COMPUTER NETWORKS

Chapter 2. The Physical Layer

Part 1

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Contents

The physical layer

- defines the mechanical, electrical, and timing interfaces to the network, provides the means to transmit bits from sender to receiver, that is, involves a lot on how to use (analog) signals for digital information.

Theoretical Basis

- Information can be transmitted on wires by varying some physical property such as voltage or current. By representing the value of this voltage or current as a single-valued function of time, f(t), we can model the behavior of the signal and analyze it mathematically. This analysis is the subject of the following sections.

Fourier Series

- Any reasonably behaved periodic function, $g(t)$, with period T can be constructed by summing a (possibly infinite) number of sines and cosines:

$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft)$$

where $f=1/T$ is the fundamental frequency and a_n and b_n are the sine and cosine amplitudes of the nth harmonics (terms).

Fourier Series

$$\int_0^T \sin(2\pi k f t)\,\sin(2\pi n f t)\,dt = \begin{cases} 0 \text{ for } k \neq n \\ T/2 \text{ for } k = n \end{cases}$$

$$a_n = \frac{2}{T}\int_0^T g(t)\sin(2\pi n f t)\,dt$$

$$b_n = \frac{2}{T}\int_0^T g(t)\cos(2\pi n f t)\,dt \qquad c = \frac{2}{T}\int_0^T g(t)\,dt$$

An example

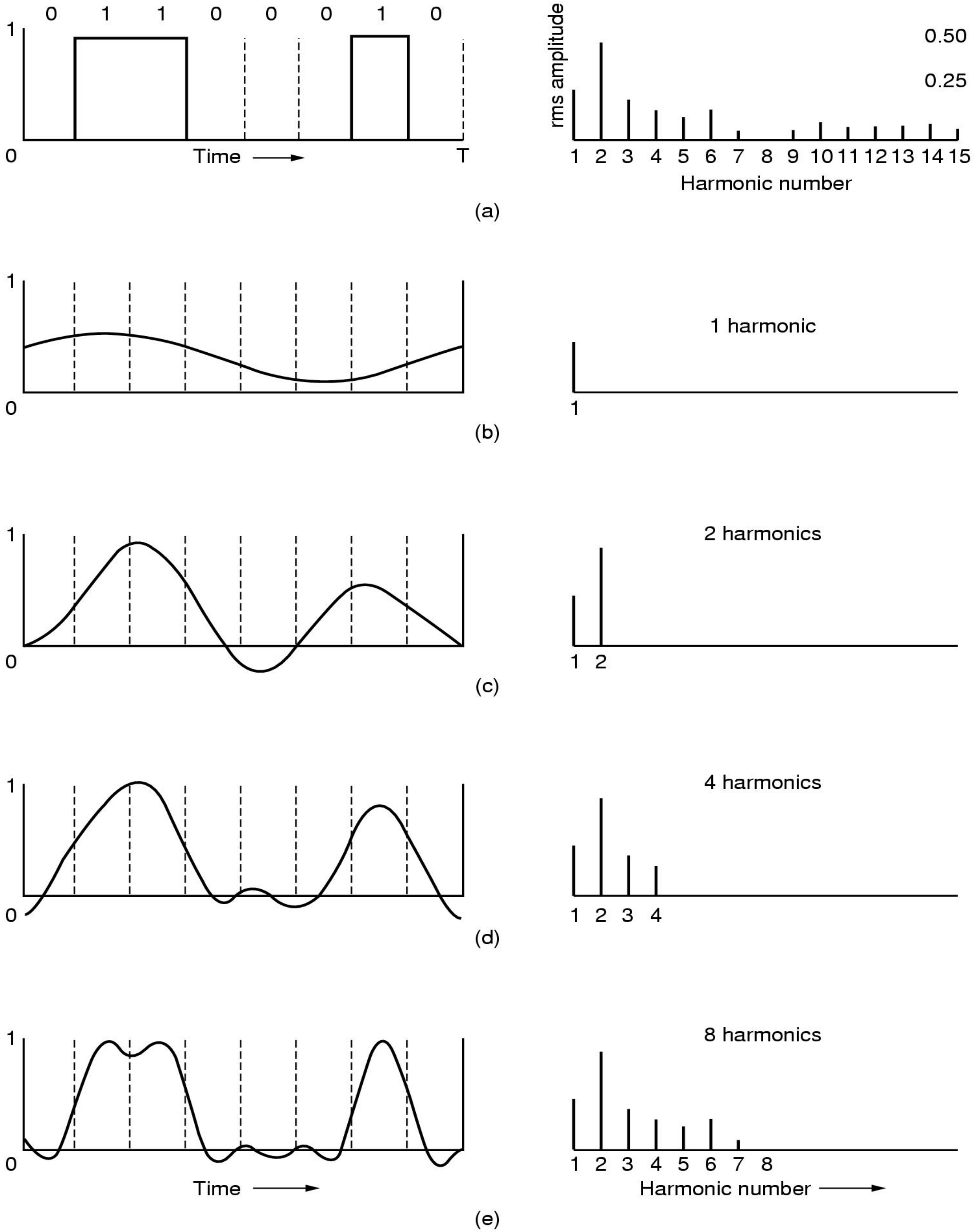
- Consider 01100010, 8 bit for ASCII character 'b':

$$a_n = 1/\pi n[\cos(\pi n/4) - \cos(3\pi n/4) + \cos(6\pi n/4) - \cos(7\pi n/4)]$$

$$b_n = 1/\pi n[\sin(3\pi n/4) - \sin(\pi n/4) + \sin(7\pi n/4) - \sin(6\pi n/4)]$$

$$c_n = 3/4$$

The root mean square amplitudes is $\sqrt{a_n^2 + b_n^2}$



Note: root mean squares (on the right) reflect the dispersed energy at the given frequency.

Bandwidth

- Digital signal transmission is subject to attenuation, distortion, etc. This is partly caused by disallowing high-frequency components to pass through.
- The range of frequency or the number of bits of a transmission medium is called **bandwidth**.

Bandwidth-Limited Signals

- The larger n is, the higher the frequency nf of the nth harmonic.
- All transmission facilities diminish different Fourier components by different amounts, thus introducing distortion.
- Usually, the amplitudes are transmitted undiminished from 0 up to some frequency f_c (in Hertz, Hz) with all frequencies above this cutoff frequency截止频率 strongly attenuated.

Bandwidth

- Hz
- bps
- ?

Bit Rate vs. Harmonics

- Given a bit rate of b bits/sec, the time T required to send 8 bits (for example) is $8/b$ sec, so the frequency f of the first (i.e., n=1) harmonic is $b/8$ Hz.

Bit Rate vs. Harmonics (cont.)

N	Frequency (Hz)
1	$b/8$
2	$2b/8$
:	:
n	$nb/8$

$nb/8 \leq f_c$

$\Rightarrow n \leq f_c/\ (b/8)$

- The number of the highest harmonic passed through is $f_c/(b/8)$ or $8f_c/b$, roughly. That is, the 1st, 2nd, 3rd, ..., and $(8f_c/b)$-th harmonics could pass through without diminution.

Telephone Line with f_c=3000 Hz

Bit Rate (bps)	T (msec)	First Harmonic (Hz)	# Harmonics sent
600	13.33	75	40
1200	6.67	150	20
2400	3.33	300	10
4800	1.67	600	5
9600	0.83	1200	2
19200	0.42	2400	1
38400	0.21	4800	0

Signal-to-Noise Ratio

- S/N
  - S: signal power
  - N: noise power
- dB
  - $10 \log_{10} S/N$
  - an S/N ratio of 1000 is 30 dB

Max. Data Rate of a Channel

- Nyquist's Theorem (noiseless channel)
  - H: bandwidth
  - V: discrete levels
  - Maximum data rate: $2H \log_2 V$ bits/sec
- Shannon's Theorem (noise channel)
  - H: bandwidth
  - S/N: signal to noise ratio
  - Maximum number of bits/sec: $H \log_2 (1 + S/N)$

Exercise

- Suppose that the bandwidth of a channel is between 3MHz and 4MHz and SN = 24dB.
  - (1) what is the capacity of this channel?
  - (2) Being able to achieve capacity, how many signaling levels are required?

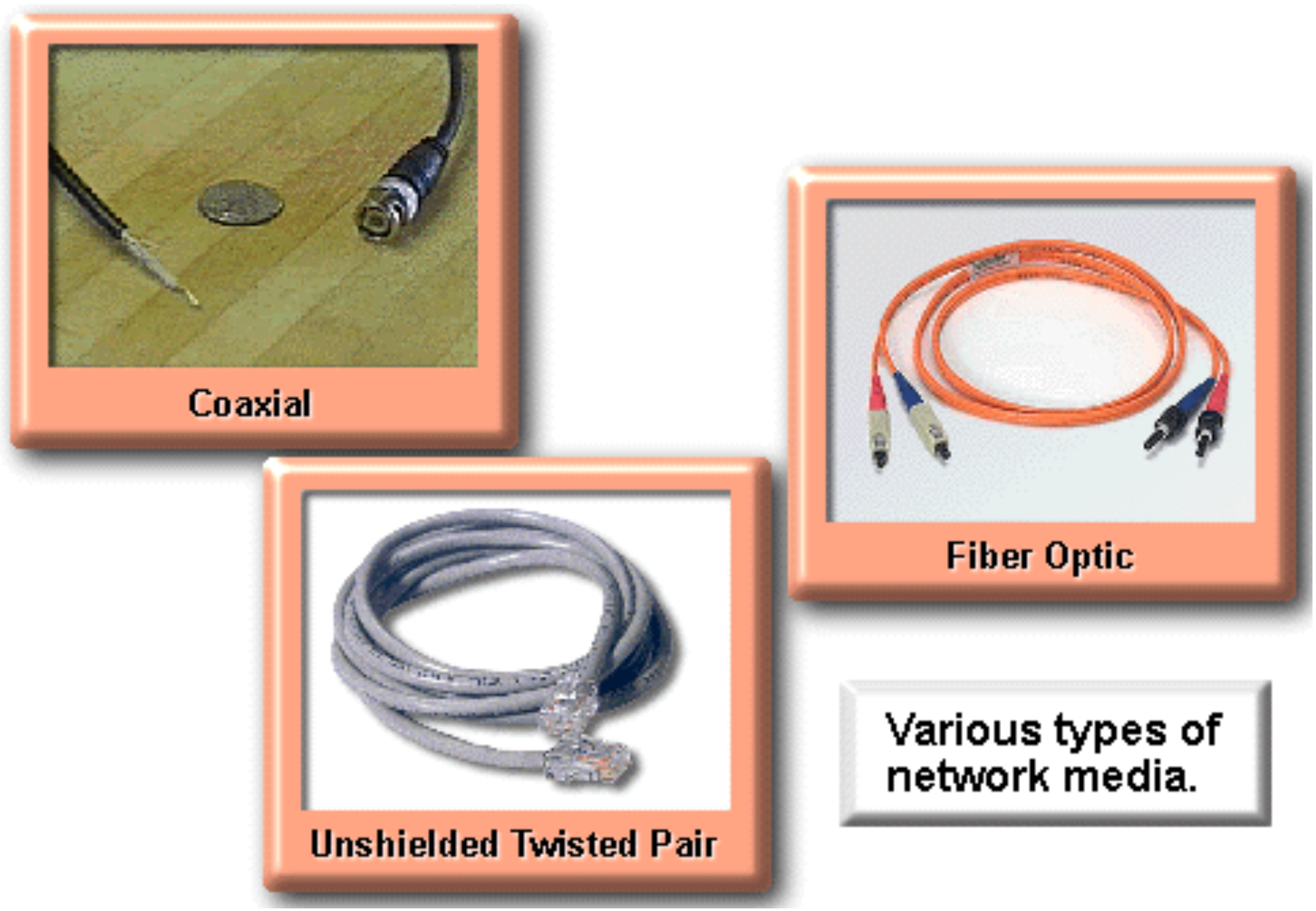
Exercise solution

- Suppose that the bandwidth of a channel is between 3MHz and 4MHz and SN = 24dB.
  - (1) what is the maximum data rate?
    - H = 1MHz
    - S/N = 251
    - $C = 10^6 \mathrm{x} \log_2(1+251) = 8\mathrm{Mbps}$
  - (2) Being able to achieve capacity, how many signaling levels are required?
    - $C = 2H \log_2 V$
    - $V = 16$

Guided Transmission Media

- Magnetic media
- Twisted pair
- Coaxial cable
- Fiber optics

Various Types of Network Media



Magnetic media

- *Never underestimate the bandwidth of a station wagon full of* tapes *hurtling down the highway*
  - Take a standard videotape that can carry about 200 gigabytes of data.
  - A box of 60 x 60 x 60 cm can hold about 1000 tapes, which corresponds to 200TB, or 1600Tb.
  - Sending such a box can be done within 24 hours, worldwide, 19Gbps; or 400Gbps within one hour.
  - Costs: roughly $5000 to ship 200TB, 3 cents for 1GB
- **So, why not just tape?**

Twisted pair

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

10Base-T: 10Mbps, 100 meters

100Base-T: 100Mbps, 100 meters

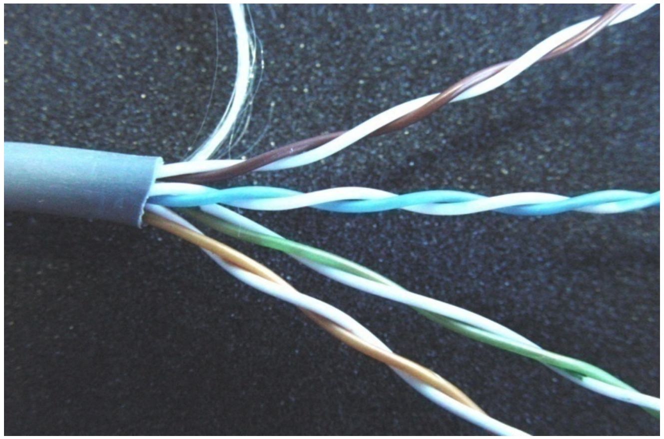
1000Base-T: 1Gbps, 100 meters

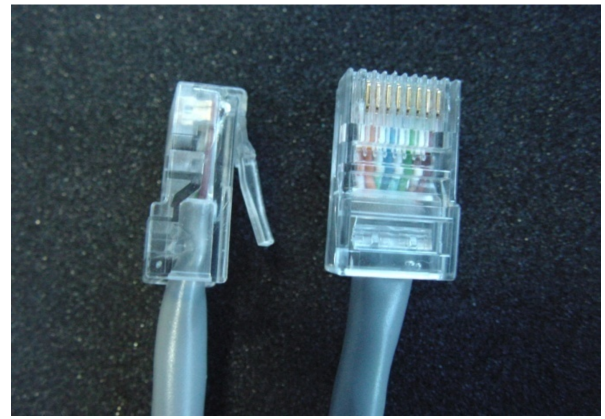
Category 3: not to use anymore

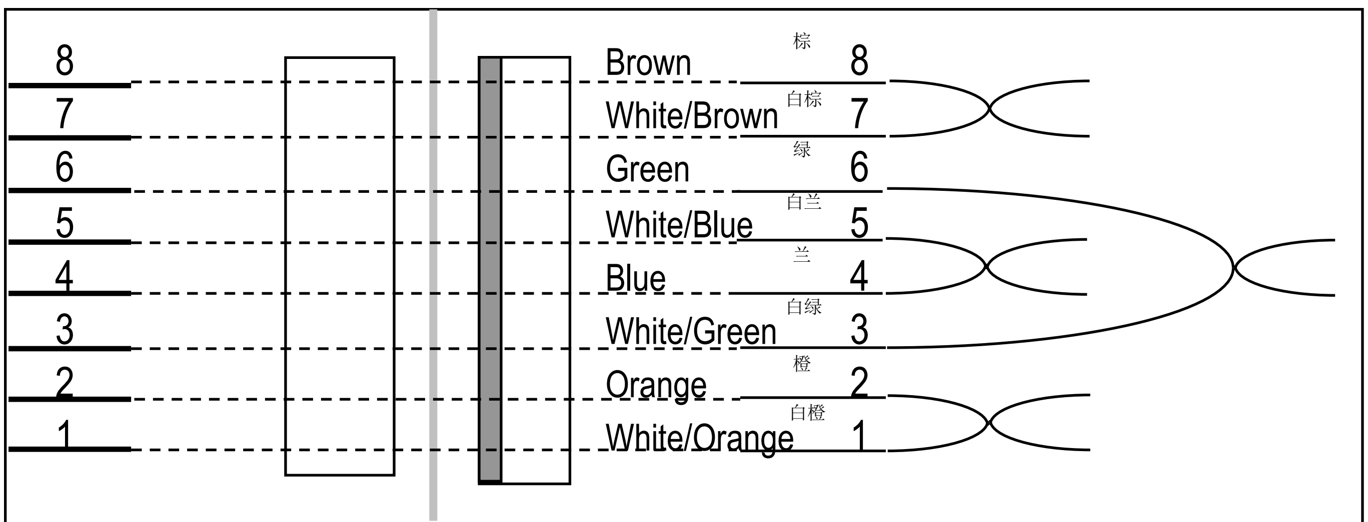
Category 5/Super Category 5

Category 6/7: for Gigabit transmission

Twisted pair (cont.)



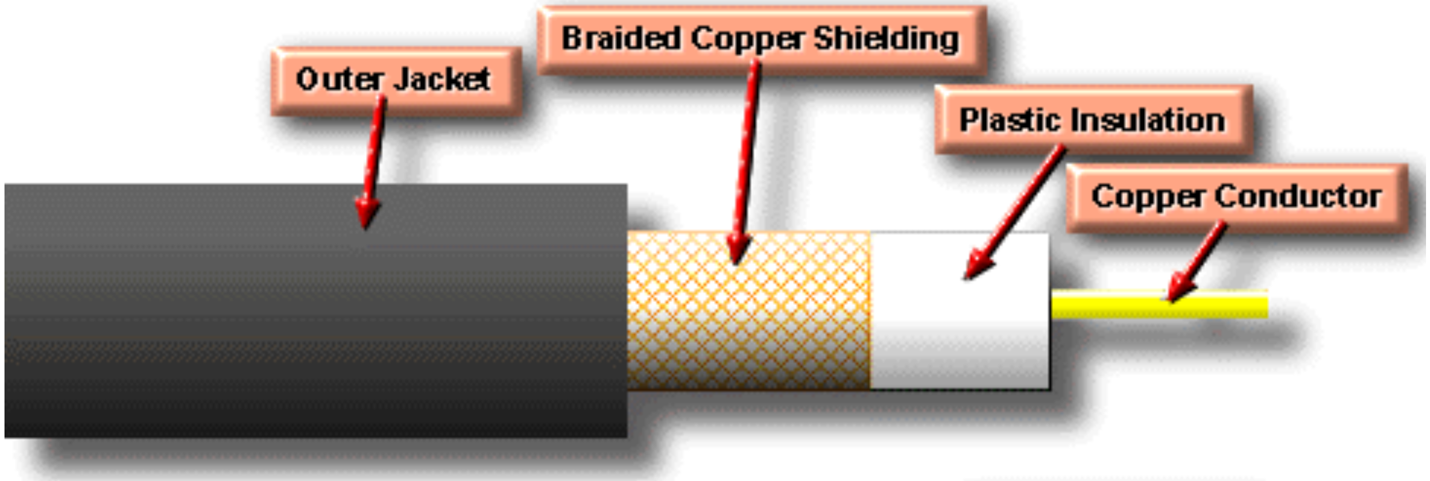




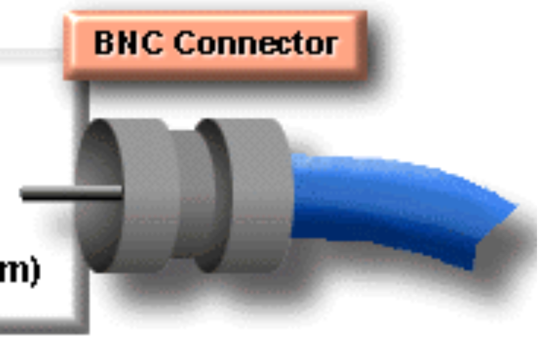
UTP in actions

- Telephone line serve 3KM-5KM
  - One pair only
- Data Cable serve 100M, Four pairs
  - Category 3 : 16MHz
  - Category 5 : 100MHz
  - Category 6 : 250MHz
  - Category 7 : 600MHz
- Data rate: 10Mbps, 100Mbps, 1000Mbps

Coaxial cable (50/75ohm:1GHz)

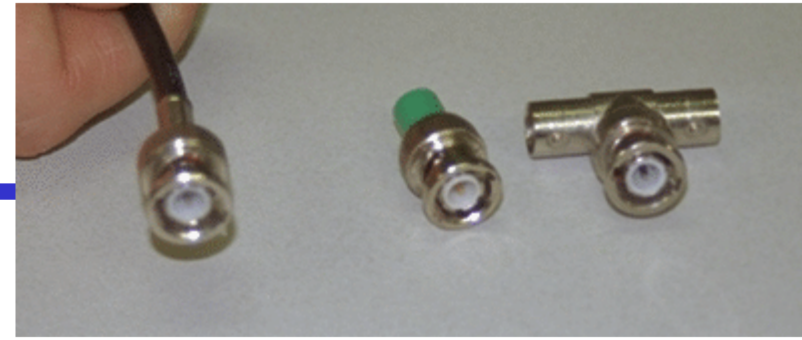


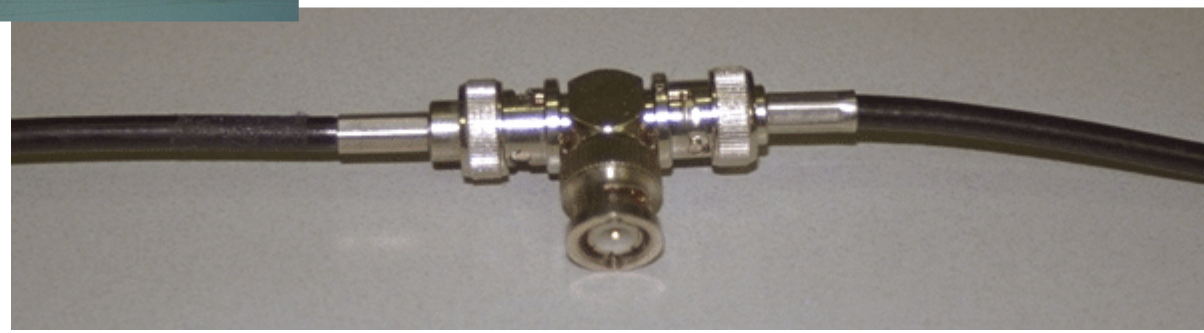
Speed and thoughput:	10 - 100Mbps
Average $ per node:	Inexpensive
Media and connector size:	Medium
Maximum cable length:	500 m (medium)



Coaxial cable consists of a hollow outer cylindrical conductor that surrounds a single inner wire made of two conducting elements.
It can be run, without as many boosts from repeaters, for longer distances between network nodes than either shielded or unshielded twisted-pair cable


2002 9 10






D-Link
Ethernet Transceiver
DE-850 Piercing Tap
2002 9 10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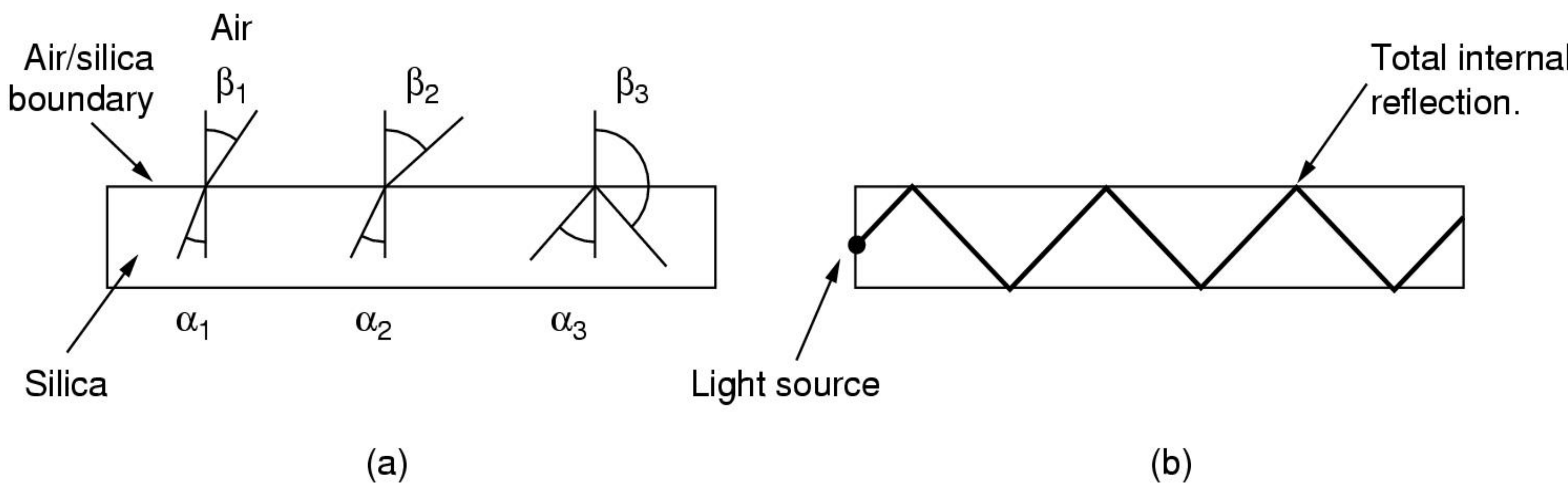
UTP vs. STP and COAX

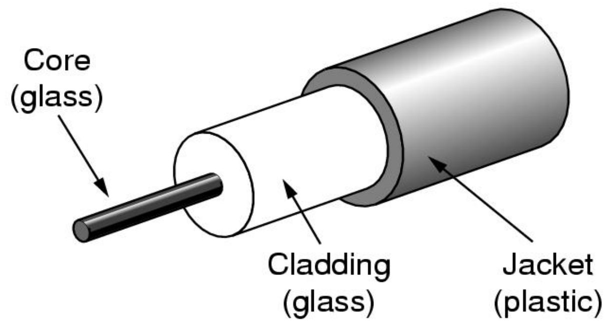
- **advantages.**
  - **It is easy to install**
  - **is less expensive**
  - **its real advantage is its size.**
- **disadvantages**
  - **is more prone to electrical noise and interference**
  - **once considered slower at transmitting data than other types of cable.**
  - **today, UTP is considered the fastest copper-based media.**
  - **The distance between signal boosts is shorter for unshielded twisted-pair than it is for coaxial cable.**

Fiber optics

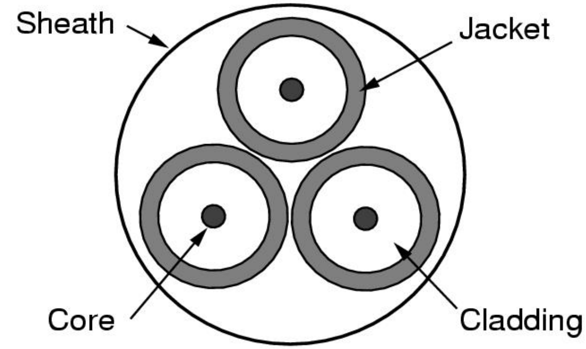
- **B**ased on light refraction:
  - Three examples of a light ray from inside a silica fiber impinging on the air/silica boundary at different angles.
  - Light trapped by total internal reflection.



As it turns out, attenuation is extremely well in optical fiber. This means that they can be used for long distances. In addition, the bandwidth is enormous.



(a)

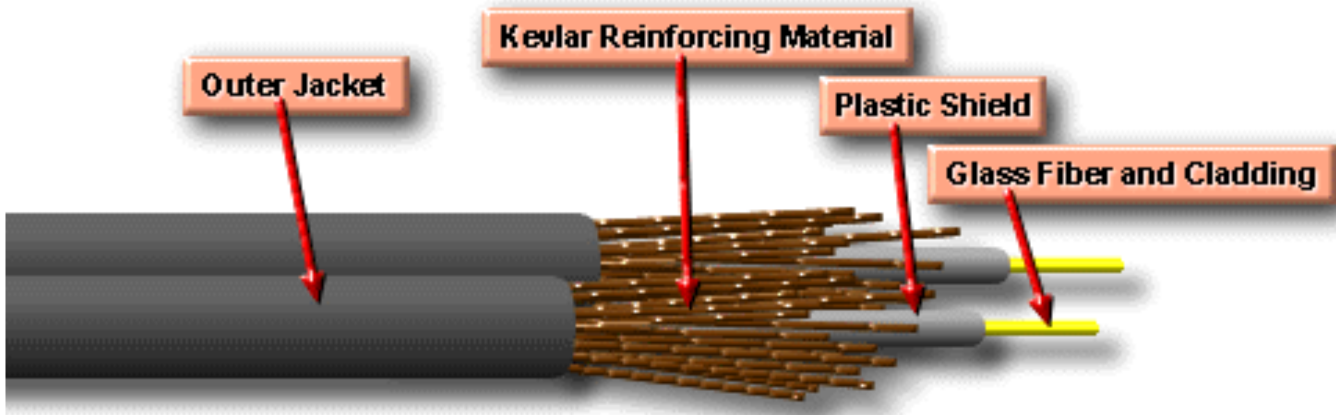


(b)

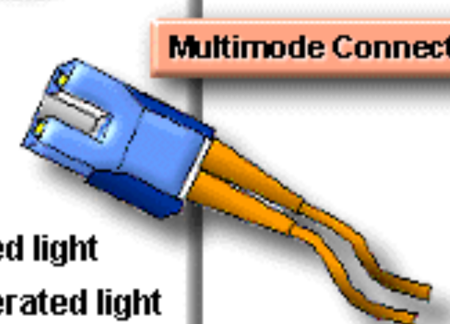
Item	LED	Semiconductor Laser
Data rate	Low	High
Mode	Multimode	Multimode or single mode
Distance	Short	Long
Lifetime	Long life	Short life
Temperature sensitivity	Minor	Substantial
Cost	Low cost	Expensive

Fiber optics

MM: multi-mode
SM: single-mode



Speed and throughput:	100+ Mbps
Average $ per node:	Most Expensive
Media and connector size:	Small
Maximum cable length:	up to 2 Km
Single mode:	One stream of laser-generated light
Multimode:	Multiple streams of LED-generated light



LED-Light Emitting Diode
Semiconductor Laser

Fiber-optic cable is a networking medium capable of conducting modulated light transmissions. It is not susceptible to electromagnetic interference and is capable of higher data rates than any of the other types of networking media discussed here. Fiber-optic cable does not carry electrical impulses, signals that represent bits, are converted into beams of light. light in fibers is not considered wireless because the electromagnetic waves are guided in the optical fiber.

Attenuation in decibels

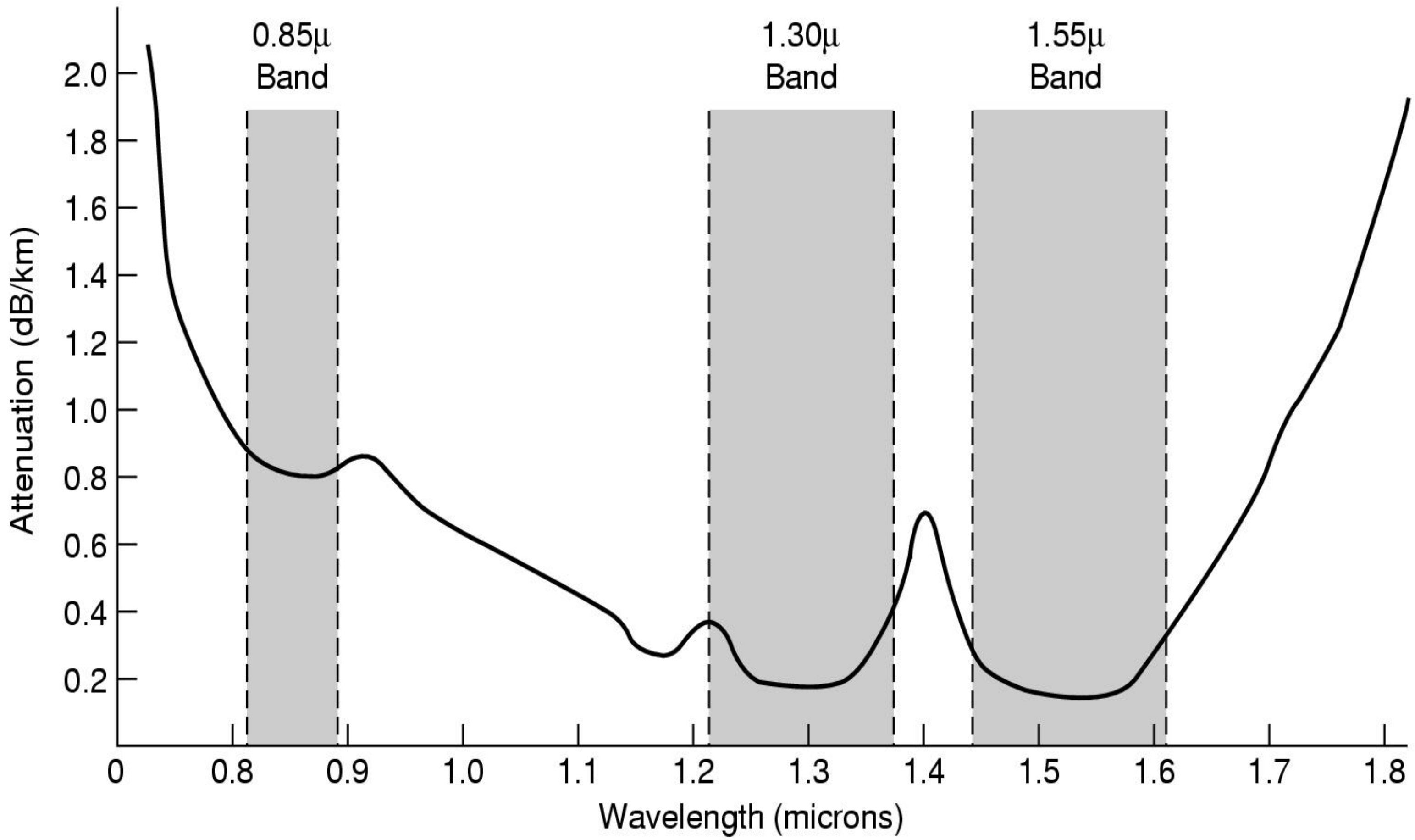
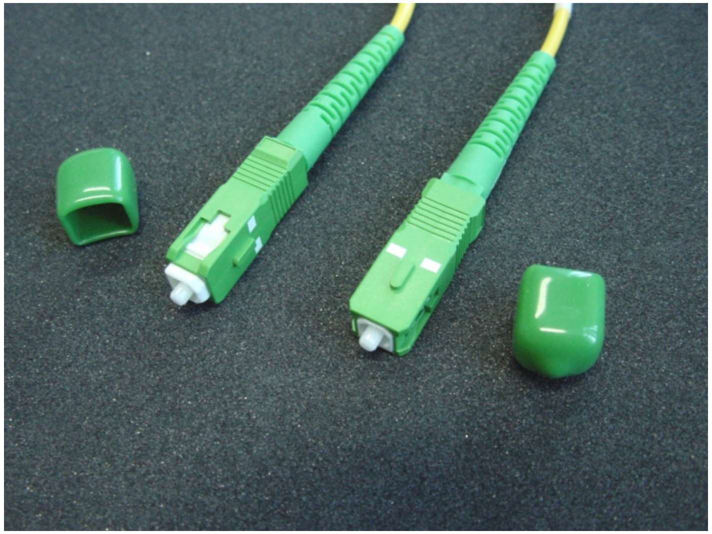


Fig. 2-6 Attenuation of light through fiber in the infrared region.

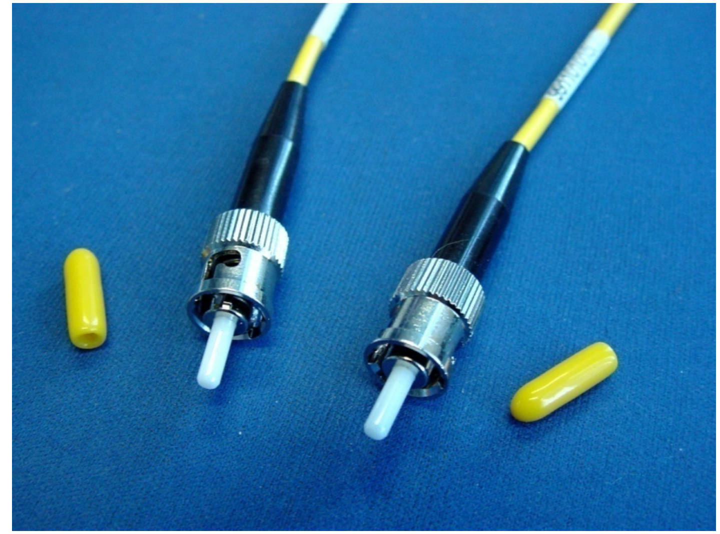
Fiber Connections

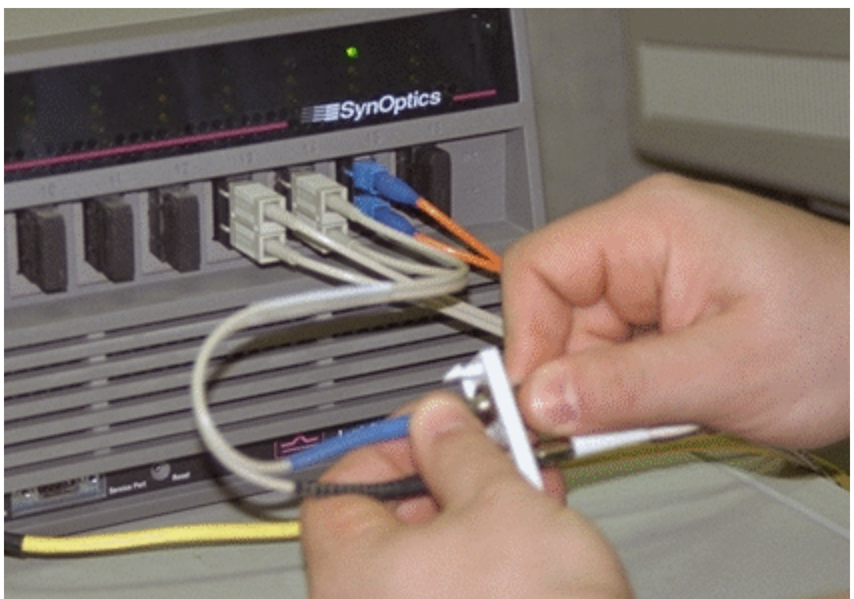
- **Observation:** An interface consists of a receiver (photodiode) which transforms light into electrical signals, and/or a transmitter (LED or laser-diode)
- **Passive interface:** A computer is directly connected to the optical fiber
- **Active interface:** There’ s an ordinary electrical repeater connected to two fiber segments and the computer:

SC：568A标准，方形，插入锁定



ST：插入锁定





光耦合器（ST）

Optical Fiber vs. Copper Wire (1)

- **Bandwidth:** Fiber can support enormous bandwidths, exactly what we need with upcoming image-based applications (video-on-demand).
- **Attenuation:** Because the attenuation in fiber is less than in copper (can you imagine why?), we don’t need to boost the signal as often. In practice, fiber requires an *active repeater* every 30 km, copper every 5 km.

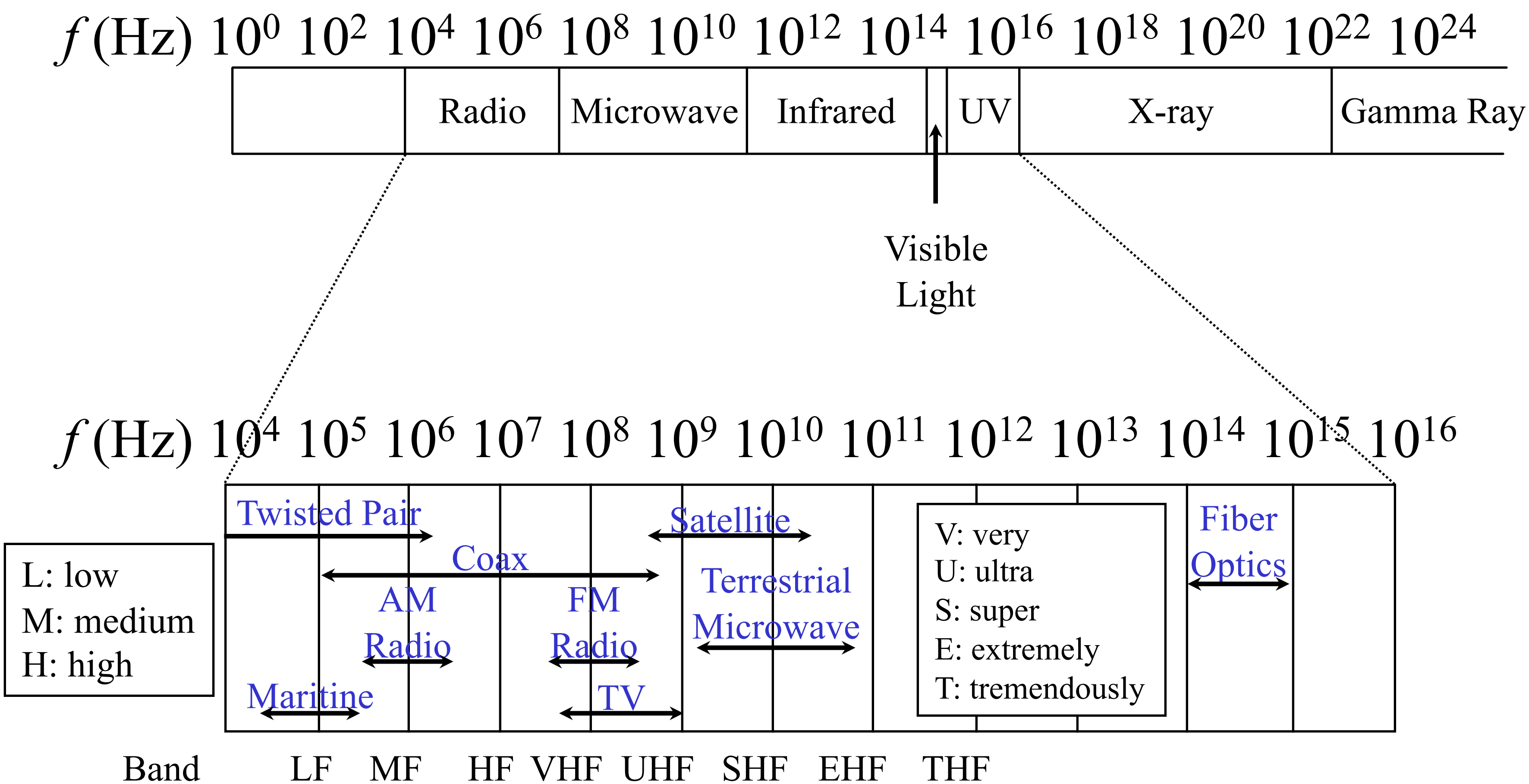
Optical Fiber vs. Copper Wire (2)

- **External influences:** That' s right, no more interference from other cables, radios, power failures, etc.
- **Weight:** Fiber simply doesn' t weigh as much. Good for backbones, and the use of heavy maintenance equipment.

Wireless Transmission

- The Electromagnetic Spectrum
- Radio Transmission
- Microwave Transmission
- Infrared and Millimeter Waves
- Lightwave Transmission

The Electromagnetic Spectrum



Wave Properties

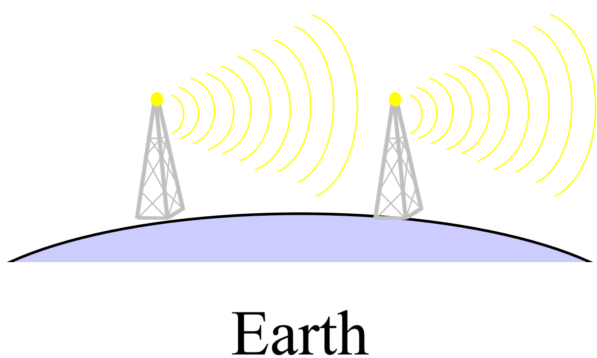
- Radio, Microwaves, Infrared, and Visible Light
  - can all be used for transmitting information
  - AM, FM, or PM
- UV, X-rays, and Gamma Rays
  - would be even better due to their higher frequencies
  - hard to produce and modulate
  - do not propagate well through buildings
  - dangerous to living things

Radio Transmission

- Radio waves
  - easy to generate
  - can travel long distances
  - penetrate buildings easily
  - omnidirectional
  - at low frequencies, the power falls off sharply with distance from the source
  - at high frequencies, radio waves tend to travel in straight lines and bounce off obstacles

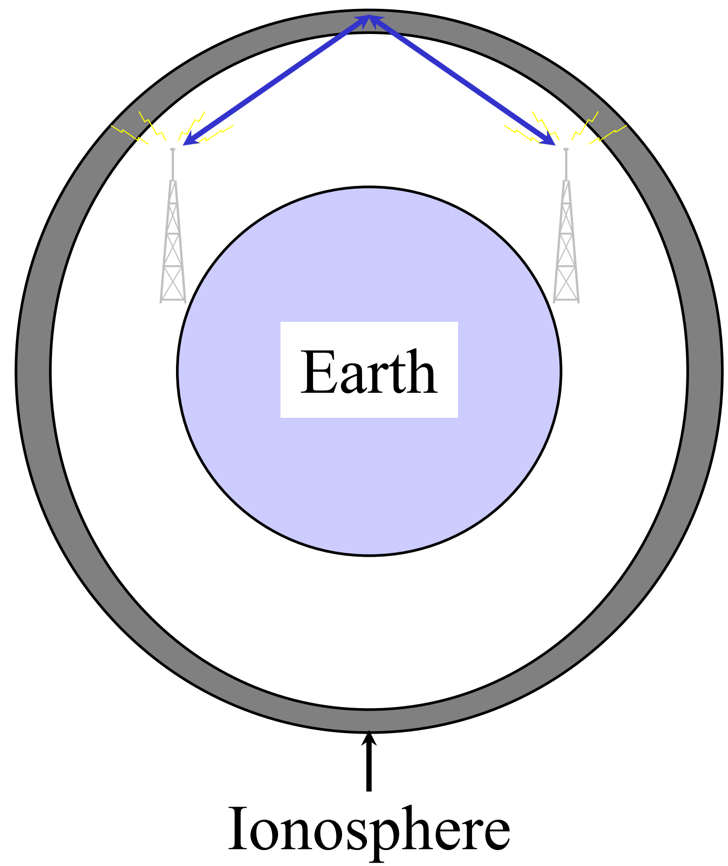
Propagation of Radio Waves

VLF, LF, and MF bands



Radio waves follow the ground

HF and VHF bands



Microwave Transmission

- Microwaves
  - travel in straight lines
    - can be narrowly focused (by a dish)
    - the transmitting and receiving antennas must be accurately aligned with each other.
  - do not pass through buildings well.
  - can be absorbed by water/rain
  - widely used for long-distance telephone communication, cellular telephones, TV distribution

Infrared and Millimeter Waves

- widely used for short-range communication.
  - TV remote controller
- do not pass through solid objects.
  - Bad: limited distance
  - Good: security
- candidate for indoor wireless LAN
- cannot be used outdoors (due to sun shines)

Lightwave Transmission

- Each side needs its own laser and its own photodetector.
- The laser's strength, a very narrow beam, is its weakness.
  - Difficult aiming at far distance
- offers high bandwidth
- easy to install

Summary

- Data communication and computer networking have solid theorectical background.
- Three major transmission media are widely used today: twisted pair, coaxial cable and optical fiber.
- Wireless transmission becomes more and more important in today's networking.