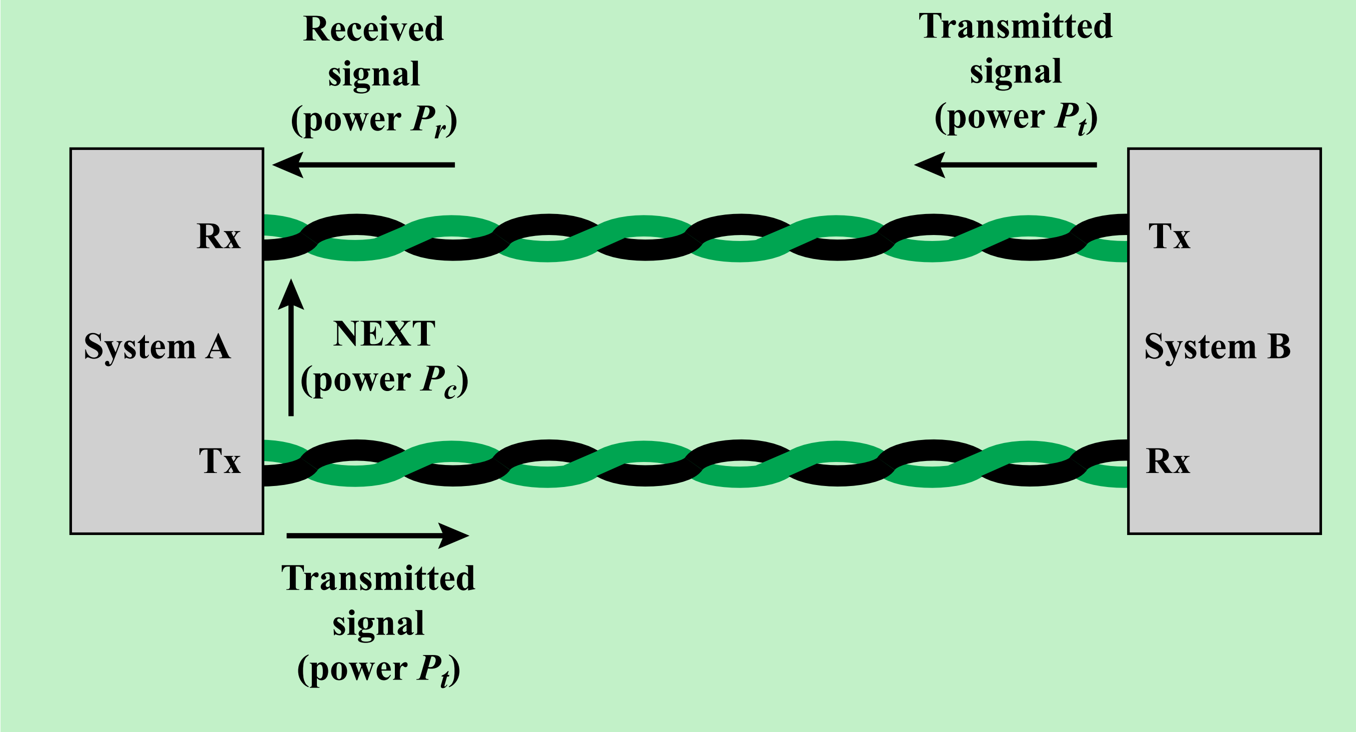
	Category 5e Class D	Category 6 Class E	Category 6A Class E_A	Category 7 Class F	Category 7_A Class F_A
Bandwidth	100 MHz	250 MHz	500 MHz	600 MHz	1,000 MHz
Cable Type	UTP	UTP/FTP	UTP/FTP	S/FTP	S/FTP
Insertion loss (dB)	24	21.3	20.9	20.8	20.3
NEXT loss (dB)	30.1	39.9	39.9	62.9	65
ACR (dB)	6.1	18.6	19	42.1	44.1

Attenuation / Near-End Crosstalk (NEXT)

- Attenuation
  - The strength of a signal falls off with distance over any transmission medium
  - For guided media (e.g., twisted-pair wire, optical fiber), attenuation is generally exponential and therefore expressed in decibels per unit distance
  - A received signal must have sufficient strength so that the electronic circuitry in the receiver can detect and interpret the signal
  - The transmitted signal must be strong enough to compensate for attenuation
  - Attenuation is greater at higher frequencies
- NEXT
  - Coupling of signal from one pair of conductors to another
  - Near end refers to coupling that takes place when the transmit signal entering the link couples back to the receive conductor pair at that same end of the link
  - Greater NEXT loss magnitudes are associated with less crosstalk noise

Attenuation / Near-End Crosstalk (NEXT)

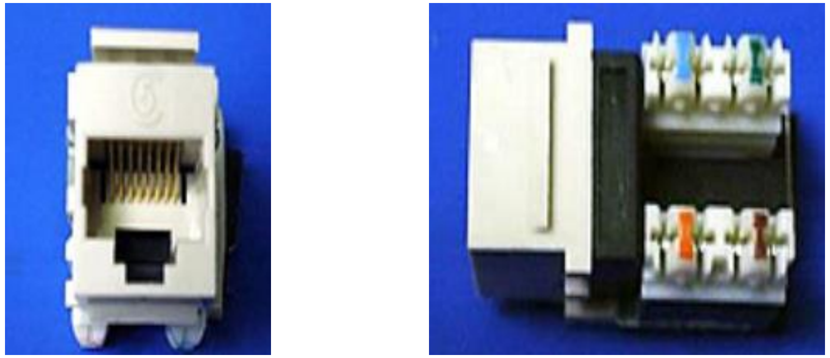
- Attenuation and NEXT are usually expressed in dB (Decibel)
- $A_{dB} = 10\log_{10}\frac{P_t}{P_r}$
- $NEXT_{dB} = 10\log_{10}\frac{P_t}{P_c}$



UTP Connectors

RJ-45 Connector

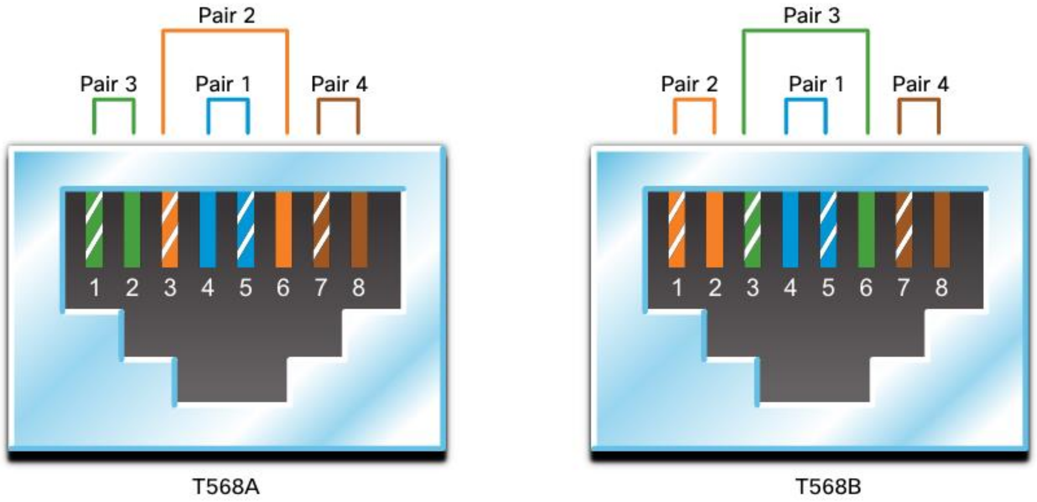
Poorly terminated UTP cable



RJ-45 Socket

Properly terminated UTP cable

Straight-through / Crossover UTP Cables



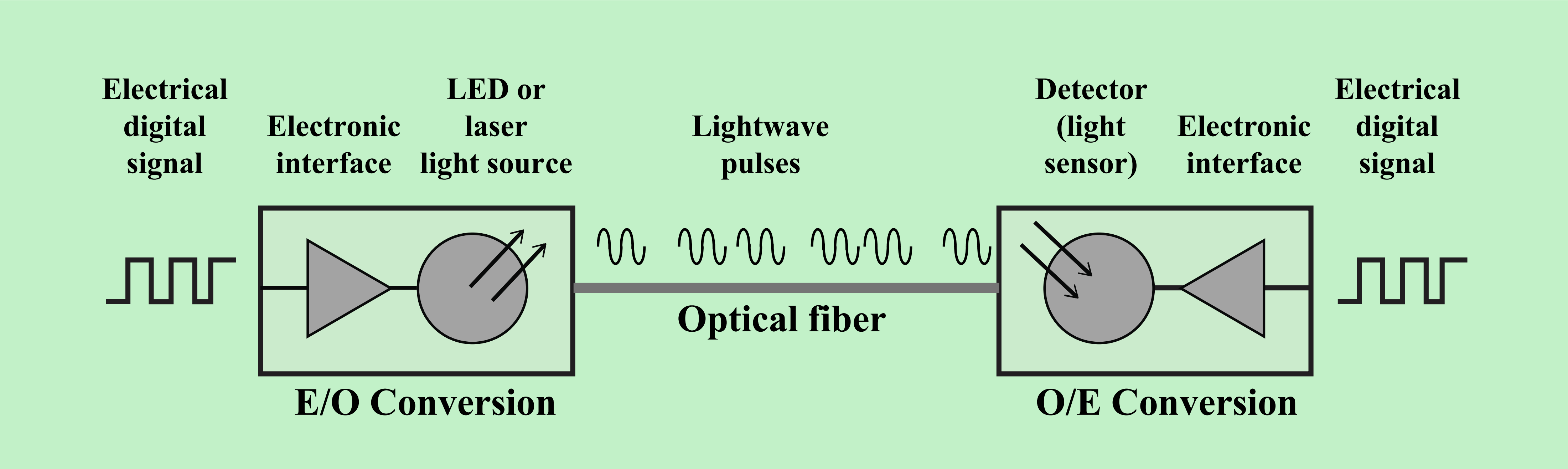
Cable Type	Standard	Application
Ethernet Straight-through	Both ends T568A or T568B	Host to Network Device
Ethernet Crossover *	One end T568A, other end T568B	Host-to-Host, Switch-to-Switch, Router-to-Router
* Considered Legacy due to most NICs using Auto-MDIX to sense cable type and complete connection		

Review questions

- What are the three main limitations in UTP cable?
- What are the differences between UTP and STP cables?
- What is attenuation?
- What is electro-magnetic interference (EMI)?
- What is crosstalk?
- What is the difference between a crossover cable and a straight-through cable?
- Why are crossover cables considered obsolete now?

Optical communication

- Optical communication using optical fiber requires
  - Electrical to optical conversion at the transmitter end
  - Optical to electrical conversion at the receiver end

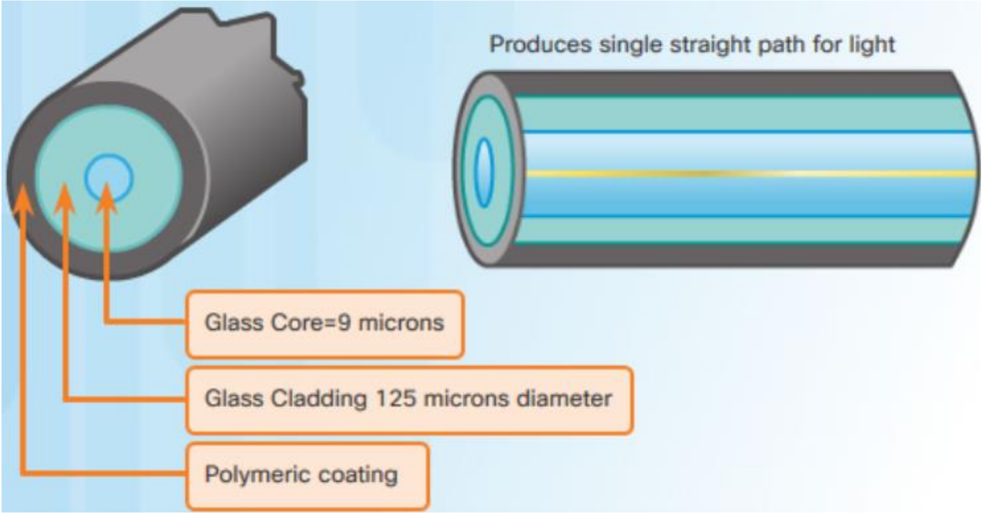


Properties of Fiber Optic Cabling

- Transmits data over longer distances at higher bandwidth than any other networking media
- Less susceptible to attenuation, and completely immune to EMI/RFI
- Made of flexible, extremely thin strands of very pure glass
- Uses a laser or LED to encode bits as pulses of light
  - 1 – presence of light
  - 0 – absence of light
- The fiber-optic cable acts as a wave guide to transmit light between the two ends with minimal signal loss

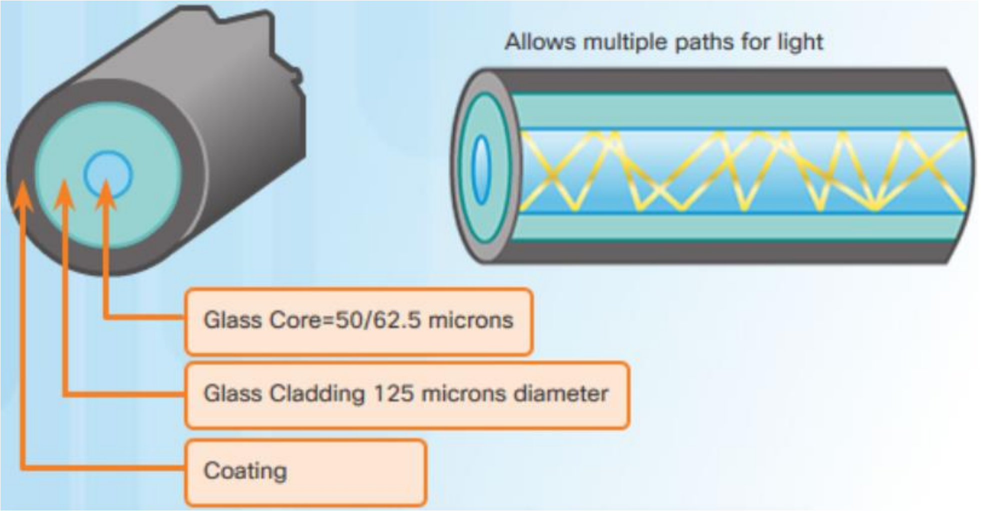
Types of Fiber Media

Single-Mode Fiber



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

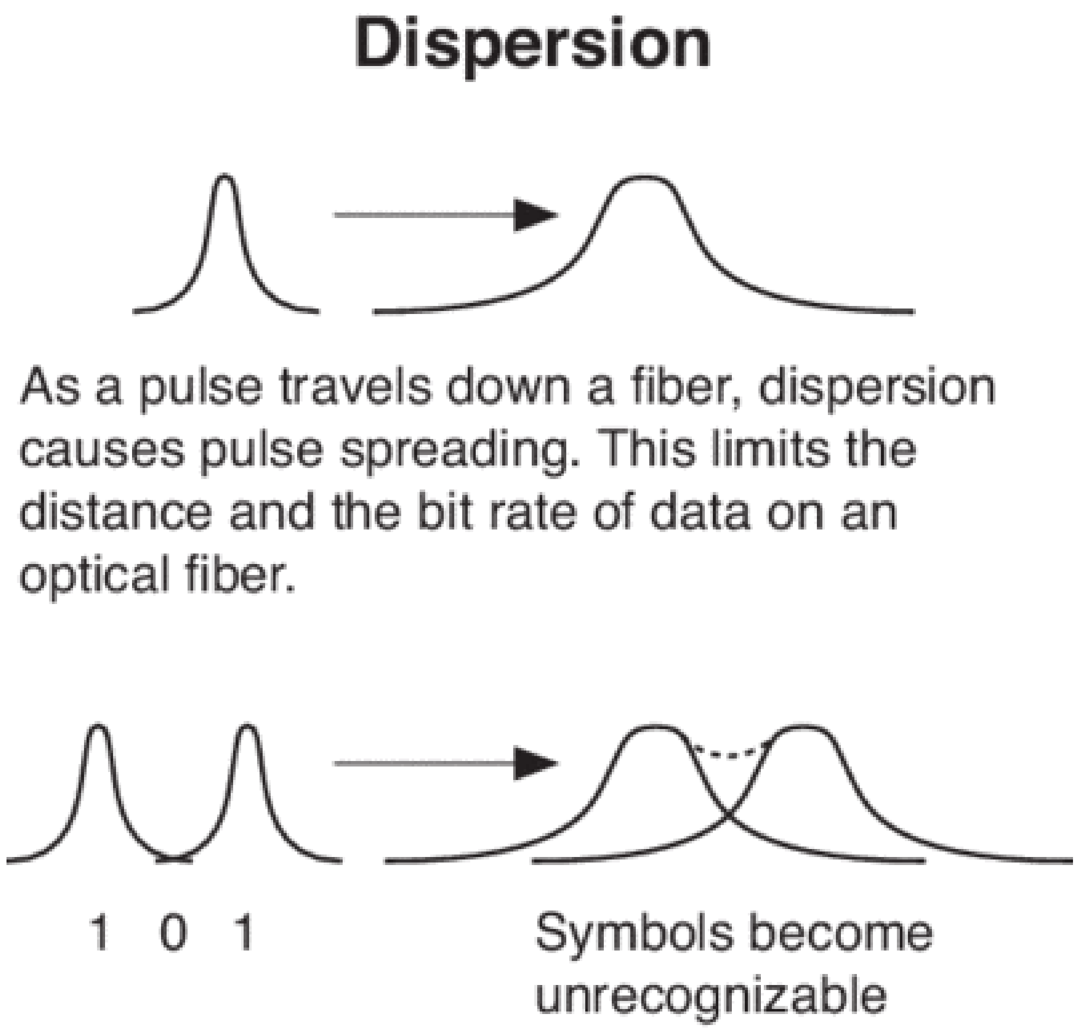
Multimode Fiber



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

Dispersion

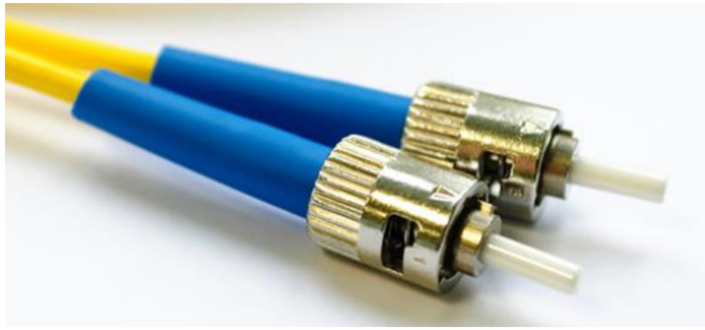
- Dispersion refers to the spreading out of a light pulse over time.
- Increased dispersion means increased loss of signal strength.
- MMF has greater dispersion than SMF.
- The maximum cable distance for MMF is 550 meters.



Fiber Optic Cabling usage

- 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

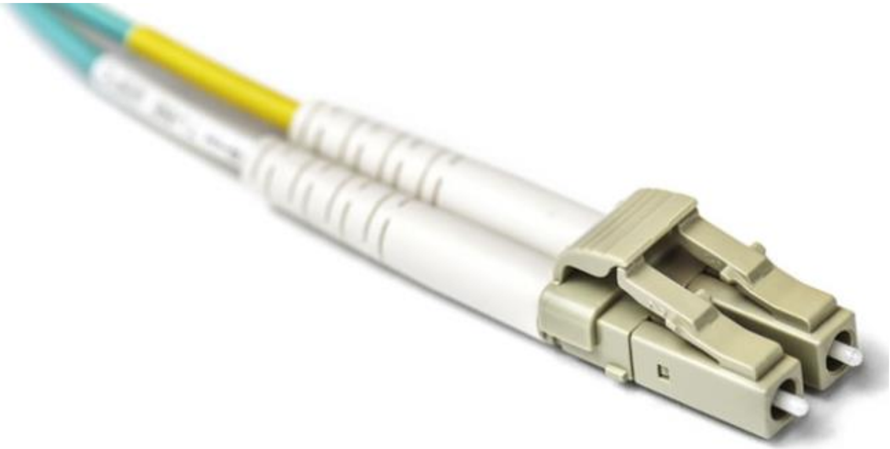
Fiber-Optic Connectors



Straight-Tip (ST) Connectors

Lucent Connector (LC) Simplex Connectors

Subscriber Connector (SC) Connectors



Duplex Multimode LC Connectors

Fiber Patch Cords

SC-SC MM Patch Cord

LC-LC SM Patch Cord

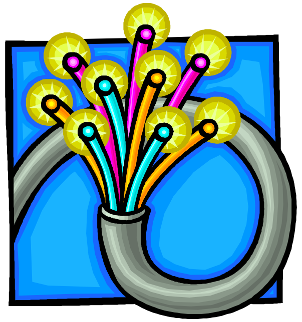
ST-LC MM Patch Cord

ST-SC SM Patch Cord

A yellow jacket is for single-mode fiber cables and orange (or aqua) for multimode fiber cables.

Optical Fiber - Benefits

- Greater capacity
  - Data rates of hundreds of Gbps over tens of kilometers have been demonstrated
- Smaller size and lighter weight
  - Considerably thinner than coaxial or twisted pair cable
  - Reduces structural support requirements
- Lower attenuation
- Electromagnetic isolation
  - Not vulnerable to interference, impulse noise, or crosstalk
  - High degree of security from eavesdropping
- Greater repeater spacing
  - Lower cost and fewer sources of error



Frequency Utilization for Fiber Applications

Wavelength (in vacuum) range (nm)	Frequency Range (THz)	Band Label	Fiber Type	Application
820 to 900	366 to 333		Multimode	LAN
1280 to 1350	234 to 222	S	Single mode	Various
1528 to 1561	196 to 192	C	Single mode	WDM
1561 to 1620	192 to 185	L	Single mode	WDM

WDM = wavelength division multiplexing

Fiber versus Copper

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 – 100m)	Relatively long (1m – 100km)
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

Review questions

- What are the differences between singlemode fiber and multimode fiber?
- What are the differences between the characteristics such as (Attenuation, EMI and Crosstalk) of UTP cabling and Fiber-Optic cabling?
- What are the benefits of Fiber-Optic cabling?
- What is the range of wavelengths of the light signals used in the L band for single mode fiber?

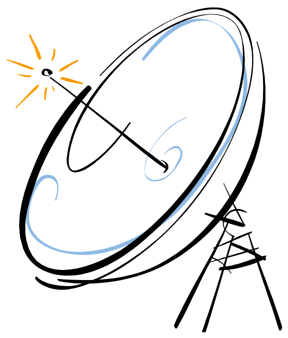
Properties of Wireless Media

- Free space carries electromagnetic signals representing binary digits using radio or microwave frequencies
- Provides the greatest mobility option
- Wireless connectivity is becoming increasingly preferred over wired for LANs
- 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
  - 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

Wireless Transmission Frequencies

- Wireless LANs (Wi-Fi)
  - 2.4 GHz band: Older Wi-Fi standards
  - 5 GHz band: Used by newer Wi-Fi standards such as 802.11a, 802.11n, 802.11ac, and 802.11ax.
  - 6 GHz band: Used by newer Wi-Fi standars (Wi-Fi 6 and later)
- Bluetooth
  - 2.4 GHz band: Specifically, Bluetooth operates in the range of 2.402 GHz to 2.480 GHz.
  - This is a globally unlicensed Industrial, Scientific, and Medical (ISM) band
- IrDA (Infrared Data Association)
  - Unlike Wi-Fi and Bluetooth, IrDA uses light waves
  - Typically around 875 nm (nanometers) to 900 nm wavelength

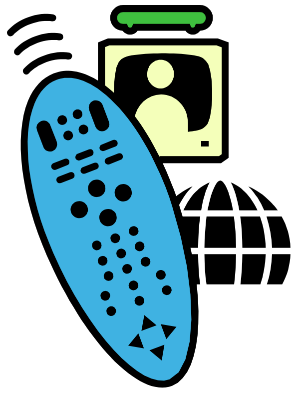
Antennas



- Electrical conductor or system of conductors used to radiate or collect electromagnetic energy
- Radio frequency electrical energy from the transmitter is converted into electromagnetic energy by the antenna and radiated into the surrounding environment
- Reception occurs when the electromagnetic signal intersects the antenna
- In two-way communication, the same antenna can be used for both transmission and reception

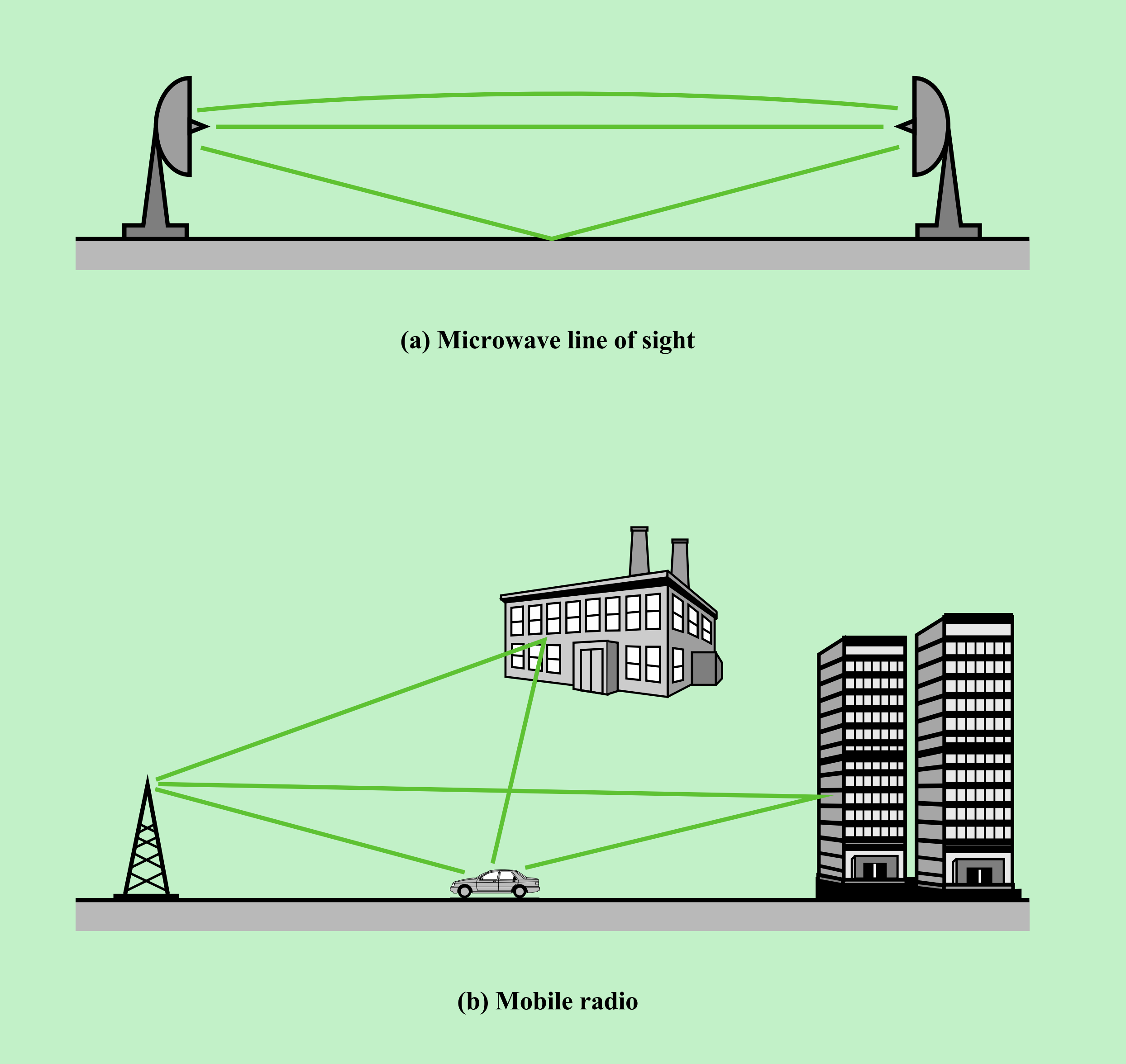
Infrared

- Achieved using transceivers that modulate noncoherent infrared light
- Transceivers must be within line of sight of each other directly or via reflection
- Does not penetrate walls
- No licensing is required
- No frequency allocation issues



Multipath interference

- Multiple interfering signals from reflections



(a) Microwave line of sight

(b) Mobile radio

Lesson summary

- Physical layer functions
  - Standards
- Signaling
  - Analog and digital signals
  - Encoding
  - Modulation
- Guided transmission media
  - Twisted pair
  - Optical fiber
- Wireless transmission
  - Antennas
  - Infrared

References

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  Chapter 4 – Transmission Media
  Chapter 5 – Signal Encoding Techniques
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