Physical Layer

Version 4.0

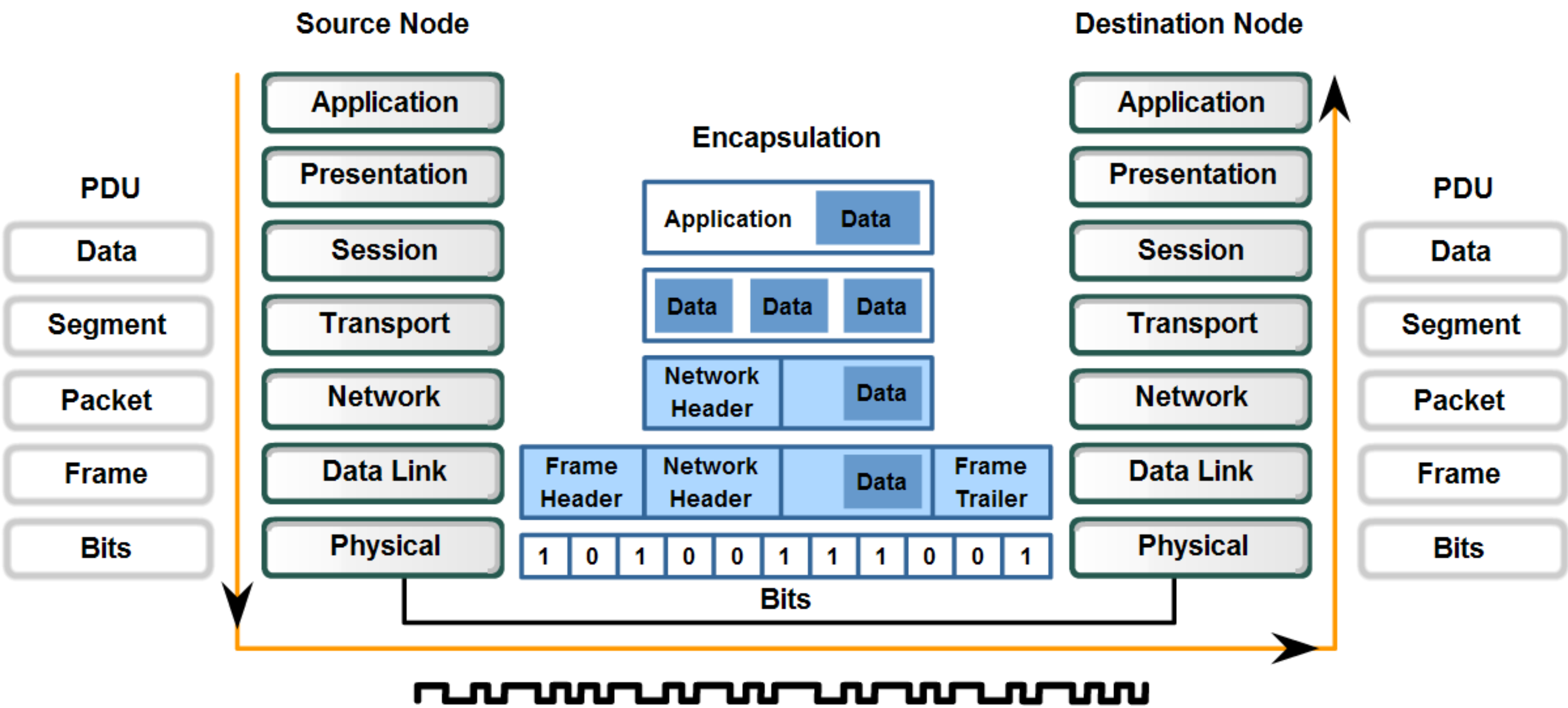
Physical Layer Protocols & Services

- Purpose: create the electrical, optical, or microwave signal that represents the bits in each frame and get them on to the media.

- This includes binary transmission, cable specifications, and the physical aspects of network communication.

Physical Layer Protocols & Services

- Frames are taken from the Data link layer and converted into bits and then into the necessary signals depending on the actual physical networking media. These are retrieved and converted back at the receiving device.

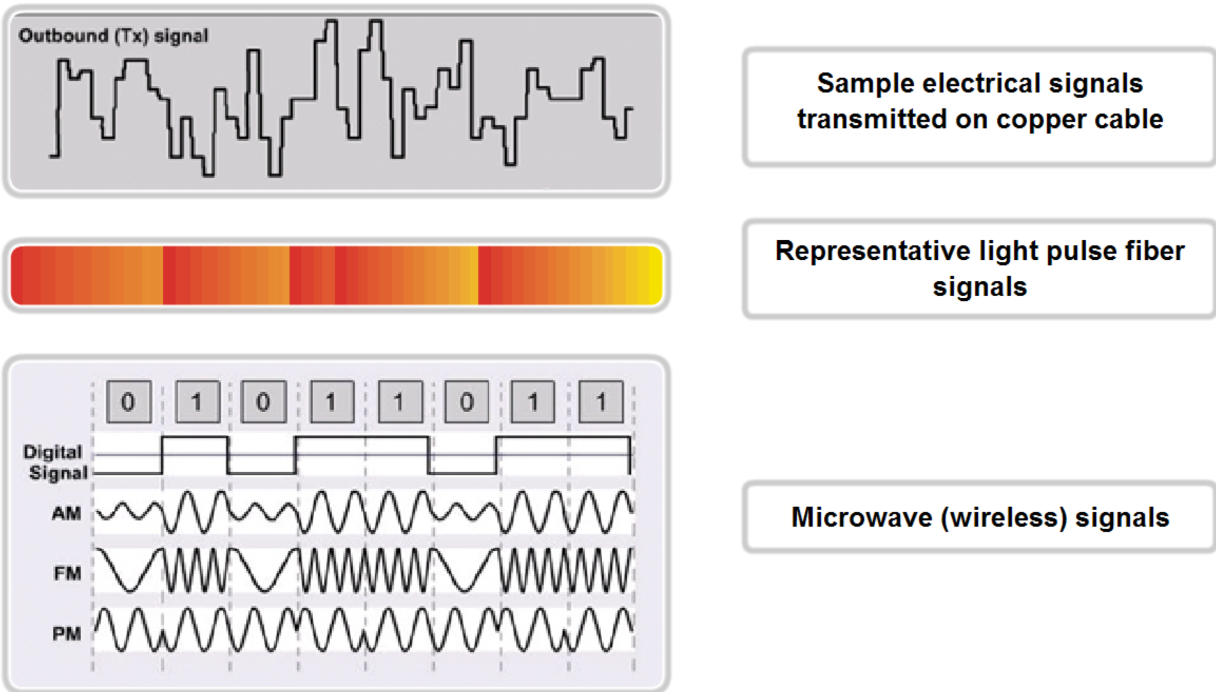


Physical Layer Protocols & Services

Three basic forms of network media: copper cable, fiber, wireless.

- Copper – electrical pulses
- Fiber – patterns of light
- Wireless – patterns of radio transmissions (Electro magnetic signal)

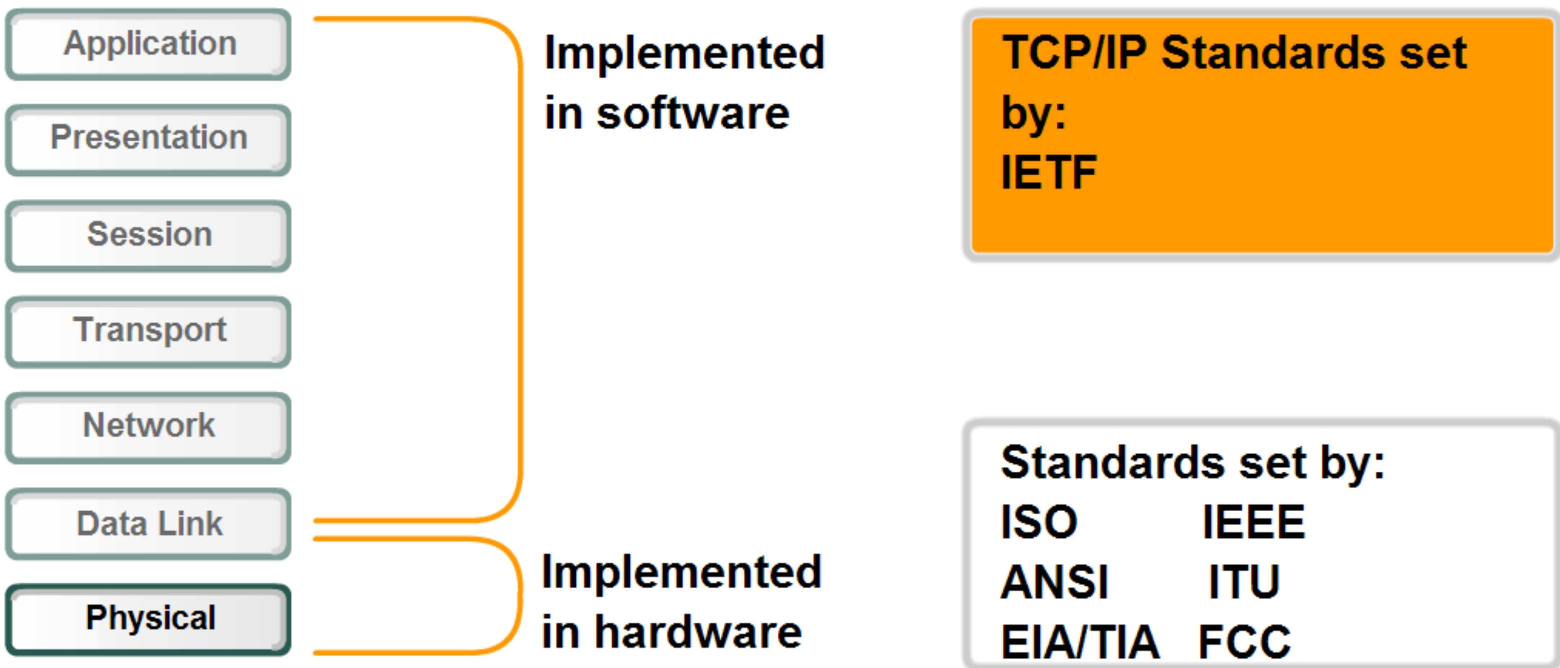
Representations of Signals on the Physical Media



Physical Layer Protocols & Services

- Physical layer standards are appropriately set by bodies who govern the hardware (relevant electrical and communications engineering organizations)

Comparison of Physical layer standards and upper layer standards



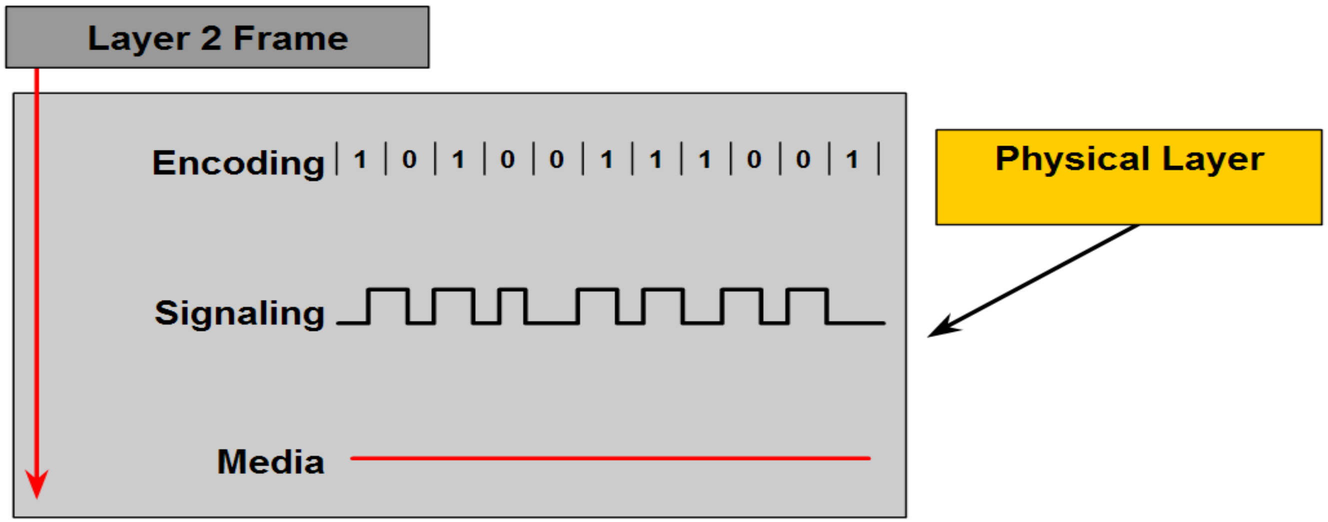
Physical Layer standards

- Four areas of physical layer standards
  - Physical and electrical properties of the media
  - Mechanical properties of the connectors (pin-outs, materials, dimensions)
  - Bit representation by the signals (encoding)
  - Definition of control information signals
- NICs, interfaces, connectors, cable materials and cable designs are all specified in these standards.

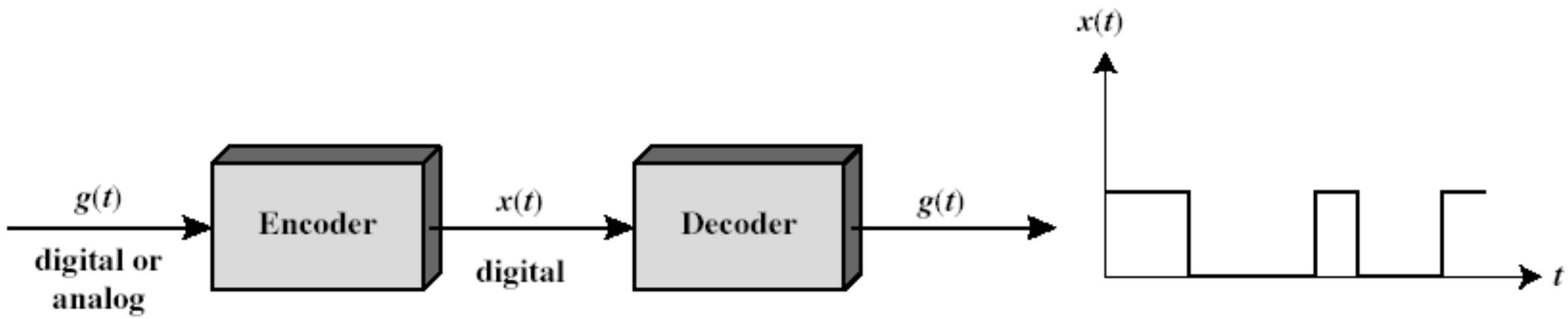
Fundamental Principles

- Encoding – converting streams of data into bit patterns
- Signaling – generating the signals (electricity, light, micro waves) that represent the "1" and "0" on the media.

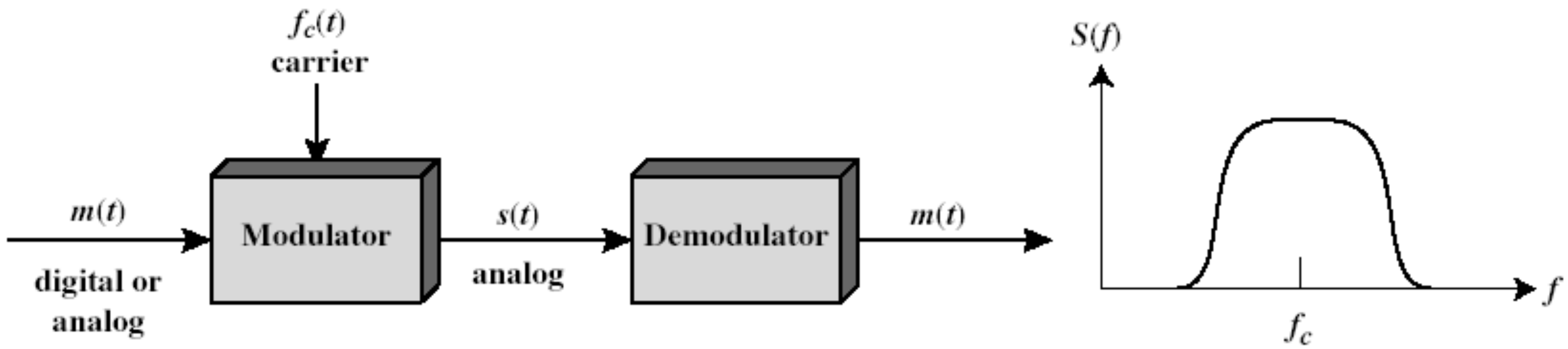
Physical Layer Fundamental Principles



ENCODING AND MODULATION



(a) Encoding onto a digital signal



(b) Modulation onto an analog signal

Modulation

- Modulation is the process of encoding source data onto a **carrier signal** with frequency f_c.
  - The frequency of the carrier signal is chosen to be compatible with the transmission medium being used.
  - Modulation techniques involve operation on one or more of the three parameters: ***amplitude, frequency, and phase***
- According to the input source signal m(t) (either analog or digital), which is called **baseband signal (or modulating signal)** , the carrier signal $f_c(t)$ will be modulated into **modulated signal** s(t).

KEY POINTS

- **Digital data, digital signal**: The simplest form of digital encoding of digital data is to assign one voltage level to binary one and another to binary zero. More complex encoding schemes are used to improve performance, by altering the spectrum of the signal and providing synchronization capability.

- **Digital data, analog signal**: A modem converts digital data to an analog signal so that it can be transmitted over an analog line. The basic techniques are **ASK**, **FSK**, and **PSK**.

KEY POINTS

- **Analog data, digital signals**: Analog data, such as voice and video, are often digitized to be able to use digital transmission facilities. The simplest technique is **PCM (Pulse Code Modulation),** which involve **sampling** the analog data periodically and **quantizing** the samples. Another technique is **Delta Modulation**.

- **Analog data, analog signals**: Analog data are modulated by a carrier frequency to produce an analog signal in a different frequency band, which can be utilized on an analog transmission system. The basic techniques are **AM (Amplitude Modulation), FM (Frequency Modulation)**, and **PM (Phase Modulation).**

(I) Digital Data, Digital Signal

- Digital signal is a sequence of discrete, discontinuous **voltage pulses**.
- Each pulse is a **signal element**.
- Binary data are transmitted by encoding the bit stream into signal elements.
- In the simplest case, one bit is represented by one signal element.
  - E.g., 1 is represented by a lower voltage level, and 0 is represented by a higher voltage level

Encoding Schemes

- Nonreturn to Zero (NRZ)
  - Nonreturn to Zero-Level (NRZ-L)
  - Nonreturn to Zero Inverted (NRZI)
- Multilevel Binary
  - Bipolar-AMI
  - Pseudoternary
- Biphase
  - Manchester
  - Differential Manchester
- Scrambling techniques
  - B8ZS
  - HDB3

DEFINITION OF DIGITAL SIGNAL ENCODING FORMATS

Nonreturn to Zero-Level (NRZ-L)
0 = high level
1 = low level

Nonreturn to Zero Inverted (NRZI)
0 = no transition at beginning of interval (one bit time)
1 = transition at beginning of interval

Bipolar-AMI
0 = no line signal
1 = positive or negative level, alternating for successive ones

Pseudoternary
0 = positive or negative level, alternating for successive zeros
1 = no line signal

Manchester
0 = transition from high to low in middle of interval
1 = transition from low to high in middle of interval

Differential Manchester
Always a transition in middle of interval
0 = transition at beginning of interval
1 = no transition at beginning of interval

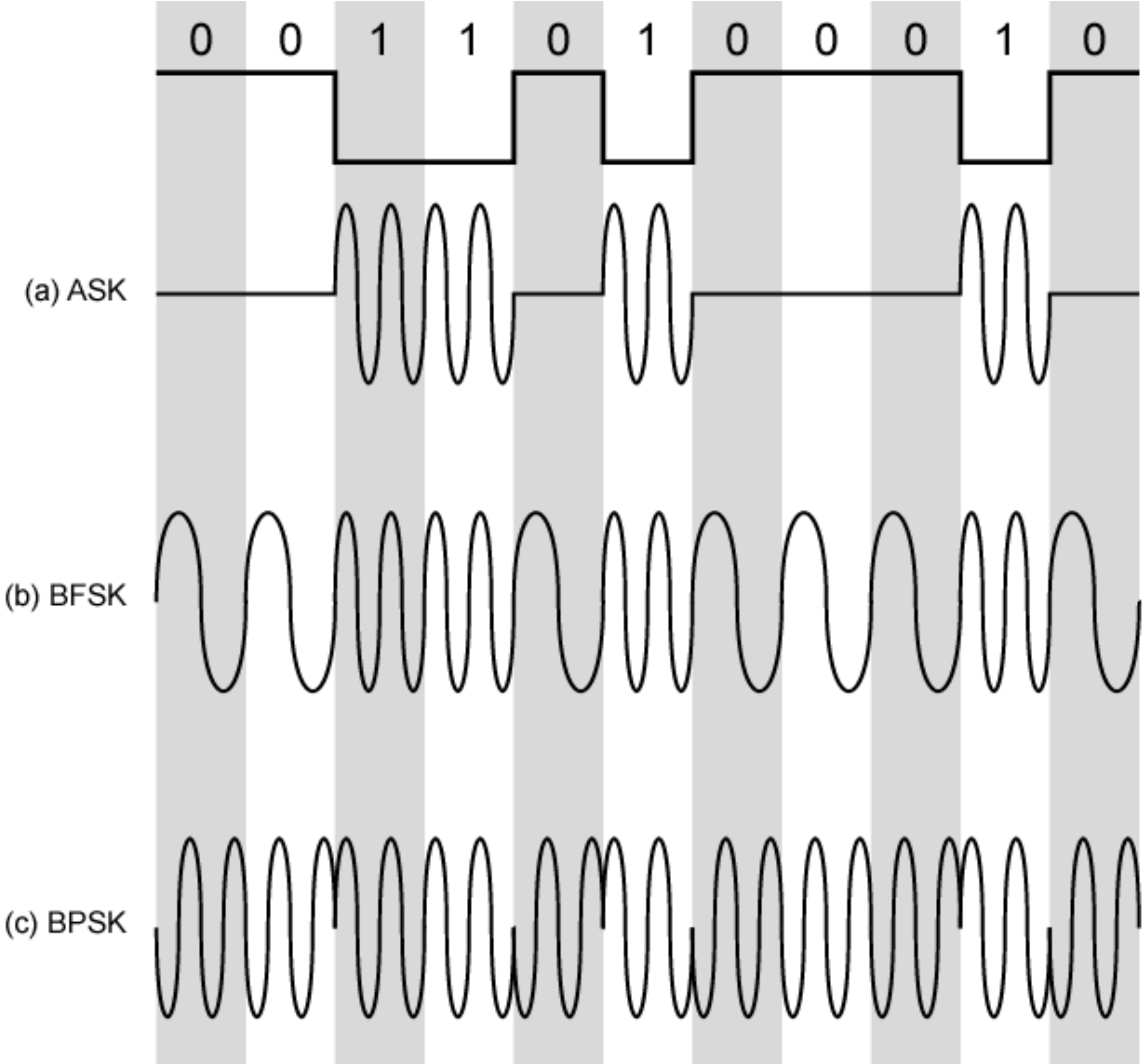
B8ZS
Same as bipolar AMI, except that any string of eight zeros is replaced by a string with two code violations

HDB3
Same as bipolar AMI, except that any string of four zeros is replaced by a string with one code violation

(II) Digital Data, Analog Signal

- Optical system and unguided media (wireless system) only propagate analog signals

- Modulation involves operation on <u>**one or more**</u> of the three characteristics of a **carrier signal**
  - Amplitude shift keying (ASK)
  - Frequency shift keying (FSK)
    - Binary FSK (BFSK)
    - Multiple FSK (MFSK)
  - Phase shift keying (PSK)
    - Binary PSK (BPSK)
    - Four-level PSK (QPSK)
    - Multilevel PSK (MPSK)
- QAM: a combination of ASK and PSK


0 0 1 1 0 1 0 0 0 1 0
(a) ASK
(b) BFSK
(c) BPSK

(III) Analog Data, Digital Signal

- Digitization
  - Conversion of analog data into digital data
    - Digital data can then be transmitted using NRZ-L
    - Digital data can then be transmitted using code other than NRZ-L
    - Digital data can then be converted to analog signal
  - Analog to digital conversion done using a **codec** (coder-decoder)
  - Two principle codec techniques
    - Pulse Code Modulation
    - Delta modulation

Digitizing Analog Data

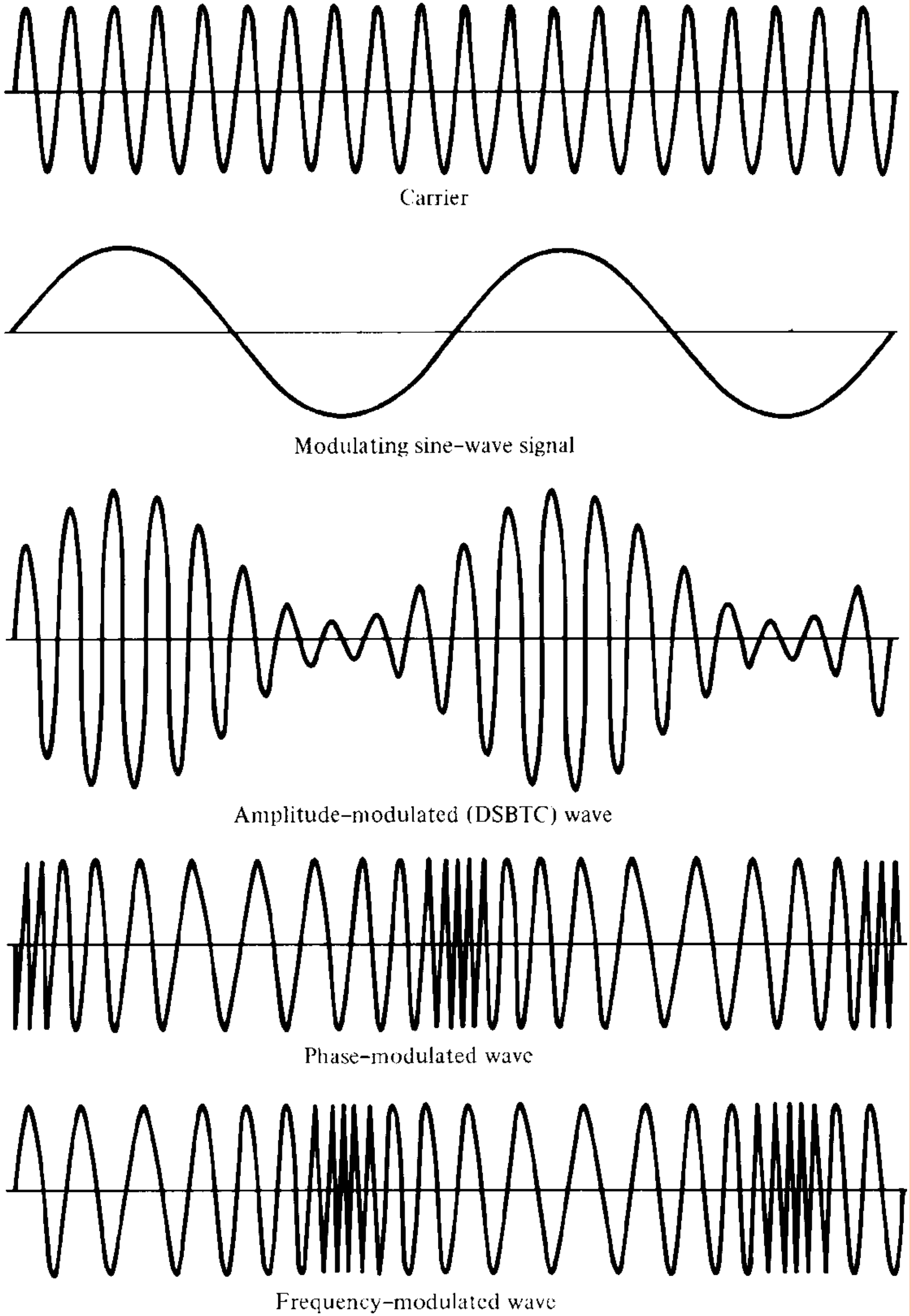
Analog data
(voice)

Digital data

(IV) Analog Data, Analog Signals

- Modulation:
  - Combine an input signal m(t) and a carrier frequency f_c to produce a signal s(t) whose bandwidth is usually centered on f_c
- E.g., voice signals are transmitted over telephone lines at their original spectrum.
- Types of modulation
  - Amplitude modulation: AM
  - Angle Modulation
    - Frequency modulation: FM
    - Phase modulation: PM

ANALOG MODULATION



Measuring data carrying capacity

- Bandwidth
  - Bandwidth is the amount of data that can be physically transferred through the media of choice. (E.g. 100Mbit/s for 100base-T Ethernet.)
  - Its the scientific calculated unit of what should be possible to send.
  - In real life, that number may well not be reached because the actual throughput is not available

Measuring data carrying capacity

- Throughput
  - Throughput is the amount of information (in bits, bytes, packets, etc) that can go or be sent through a connection or conductor in real life situation.
  - Things that can hit it are bad connectors, bad cables, noise, or even collisions and the size of the packets being sent etc.
  - All these things can impact the throughput of the circuit.

Modulation Rate

- The modulation rate is the rate at which signal elements are generated
- **Where**
  - **D = Baud Rate/ modulation rate/Symbol rate**
  - R = data rate, (bit per second, bit/s, bps)
  - N = number of bits per Symbol
  - M = number of different symbol required = 2^N

$$D = \frac{R}{N} = \frac{R}{\mathrm{Log}_2 \mathrm{M}}$$

MAXIMUM DATA RATE

The maximum theoretical bit rate C bit/s

- For a given bandwidth B. Hz or bit/s (analog or digital)
- When using multilevel modulation with multiple bits per symbol is

$$C = 2B \log_2 M \text{ (Nyquist Formula)}$$

- Where M is the number of symbols for symbol interval
- Assumption: Channel is noise free

Factoring in the noise requires the well-known Shannon-Hartley law::

$$C = B \log_2 ((s/n) + 1) \text{ (Shannon Capacity Formula)}$$

- where s/n = signal-to-noise power ratio

The number of symbols needed to get a desired data rate in a fixed bandwidth can be calculated as:

$$M = \log_{10}{}^{-1} (C/(6.64B))$$

EXAMPLE

- Consider an example that relates the Nyquist and Shannon formulations. Suppose the spectrum of a channel is between 3 MHz and 4 MHz, and SNR_{dB} = 24dB. So,

  $B = 4\text{ MHz} – 3\text{ MHz} = 1\text{ MHz}$

  $SNR_{dB} = 24\text{ dB} = 10\log_{10}(SNR) \rightarrow SRN = 251$

- Using Shannon's formula, the capacity limit C is:

  $C = 10^6 \times \log_2(1+251) \approx 8\text{ Mbps}.$

- If we want to achieve this limit, how many signaling levels are required at least?

  By Nyquist's formula: $C = 2B\log_2 M$

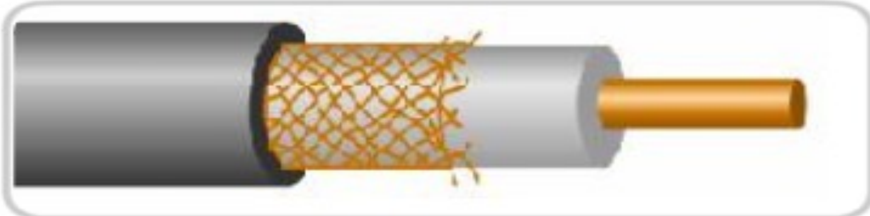
  We have $8 \times 10^6 = 2 \times 10^6 \times \log_2 M \rightarrow M = 16$.

  Then we need N=4 (4 bit/symbol where $\log_2 M=N$)

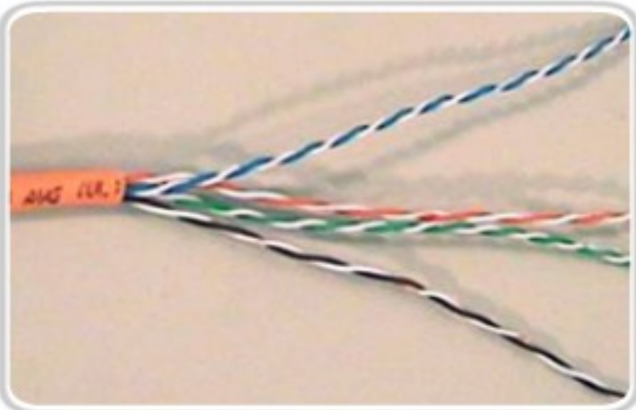
Characteristics & Uses of Network Media

Copper Media – most commonly used

Copper Media



Coaxial cable

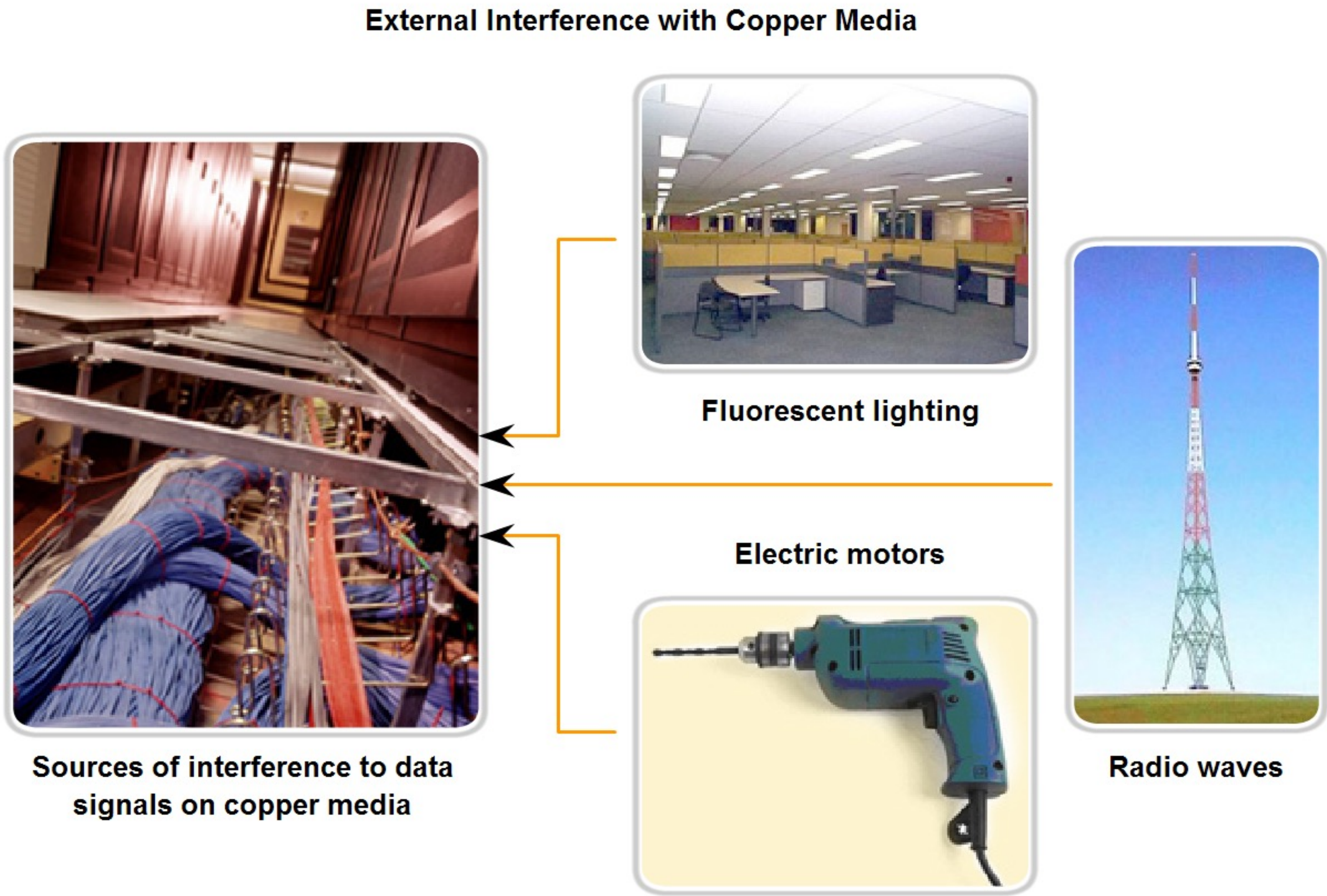


Unshielded twisted-pair cable

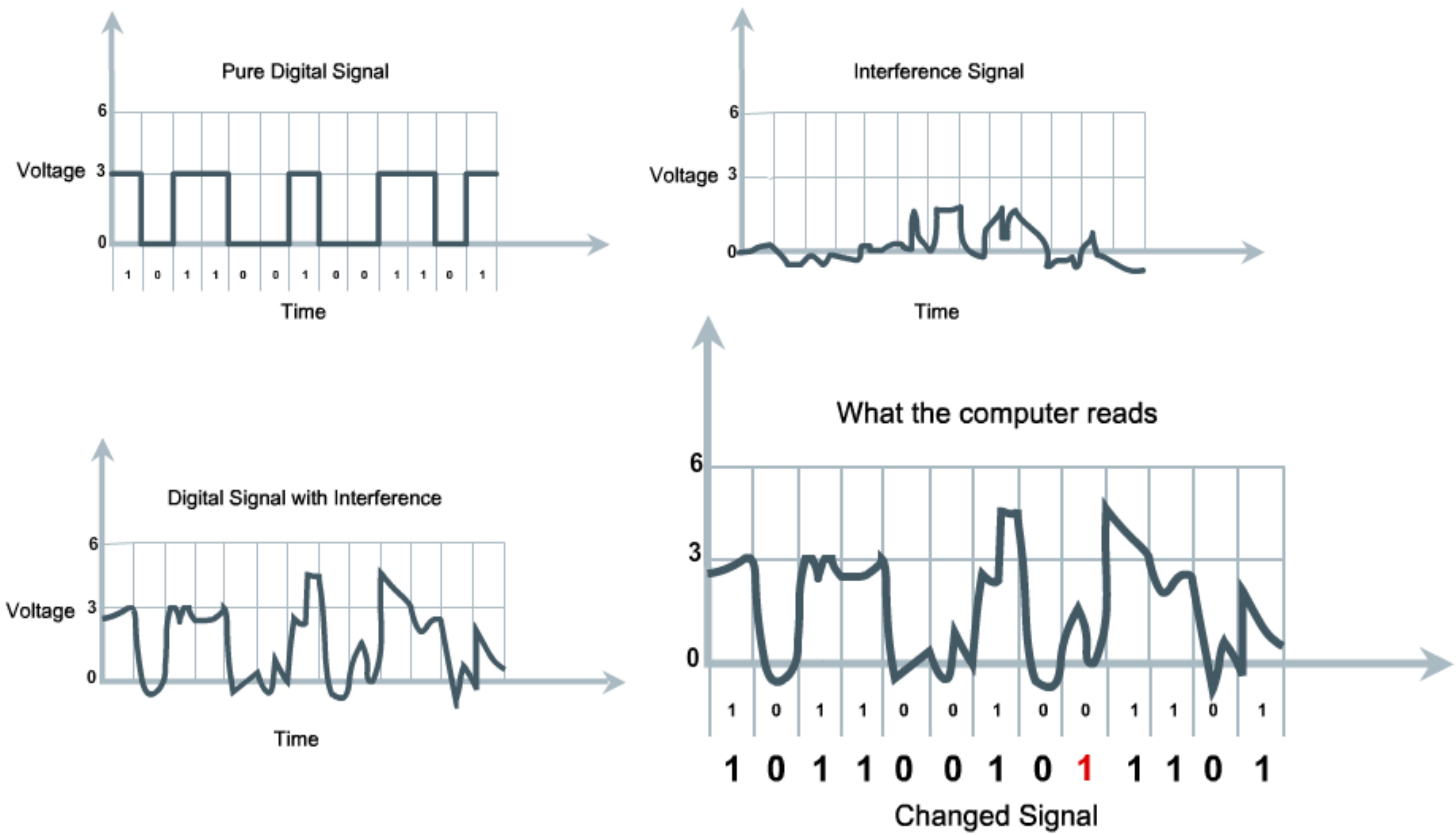
RJ-45 connections

Copper Media - interference

- Shielding and twisting of wire pairs are designed to minimize signal degradation due to noise.



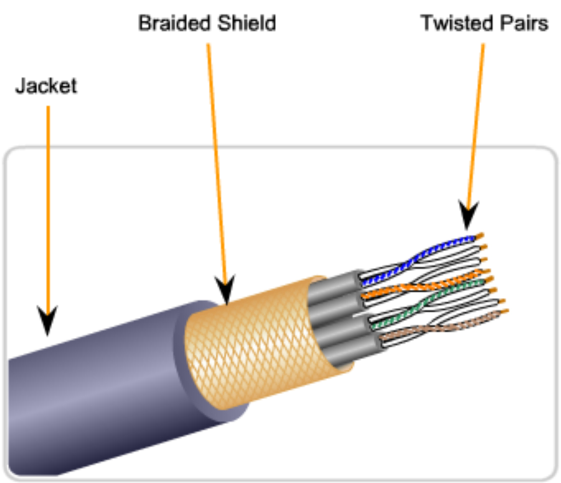
Copper Media - interference



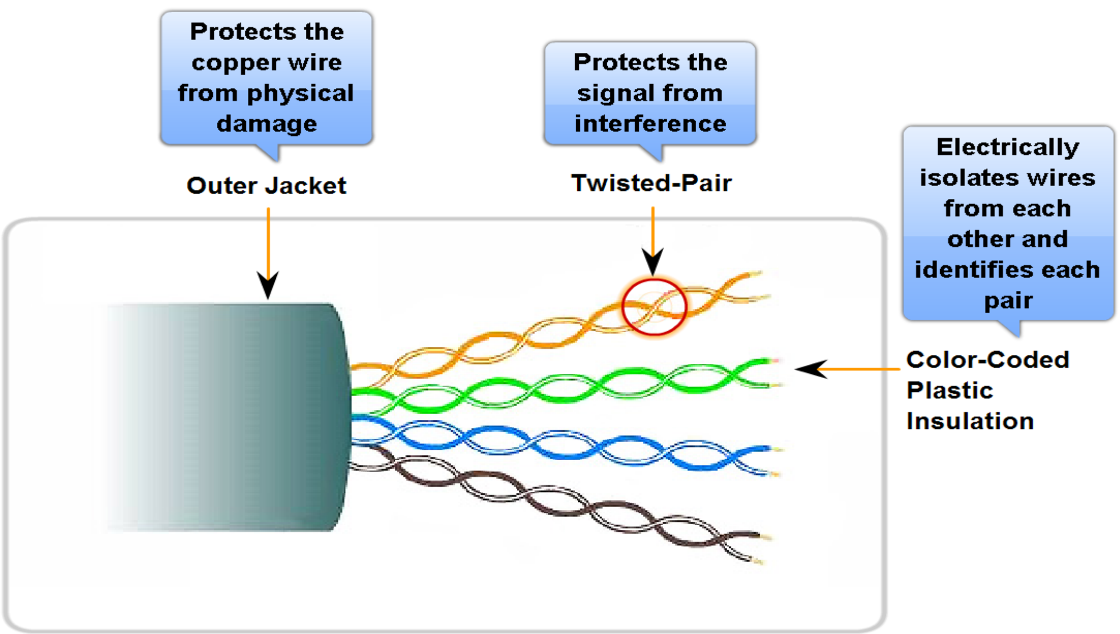
Twisted Pair Cable (UTP & STP)

- Crosstalk – interference caused by the magnetic field around adjacent pairs of wire within the cable.
- Cancellation – maintaining twists cancels out the effects of the crosstalk between the 2 twisted wires and between wire pairs.

Shielded Twisted-Pair (STP) Cable



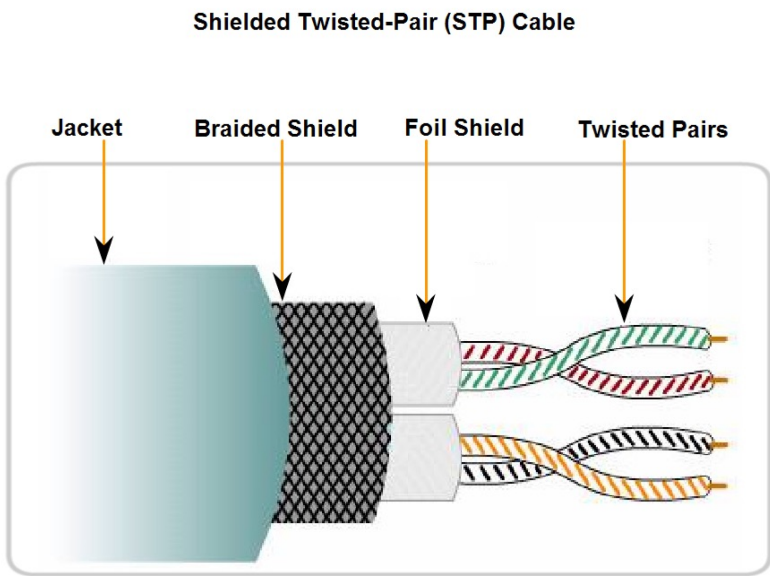
Unshielded Twisted-Pair (UTP) Cable



Shielded Twisted-Pair (STP) cable

- Uses 4 wire-pairs wrapped in a metallic braid or foil
- Shields all the wires as a bundle and each independently.
- Better noise protection than UTP, but more expensive.
- Used in Token-ring networks, demand is not there anymore.

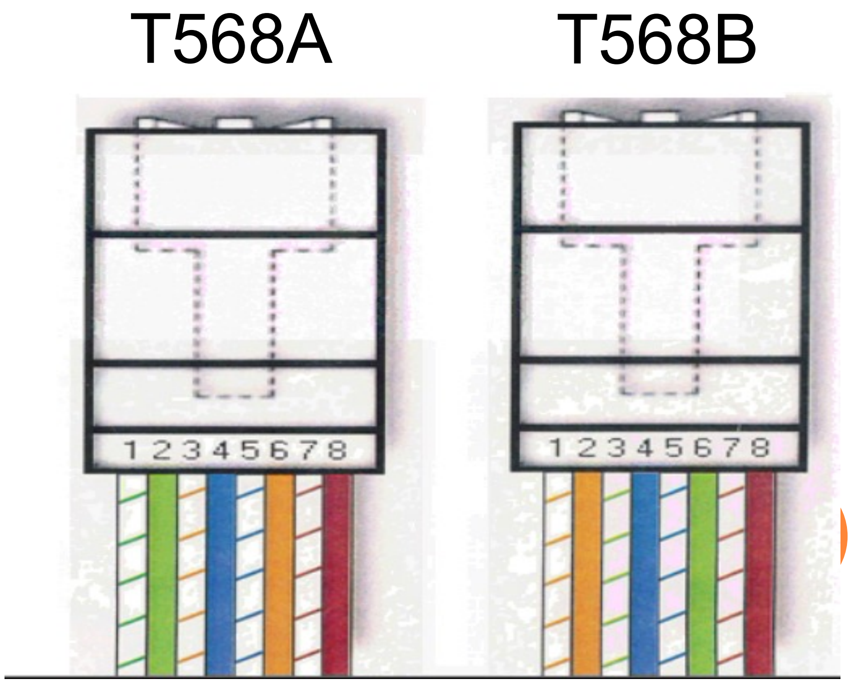
10GB Ethernet has a provision for STP which may provide for renewed interest in STP



Characteristics & Uses of Network Media

Ethernet Cable Standards

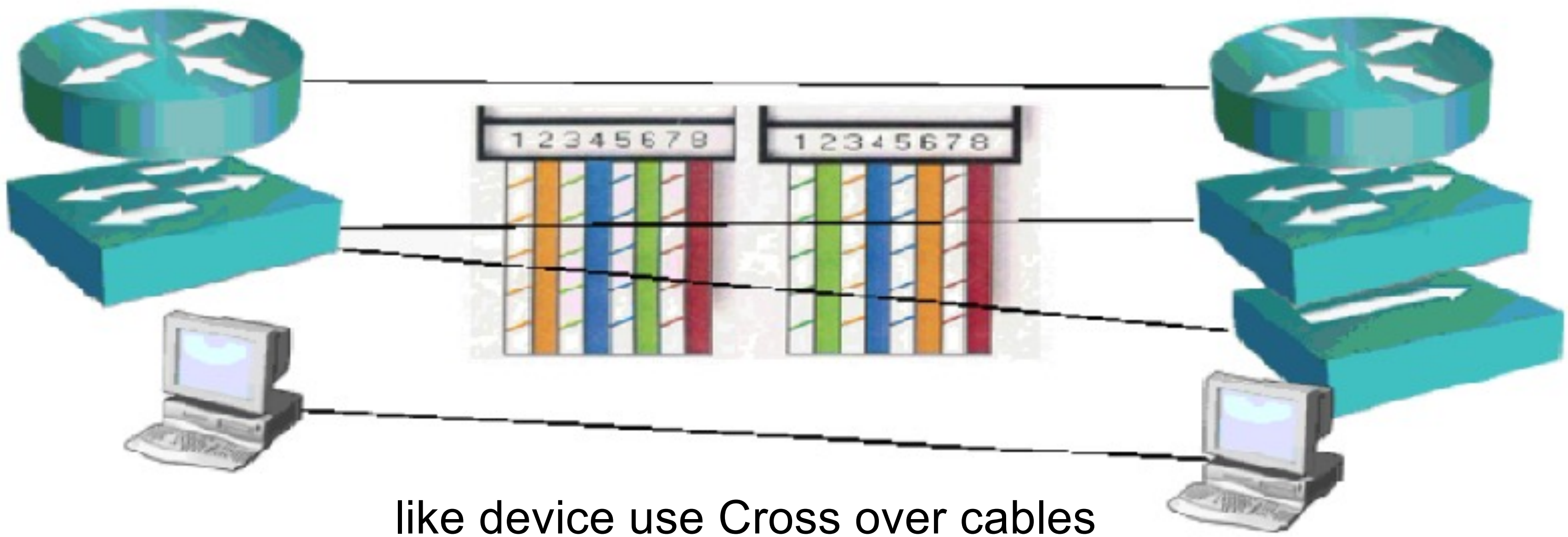
- Because of the way cable twist, end should follow standards
- T568A + T568A = Straight Through
- T568B + T568B = Straight Through
- T568A + T568B = Cross over



Characteristics & Uses of Network Media

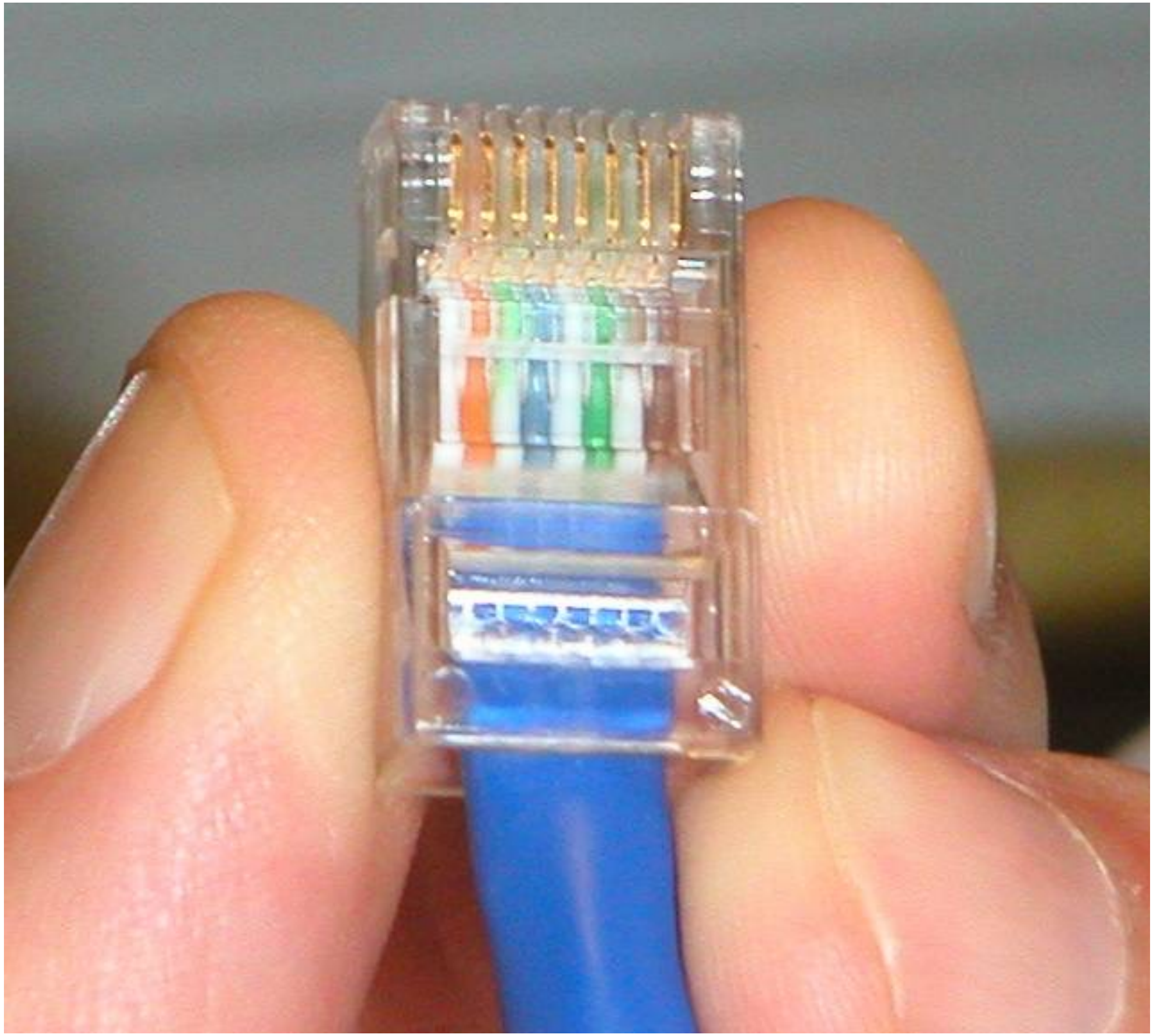
Ethernet Connection Rules

Unlike device use Straight through cables



like device use Cross over cables

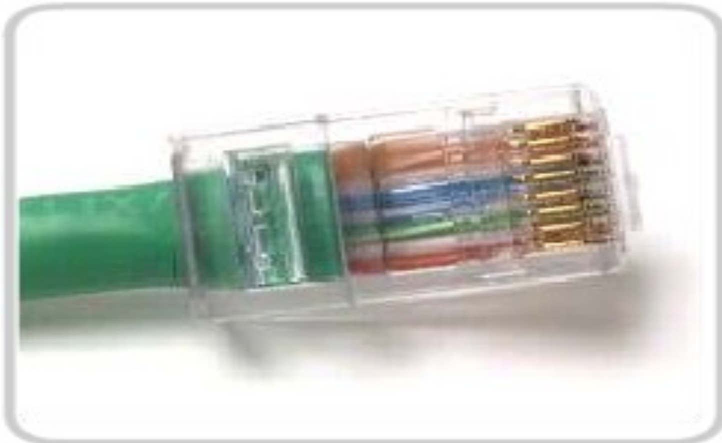
CORRECTLY TERMINATED RJ-45 CONNECTOR



PROPER VS. IMPROPER CONNECTION

Copper Media Connectors
RJ-45 Termination

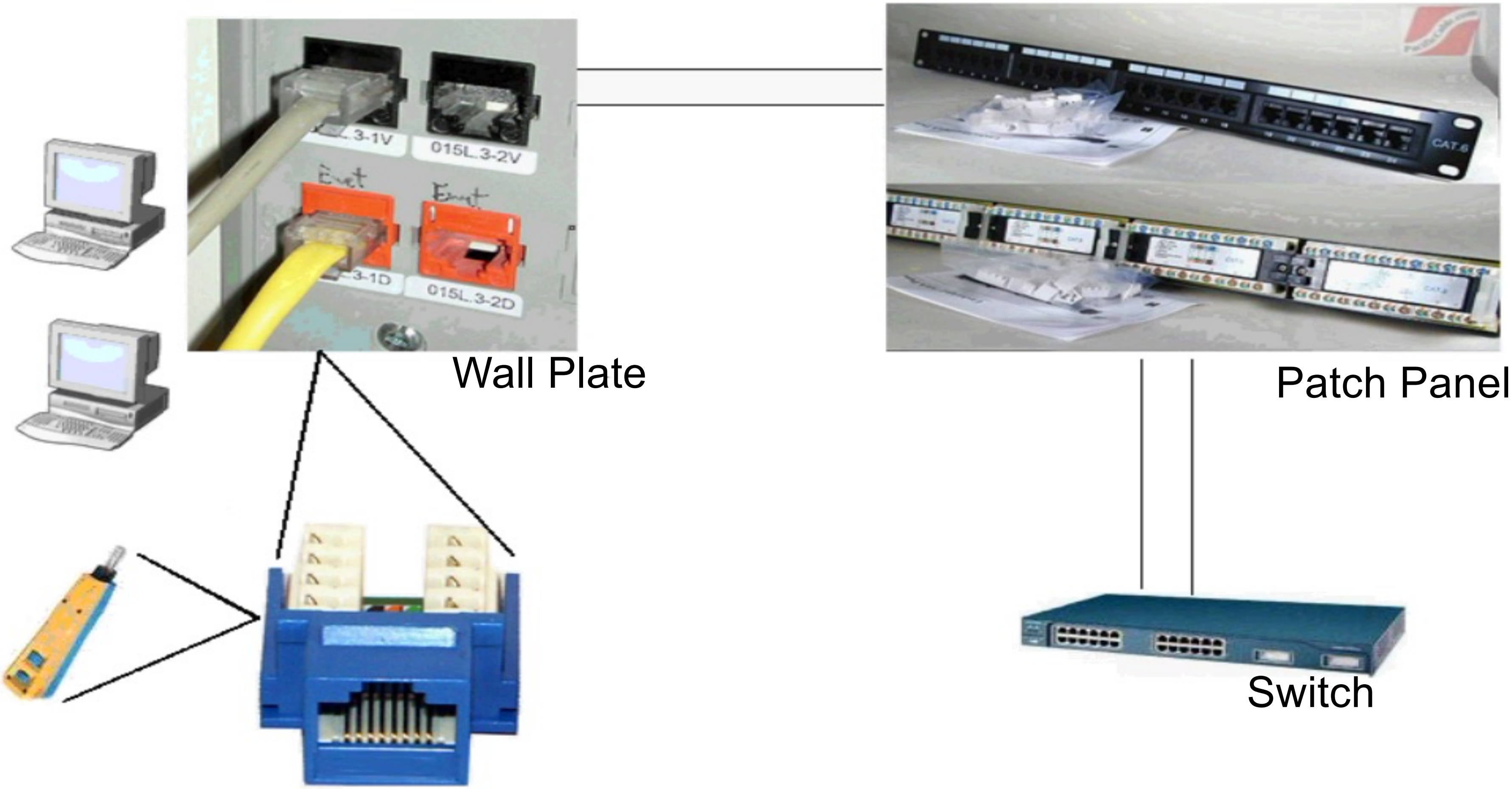
Bad connector - Wires are untwisted for too great a length.



Good connector - Wires are untwisted to the extent necessary to attach the connector.

Characteristics & Uses of Network Media

How cabling look in real World



CHARACTERISTICS & USES OF NETWORK MEDIA

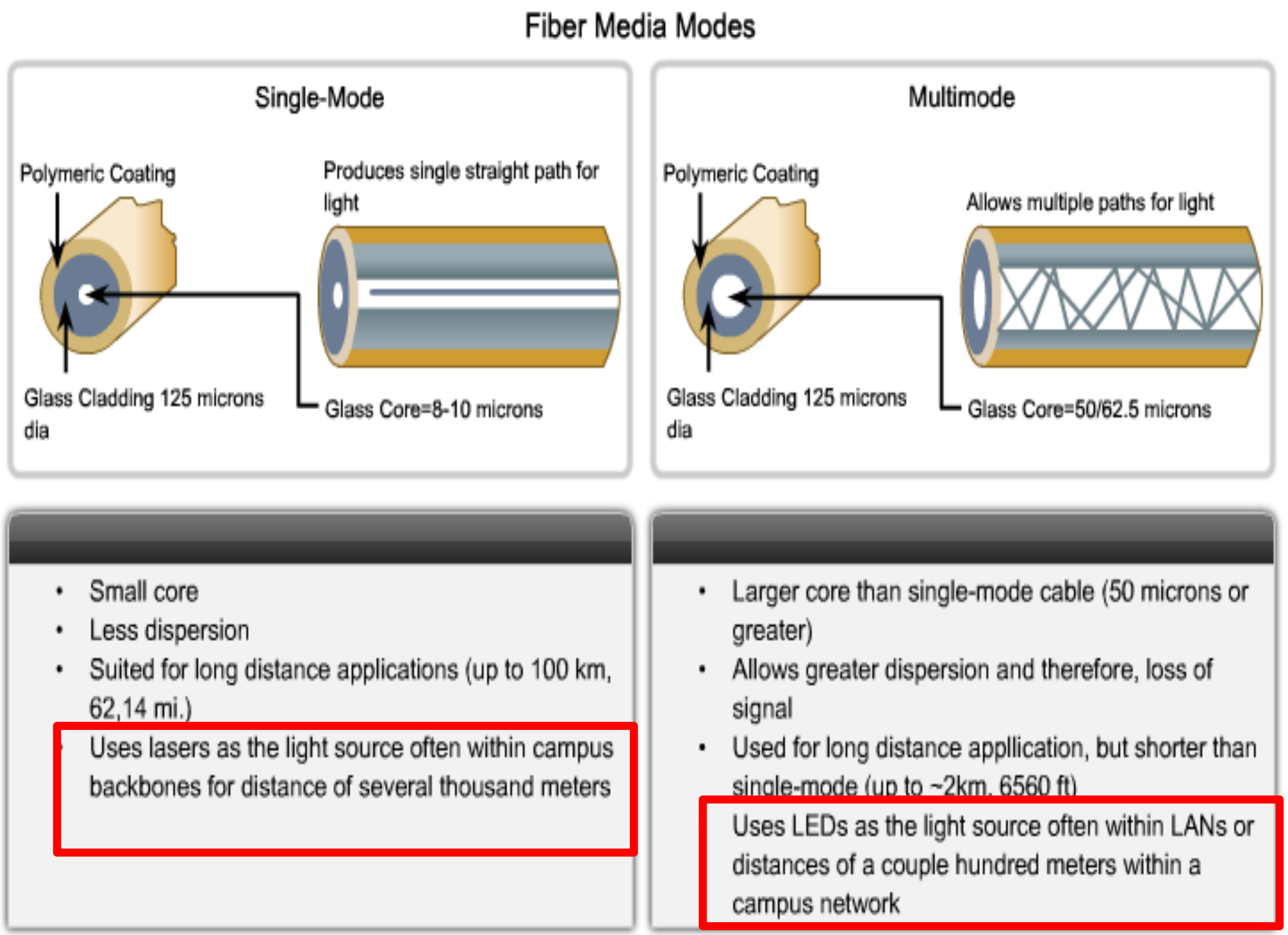
Category 5e unshielded swished pair (UTP)
Maximum distance :100m
Connection type: RJ 45

Multi Mode Fiber
Maximum distance :~2Km
Connection type: varies

Single Mode Fiber
Maximum distance :~100Km
Connection type: varies

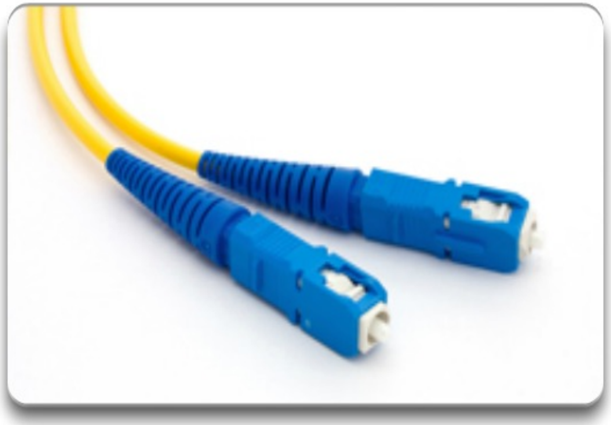
Fiber

- Main advantage – NO EMI or RFI. Use primarily for BACKBONE cabling.
- Disadvantage – Most expensive



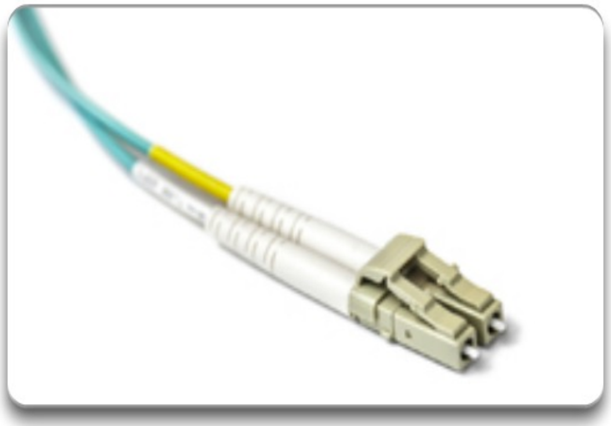
Network Fiber Connectors

ST Connectors



SC Connectors

LC Connector



Duplex Multimode LC Connectors

TESTING FIBER CABLES

Optical Time Domain Reflectometer (OTDR)

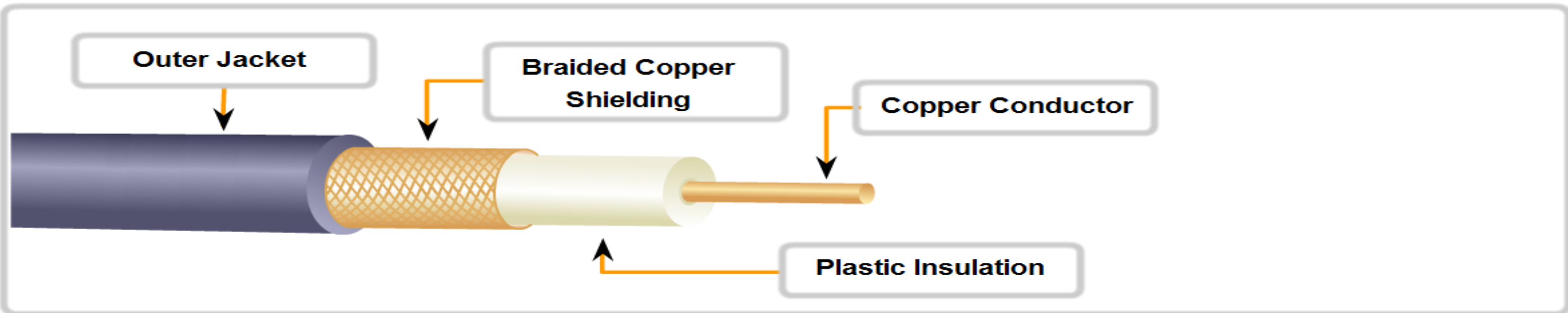
Fiber versus Copper

Implementation issues	Copper media	Fibre-optic
Bandwidth supported	10 Mbps – 10 Gbps	10 Mbps – 100 Gbps
Distance	Relatively short (1 – 100 meters)	Relatively High (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

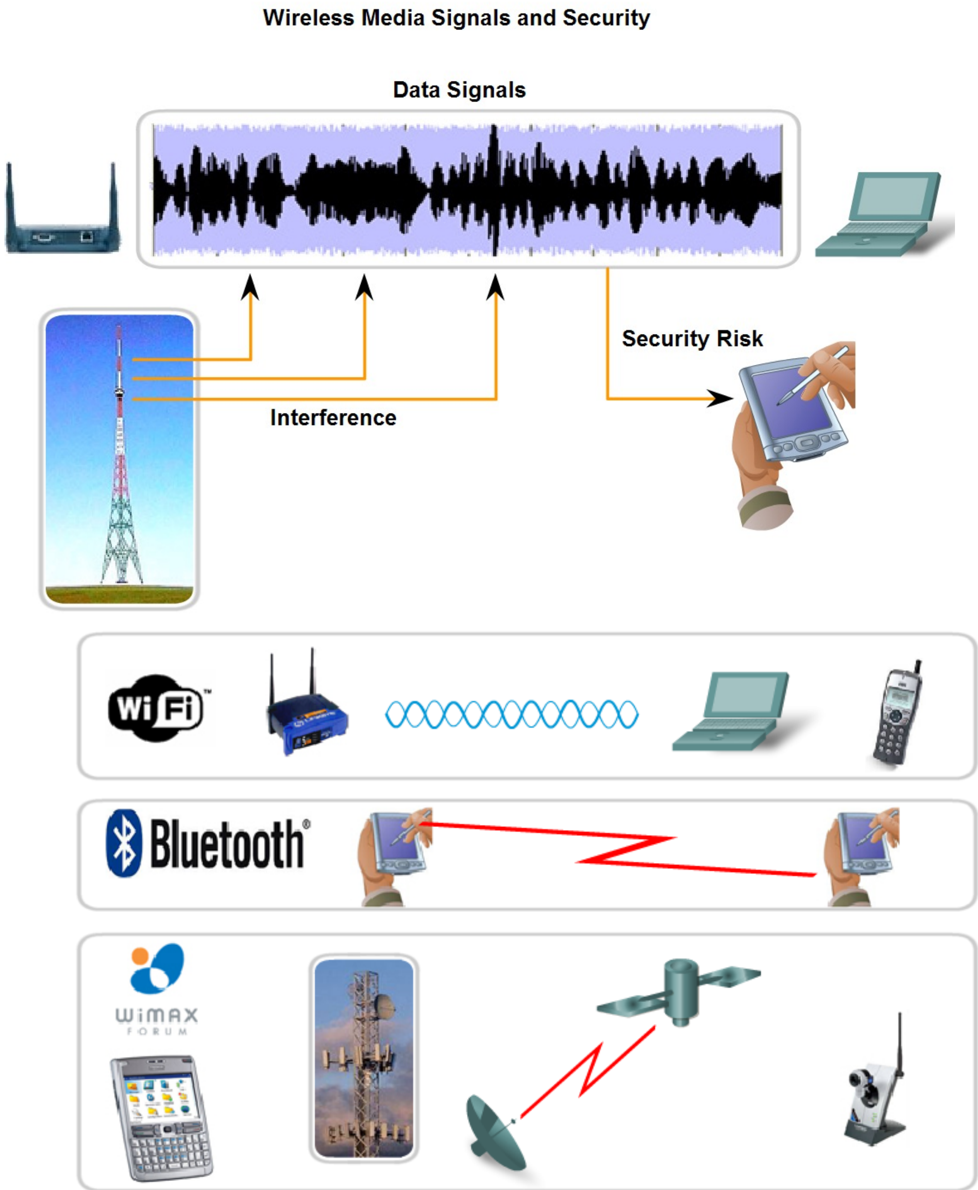
Characteristics & Uses of Network Media

- Coaxial – copper surrounded by flexible insulation. Woven copper braid or metallic foil acts as a second wire and as a shield for the inner conductor. Used in cable and wireless technologies. Can carry RF energy.

Coaxial Cable Design



Wireless Media



- Uses radio waves to carry signals. Gives you **mobility** (convenience)
- Interference from cordless phones, some fluorescent lights, microwaves, other wireless devices.
- Network security is a big issue!

Types of Wireless Media

Wi Fi	• IEEE 802.11 standards
	• Commonly referred to as Wi-Fi.
	• Uses CSMA/CA
	• Variations include:
	  • 802.11a: 54 Mbps, 5 GHz
	  • 802.11b: 11 Mbps, 2.4 GHz
	  • 802.11g: 54 Mbps, 2.4 GHz
	  • 802.11n: 600 Mbps, 2.4 and 5 GHz
	  • 802.11ac: 1 Gbps, 5 GHz
	  • 802.11ad: 7 Gbps, 2.4 GHz, 5 GHz, and 60 GHz

Bluetooth®	• IEEE 802.15 standard • Supports speeds up to 3 Mbps • Provides device pairing over distances from 1 to 100 meters.
Wi MAX	• IEEE 802.16 standard • Provides speeds up to 1 Gbps • Uses a point-to-multipoint topology to provide wireless broadband access.