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 continuously varying electromagnetic wave that propagates over (a variety of) medium
  - digital (or discrete) signal is 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

Digital (2-level) signal
**Analog Signal Carrying Analog & Digital Data**

Analog Signals: Represent data with continuously varying electromagnetic wave

Analog Data (voice sound waves) → Analog Signal → Telephone

Digital Data (binary voltage pulses) → Analog Signal (modulated on carrier frequency) → Modem

**Figure 3.14**

**Digital Signal Carrying Analog & Digital Data**

Digital Signals: Represent data with sequence of voltage pulses

Analog Signal → Codec → Digital Signal

Digital Data → Digital Transceiver → Digital Signal

**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

<table>
<thead>
<tr>
<th>Analog Transmission</th>
<th>Digital Transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is propagated through amplifiers; same treatment whether signal is used to represent analog data or digital data.</td>
<td>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.</td>
</tr>
<tr>
<td>Digital signal</td>
<td>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.</td>
</tr>
</tbody>
</table>

Table 3.1(b)
Periodic Signals

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

![Figure 3.2](image)

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 ($\phi$)**
  – relative position in time

• **Wavelength** $\lambda$ 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 $c = 3 \times 10^8 \text{ m/s}$
Sine Waves: $s(t) = A \sin(2\pi ft + \Phi)$

**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 frequencies, 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.
- $G_{dB} = 10 \log_{10} \left( \frac{P_{Out}}{P_{In}} \right)$
  - $G_{dB}$ – 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
  - $G_{dB} = 10 \log_{10} \left( \frac{5}{10} \right) = 10 \times (-0.3) = -3$ dB (loss)
- Example 2: $P_{In} = 5$ mW, $P_{Out} = 10$ mW
  - $G_{dB} = 10 \log_{10} \left( \frac{10}{5} \right) = 10 \times 0.3 = 3$ 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**

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

**Table 5.1**

Presentation B
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.

Nyquist Capacity Formula

- If rate of signal transmission is **2B bauds** then signal with frequencies no greater than **B Hz** is sufficient to carry that signal rate, or
- Given bandwidth **B Hz**, highest possible signal rate is **2B bauds**.
- **Error free channel assumed**
- Capacity limit is due to the effects of inter-symbol interference, such as produced by delay distortion.
- Given **binary** signal (i.e. **two level** signal), maximum data rate supported by bandwidth of **B Hz** is **2B bps**, i.e.
  - Channel capacity in bits/sec \( C = 2B \)
- Can be increased by using **M level signal**
  - Channel capacity in bits/sec \( C = 2B \times \log_2 M \)
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} \left( \frac{\text{Signal Power}}{\text{Noise Power}} \right)
- 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 \rightarrow 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)  
  \approx 31 \text{kbps}
- 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

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

- Separately insulated
- Twisted together
- Often "bundled" into cables
- Usually installed in building during construction

(a) Twisted pair

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 100 MHz, 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)

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Coaxial Cable

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**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

(a) Step-index multimode

(b) Graded-index multimode

(c) Single mode

Figure 4.4
### Frequency Utilization for Fiber Applications

<table>
<thead>
<tr>
<th>Wavelength range in vacuum (nm)</th>
<th>Freq. range (THz)</th>
<th>Band label</th>
<th>Fiber type</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>820 to 900</td>
<td>366 to 333</td>
<td></td>
<td>Multimode</td>
<td>LAN</td>
</tr>
<tr>
<td>1280 to 1350</td>
<td>234 to 222</td>
<td>S</td>
<td>Single mode</td>
<td>Various</td>
</tr>
<tr>
<td>1528 to 1561</td>
<td>196 to 192</td>
<td>C</td>
<td>Single mode</td>
<td>WDM</td>
</tr>
<tr>
<td>1561 to 1620</td>
<td>192 to 185</td>
<td>L</td>
<td>Single mode</td>
<td>WDM</td>
</tr>
</tbody>
</table>

- Wavelength $\lambda = \frac{v}{f}$; $v$ = signal velocity, $f$ = signal frequency
- speed of light in vacuum $c = 3 \times 10^8$ ms\(^{-1}\)
  - for $\lambda = 1550$ nm $\rightarrow f = \frac{c}{\lambda} = 193.5$ THz
- speed of light in a typical fiber $v = 2 \times 10^8$ ms\(^{-1}\)
  - for $f = 193.5$ THz $\rightarrow \lambda = \frac{v}{f} = 1034$ 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
- $3 \times 10^{11}$ to $2 \times 10^{14}$ Hz
  - Infrared
  - Local
Acoustic Spectrum of Speech & Music

Figure 3.9