CSE 3461 / 5461: Computer Networking & Internet Technologies

Data Transmission

Presentation B

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Data Communications Model

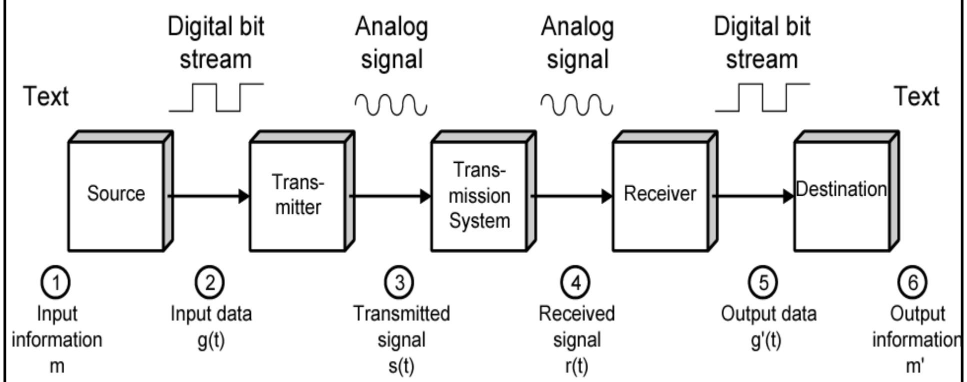

Figure 1.2 Studying Assignment: 3.1-3.4, 4.1

Data and Signals

- Data: entities that convey meaning
  - analog data:
    - continuous values within some interval
    - e.g. sound, video
  - digital data:
    - discrete values
    - e.g. text, integers
- Signals (electromagnetic or electric): means by which data are propagated
  - analog (or contiguous) signal is a continuously varying electromagnetic wave that propagates over (a variety of) medium
  - digital (or discrete) signal is a sequence of voltage pulses that are transmitted over a wire medium. The signal intensity maintains a constant level for some time and then changes to another constant level.

Analog and Digital Signals: Examples

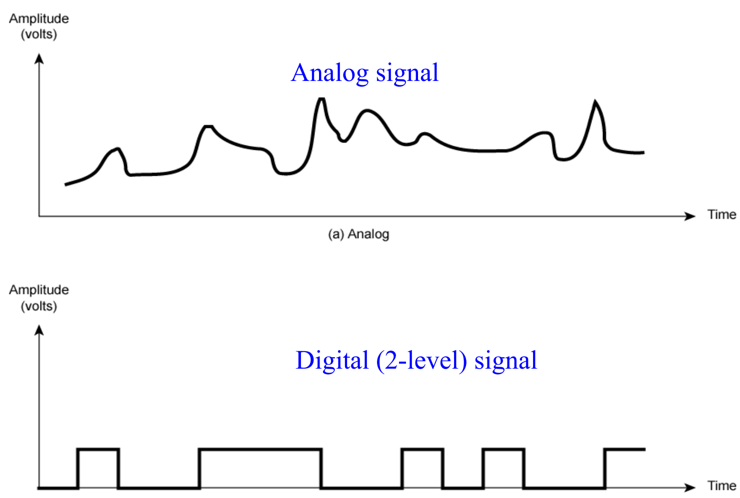

Figure 3.1

Analog Signal Carrying Analog & Digital Data

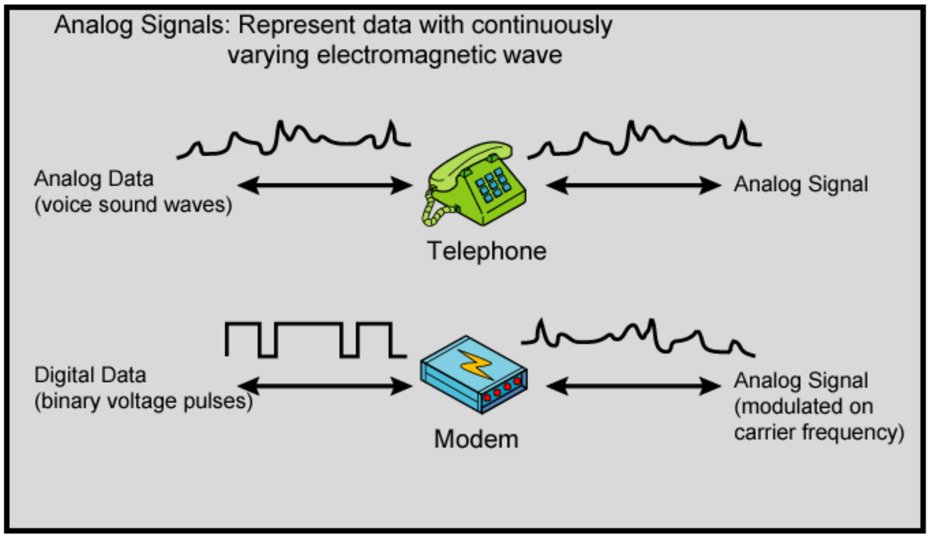

Figure 3.14

Digital Signal Carrying Analog & Digital Data

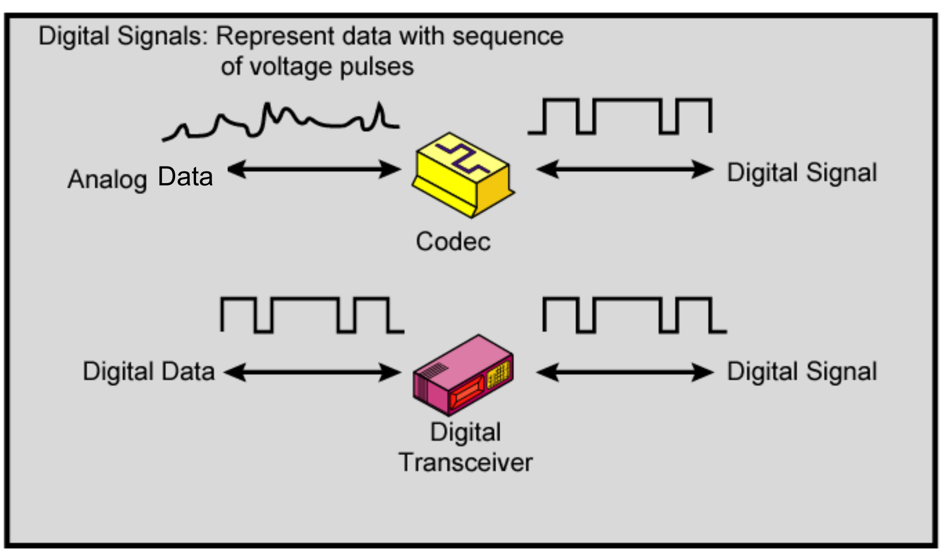

Figure 3.14

Transmission System

- Transmission is communication of data by propagation and processing of signals
- Transmission system includes:
  - transmission medium and
  - amplifiers or repeaters
- Transmission medium
  - guided medium: electromagnetic waves are guided along physical path, e.g. twisted pair, coax cable, optical fiber
  - unguided medium: waves are transmitted but not guided, e.g. air, water, vacuum
- Guided transmission medium:
  - point-to-point: only 2 devices share link
  - multi-point: more than two devices share the link

Transmission Types and Methods

- Simplex transmission: one direction, e.g. television
- Half duplex transmission: either direction, but only one way at a time, e.g. police radio
- Full duplex transmission: both directions at the same time, e.g. telephone
- Two methods of transmission:
  - analog transmission
    - analog signal transmitted without regard to content
    - signal may be carrying analog or digital data
    - attenuated over distance
    - use amplifiers to boost signal, but also amplifies noise
  - digital transmission

Digital Transmission

- Signal may be analog or digital
- Signal may be carrying digital data or analog data,
- Repeaters (also called regenerator) used
  - repeater receives signal, extracts bit pattern and retransmits
  - attenuation is overcome
  - noise is not amplified
- Advantages:
  - digital technology: low cost LSI/VLSI technology
  - data integrity: longer distances over lower quality lines
  - capacity utilization: high bandwidth (i.e. speed) links economical
  - security & privacy: easy encryption
  - integration: can treat analog and digital data similarly

Treatment of Signals

	Analog Transmission	Digital Transmission
Analog Signal	Is propagated through amplifiers; same treatment whether signal is used to represent analog data or digital data.	Assumes that the analog signal represents digital data. Signal is propagated through repeaters; at each repeater, digital data are recovered from inbound signal and used to generate a new analog outbound signal.
Digital signal	Not used	Digital signal represents a stream of 1s and 0s, which may represent digital data or may be an encoding of analog data. Signal is propagated through repeaters; at each repeater, stream of 1s and 0s is recovered from inbound signal and used to generate a new digital outbound signal.

Table 3.1(b)

Periodic Signals

- Periodic signal: pattern repeated over and over time;
- Otherwise aperiodic signal.

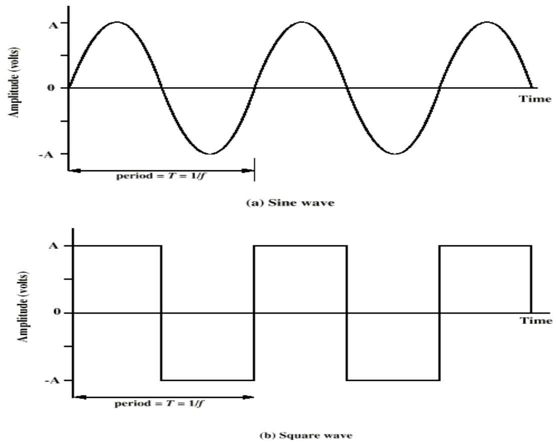

Figure 3.2

Sine Wave Characteristics

- Peak Amplitude (A)
  - maximum strength of signal, typically measured in volts
- Frequency f = 1/T
  - T = time for one repetition
  - rate of change of signal, measured in hertz (Hz) or cycles per second
- Phase (ϕ)
  - relative position in time
- Wavelength = λ is a distance occupied by one cycle
  - Assuming signal velocity v, then $\lambda = v \times T$ or $\lambda \times f = v$
  - speed of light in free space $c = 3\times10^8$ m/s

Sine Waves: $s(t) = A \sin(2\pi ft + \Phi)$

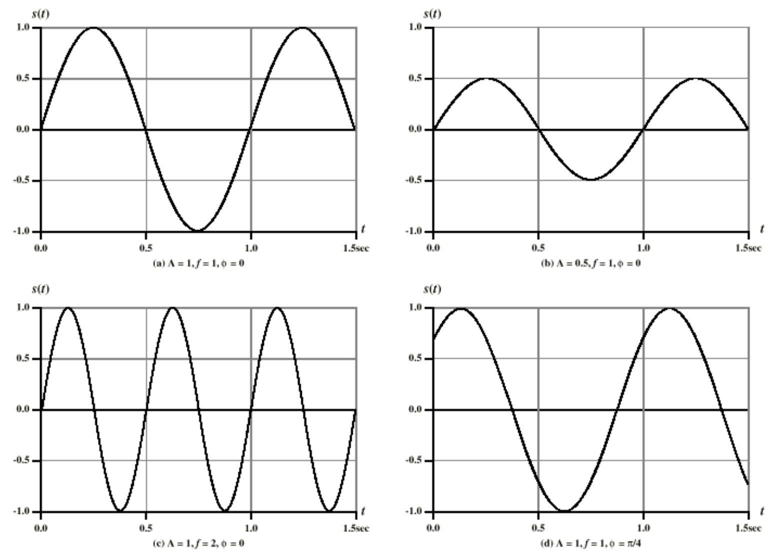

Figure 3.3

Signal Characteristics

- It can be shown (by Fourier analysis) that any signal is made up (i.e. composed) of a number (possible an infinite number) of components and each signal component is a sine wave.
- Component sine waves are of different frequencies, amplitudes and phases.
- Any periodic signal consists of discrete frequency components, i.e. its components have frequencies that are multiple of one base frequency.
- Any aperiodic signal consists of continuum of frequencies.
- DC (direct current) or constant component
  – component of zero frequency

Signal Spectrum & Bandwidth

- Spectrum of signal
  - range of frequencies contained in signal
- Absolute bandwidth of signal
  - width of signal spectrum
- Effective bandwidth of signal
  - often just *signal bandwidth*
  - narrow band of frequencies containing most of the signal energy

Transmission Systems and Signals

- Any transmission system supports a limited band of freque-ncies, i.e. it passes only a certain range of frequencies, thus:
  - sine waves of frequencies in the given range are passed through and transferred efficiently,
  - while sine waves of frequencies out of the range are not passed through.
- Thus, the bandwidth of a signal should match that of a transmission system for the signal to be efficiently transferred through the given transmission system.
- We shall see that a limited band of frequencies is one of the main factors that limits the data rate that can be carried both by signal and by transmission system.
- Another factor that influences the data rate are transmission impairments.

Transmission Impairments

- Signal received may differ from signal transmitted
- Analog signal - degradation of signal quality
- Digital signal - bit errors
- Caused by
  - attenuation and attenuation distortion
  - delay distortion
  - noise; additional signals inserted between transmitter and receiver: impulse noise, crosstalk, thermal (white) noise or noise

Attenuation and Delay Distortion

- Attenuation: Signal strength falls off with distance
  - Depends on medium
  - Received signal strength:
    1. must be enough to be detected
    2. must be sufficiently higher than noise to be received without error
- Attenuation distortion: attenuation is different for different frequencies; an increasing function of frequency
- Delay distortion (only in guided media)
  - propagation velocity varies with frequency, thus some components of one bit position may spill over into another bit position; causing inter-symbol interference, which is a major limitation to maximum bit rate.

Attenuation of Digital Signals

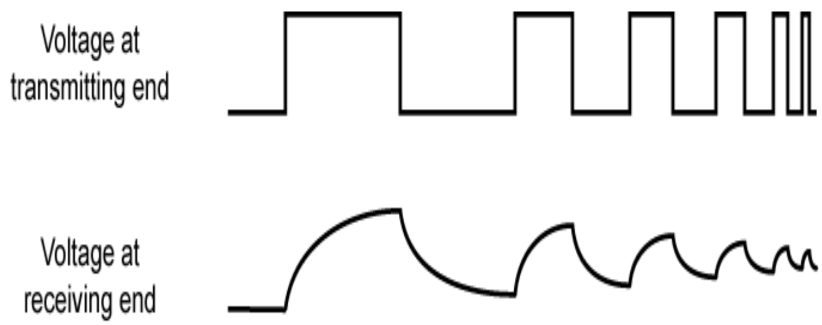

Figure 3.11

Decibels and Signal Strength

- Gain or loss of a signal, as well as a relative level of two signals, is often expressed in decibels
- $G_{dB} = 10 \log_{10} (P_{out} / P_{in})$

  G_{dB} – gain/loss or ratio in decibels

  P_{out} – output power level of signal in W

  P_{in} – input power level of signal in W
- Example 1: P_{in} = 10 mW, P_{out} = 5 mW

  $G_{dB} = 10 \log_{10} (5 / 10) = 10 \times (-0.3) = -3$ dB (loss)
- Example 2: P_{in} = 5 mW, P_{out} = 10 mW

  $G_{dB} = 10 \log_{10} (10 / 5) = 10 \times 0.3 = 3$ dB (gain)
- The net gain or loss in a cascaded transmission path can be calculated with simple additions.

Components of Speech

- Frequency range of hearing:
  - from 20Hz to 20kHz
- Frequency range of normal speech:
  - from 100Hz to 7kHz
- Frequencies below 600 Hz add very little to the intelligibility of speech to the human ear
- Typical speech has a dynamic range of about 25 dB
  - the power of loudest shout may be as much as 300 times greater than the least whisper
- Easily converted into electromagnetic signal for transmission
- Sound frequencies with varying volume converted into electromagnetic frequencies with varying voltage
- Frequency range for voice (telephone) channel:
  - from 300Hz to 3400Hz
- Video bandwidth of an analog TV channel is 4MHz

Key Data Transmission Terms

Term	Units	Definition
Data element	Bits	A single binary one or zero
Data rate	Bits per second (bps)	The rate at which data elements are transmitted
Signal element	Digital: a voltage pulse of constant amplitude Analog: a signal of constant frequency, phase, and amplitude	That part of a signal that occupies the shortest interval of a signaling code
Signaling rate or modulation rate	Signal elements per second (baud)	The rate at which signal elements are transmitted

Table 5.1

Channel Capacity

- Channel capacity: the maximum rate (in bits per second) at which data can be transmitted over given communication path, or channel, under given conditions
- The following four concepts are related to one another:
  - Data rate: the rate at which data can be communicated, in bits per second
  - Bandwidth (of a signal): constrained by transmitter and communication medium (and amplifiers or repeaters).
  - Noise: the average level of noise over the communication path.
  - Error rate: the rate at which errors at receiver occurs, i.e. 1 or 0 transmitted is received as 0 or 1, respectively.

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Nyquist Rate Formula

- Nyquist rate concerns exact reproduction of a signal in the absence of noise.
  - If a signal has a bandwidth of B Hz, then it has to be sampled at least at twice the bandwidth (2xB Hz)
  - Sampling frequency, Fsamp = 2xB Hz (or samples/sec)
- Error-free channel is assumed
- Infinite precision in amplitude is also assumed
- Capacity limit is due to the effects of inter-symbol interference, such as produced by delay distortion
  - In practice, finite precision is used. For example, a system that uses M levels of amplitude needs a Nyquist data rate of $C_{Nyquist} = 2B \times \log_2 M$ bits/sec
- Example: Given binary signalling (i.e. two level signal), the data rate needed for a signal of bandwidth, B Hz is $C_{Nyquist} = 2B \times \log_2 2 = 2B$ bits/sec

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Shannon Capacity Formula

- Considers data rate, bandwidth, noise and error rate
- Faster data rate shortens each bit time so burst of noise affects more bits
  - At given noise level, high data rate means higher error rate
- Only white (thermal) noise assumed
  - Signal to noise ratio (in decibels) = SNR_{dB}
  - $SNR_{db} = 10 \log_{10}$ (Signal_Power / Noise_Power)
- Capacity in bits/sec $C = B \times \log_2(1+SNR)$
- This is error free capacity

Shannon Formula: Example

Problem:

- Find capacity of ordinary voice grade telephone line, assuming SNR_{dB} = 30 dB.

  Note: Given SNR_{dB} is characteristic for many voice channels

Answer:

- SNR_{dB} = 30 dB → Signal to noise ratio = 1000
- Frequency range for voice channel is 300-3400Hz:
  - Bandwidth B = 3100Hz
- Capacity $C = B \log_2(1+SNR) = 3100 \log_2 (1001)$

  ≈ 31kbps
- Higher capacities (speeds), such as 56kbps can be achieved only over cleaner channels, i.e. over voice channels with higher SNR.

ADSL Channel Configuration

- ADSL (Asymmetric Digital Subscriber Line) is a family of new modem technologies over ordinary telephone wire:
  - from 16 kbps to 640 kbps upstream
  - from 1.5 Mbps to 9 Mbps downstream
- POTS: plain old telephone service

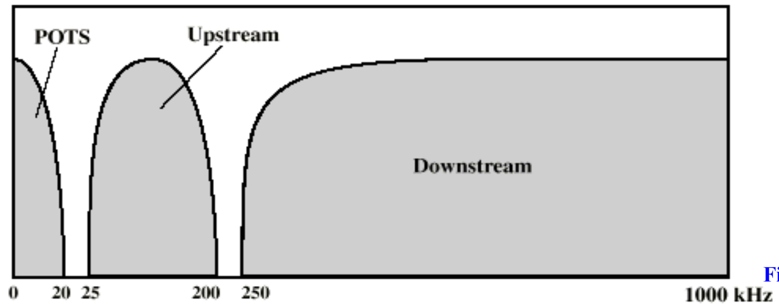

Figure 8.17

Transmission Media

- Guided transmission media – wire:
  - twisted pair
  - coaxial cable
  - optical fiber
- Unguided transmission media - wireless
- Characteristics and quality determined by medium and signal
- For guided, the medium is more important
- For unguided, the bandwidth produced by the antenna is more important
- Key concerns are data rate and distance
- Design factors:
  - Bandwidth
    - Higher bandwidth gives higher data rate
  - Transmission impairments

Twisted Pair - TP

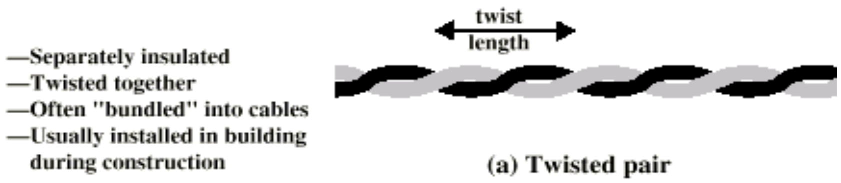

Figure 4.2a

- Most common medium
- Telephone network
  – Between house and local exchange (subscriber loop)
- Within buildings
  – To private branch exchange (PBX)
- For local area networks (LAN): 10 Mbps or 100 Mbps
- Cheap and easy to work with
- But lower data rate and shorter range

Twisted Pair Transmission Characteristics

- Analog transmission
  – amplifiers every 5km to 6km
- Digital transmission
  – use either analog or digital signals
  – repeater every 2km or 3km
- Limited distance and limited bandwidth
- Limited data rate
  – a few Mbps for long-distance point-to point
  – up to 1 Gbps for very short distances
- Susceptible to interference and noise

Unshielded and Shielded Twisted Pair

- Unshielded Twisted Pair (UTP)
  - Ordinary telephone wire
  - Cheapest and easiest to install
  - Suffers from external electromagnetic interference
- EIA-568-A defines three UTP standards: Cat 3, Cat 4, & Cat 5
- UTP Cat 3: up to 16MHz, voice grade found in most offices
  - Twist length of 7.5 cm to 10 cm
- UTP Cat 4: up to 20 MHz, not common
- UTP Cat 5: up to 100MHz, pre-installed in new office buildings
  - Twist length 0.6 cm to 0.85 cm
- Shielded Twisted Pair (STP)
  - Metal braid or sheathing that reduces interference
  - More expensive and harder to handle (thick, heavy)

Coaxial Cable

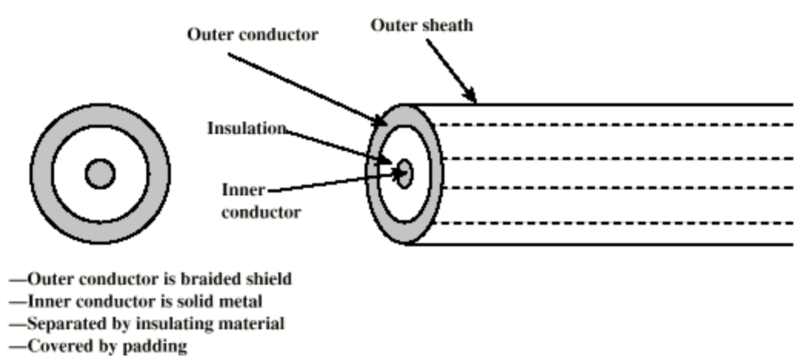

Figure 4.2b

Coaxial Cable Characteristics

- Most versatile medium
- Television distribution
  - Ariel to TV
  - Cable TV
- Long distance telephone transmission
  - Can carry 10,000 voice calls simultaneously
  - Being replaced by fiber optic
- Short distance computer systems links
- Local area networks
- Analog: Up to 500MHz
  - Amplifiers every few km
  - Closer if higher frequency
- Digital
  - Repeater every 1km
  - Closer for higher data rates

Optical Fiber

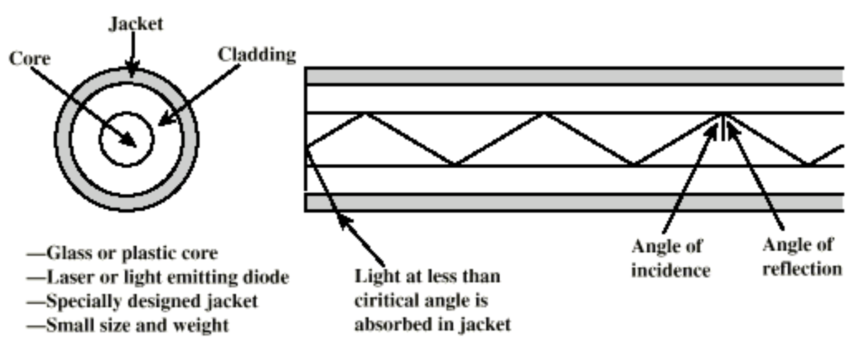

Figure 4.2c

Optical Fiber Characteristics

- Act as wave guide for 10^{14} to 10^{15} Hz waves
  – Portions of infrared and visible spectrum
- Light Source: light emitting diode (LED)
  – cheaper, wider operating temp range, last longer
- Light Source: Injection Laser Diode (ILD)
  – more efficient, greater data rate
- Receiver: Photodiode converts light into electrical signal
- Greater capacity: Data rates of hundreds of Gbps
- Smaller size & weight
- Lower attenuation & good electromagnetic isolation
- Greater repeater spacing: 10s of km at least
- Used for: Long-haul trunks, Metropolitan trunks, Rural exchange trunks, Subscriber loops and LANs

Optical Fiber Transmission Modes

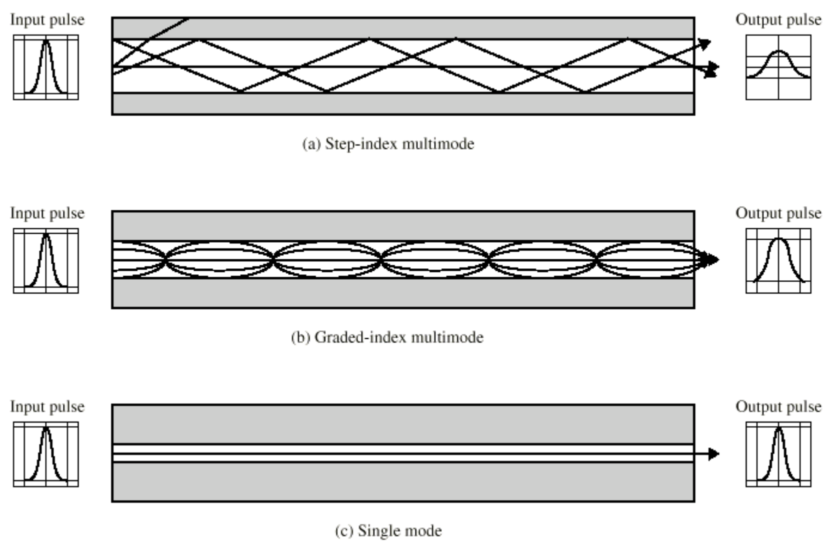

Figure 4.4

Frequency Utilization for Fiber Applications

Wavelength range in vacuum (nm)	Freq. 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

- Wavelength $\lambda = v / f$; v = signal velocity, f = signal frequency
- speed of light in vacuum c = 3×10^8 ms^{-1}
  - for λ = 1550 nm → f = c/λ = *193.5 THz*
- speed of light in a typical fiber v = 2×10^8 ms^{-1}
  - for f = 193.5 THz → λ = v / f = 1034 nm
- Thus, a wavelength of 1550 nm in the table is actually 1034 nm on the fiber

Wireless Transmission Frequencies

- 2GHz to 40GHz
  - Microwave frequencies
  - Highly directional
  - Point to point
  - Satellite
- 30MHz to 1GHz
  - Omnidirectional
  - Broadcast radio
- 3×10^{11} to 2×10^{14} Hz
  - Infrared
  - Local

Acoustic Spectrum of Speech & Music

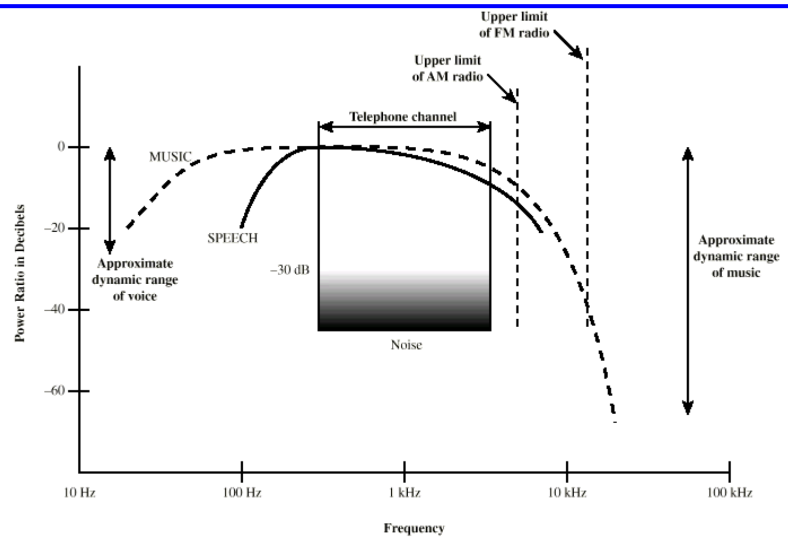

Figure 3.9