Physical Layer

Transmission Media
Signaling
Bandwidth vs. Data Rate
Data Encoding
Multiplexing

Transmission Media

- The transmission medium is the physical path between transmitter and receiver in a data transmission system.

- Unguided Media (transmission through air)
- Guided Media
  - Point-to-point (direct link between 2 devices)
  - Multipoint (>2 devices share medium)
Transmission Media

• Transmission Medium can be:
  
  – **Simplex**
    • Transmission in one direction only.
  
  – **Half-duplex**
    • Transmission in both directions; but not at the same time.
  
  – **Full-duplex (duplex)**
    • Simultaneous transmission in both directions.

Twisted Pair

• Two insulated wires are twisted around each other, and combined with others into a cable
• Used to connect telephone subscribers to switching centers and for wiring local area networks

• Different qualities:
  – Two popular varieties:
    • Category 3: 10 Mbps
    • Category 5: 100 Mbps
  
  • Most twisted pair cables are of type UTP (Unshielded twisted pair), that is, they do not have a ground shield.
Coaxial Cable

- Like twisted pair a coaxial cable (“coax”) has two conductors that are shielded
- Used for digital transmissions in local area networks (e.g., Ethernet) and analog transmissions for cable television
- Coax used for Cable TV supports a spectrum of 50 - 750 Mhz

Optical Fiber

- Optical fiber is a thin (2-125 mm), flexible medium capable of conducting an optical ray.
- Fiber is built of various glasses or plastics.
- Very high bandwidth (currently up to 10 Gbps).
- Used for long-distance trunks, local area networks, high-speed transmissions.
- Inherently unidirectional.
Types of Optical Fiber

• **Multimode Fiber:**
  – Rays may take different paths

• **Single Mode Fiber:**
  – By reducing the radius of the fiber core to the order of the wavelength, only the axial ray can pass.
  – Single Mode fiber has superior performance but needs a laser diode as a light source (instead of a LED for multimode fiber).

Signals

• Signals, electromagnetic or optical, are used to transmit data.
• A signal can be viewed as a function of time (time-domain) and as a function of its frequencies (frequency-domain)

• Signals:
  • Continuous (analog)
  • Discrete (digital)
Signals in the Time Domain

- A **continuous signal** has no discontinuities, that is, for all \( a \):
  \[ \lim_{t \to a} s(t) = a \]

- **Periodic signals** are of the form:
  \[ s(t) = s(t + T) \] for all \( t \)

- The most basic continuous periodic signal is a sine wave
- An aperiodic signal can be represented by (an infinite number of) sine waves

---

Sine Waves

- Generic sine wave is:
  \[ s(t) = A \cdot \sin(2\pi ft + \Phi) \]
  
  Amplitude \( A \): Peak value of a signal at any time
  Frequency \( f \): Inverse of the period
  Phase \( \Phi \): Relative position within a signal period
Signals in the Frequency Domain

- The time-domain view represents the amplitude of the signal as a function $s(t)$ of time.
- In a similar way, one can represent a signal in terms of a frequency-domain function $S(f)$.

Electromagnetic Signals

- Electromagnetic signals are composed of multiple frequencies.
- The plot for the signal in the time domain $s(t) = \sin(2 \pi f t) + \frac{1}{4} \sin(2 \pi (10f) t)$ looks like this:
Fourier Analysis

- Using Fourier Analysis any signal can be represented by a number of sine waves.
- Any periodic signal can be expressed as sum of sine waves:

\[ s(t) = \sum A_j \cdot \cos(2 \cdot \pi \cdot f_j \cdot t) \]

- Thus, a discrete signal can be represented:

![Fourier Signal Representation](image)

Bandwidth and Capacity

- **Spectrum**: Range of frequencies of a signal \([f_{\text{min}}, f_{\text{max}}]\)
- **Bandwidth**: Width of the spectrum \((f_{\text{max}} - f_{\text{min}})\) (measured in Hz)
- **Capacity**: Rate at which data can be transmitted (measured in bits per seconds, bps)
- **Noise**: Random noise which distorts a signal (measured as ratio of signal power to noise power, units are decibels (dB))

- **Signal-to-Noise Ratio**
  - signal-to-noise ratio (db) = \(10 \log_{10} \frac{S}{N}\)
Bandwidth and Capacity

- Capacity of a noiseless channel (H. Nyquist, 1924)
  - $H$: bandwidth;
  - $V$: number of discrete levels of a signal;
  - $C$: Capacity
    \[ C = 2H \log_2 V \text{ bps} \]

- Capacity of a noisy channel: (C. Shannon, 1948)
  - $H$: bandwidth
  - $S/N$: signal-to-noise ratio
    \[ C = H \log_2 (1 + S/N) \text{ bps} \]

Data and Signals

Data = Something which carries meaning

Signals = Encoded data

- Data
  - Analog Data - takes on continuous values (e.g., audio)
  - Digital Data - takes on discrete values (e.g., text)

- Signals: All data are propagated by signals
  - Analog Signals - Represents data with continuously varying electromagnetic wave
  - Digital Signals - Represents data with a sequence of voltage pulses
Data Encoding

- All of the following combinations are used:

<table>
<thead>
<tr>
<th>Digital Data</th>
<th>Digital Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital Signal</td>
<td>Analog Signal</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Analog Data</th>
<th>Analog Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital Signal</td>
<td>Analog Signal</td>
</tr>
</tbody>
</table>

Analog vs. Digital Data/Signaling

- Example:

  - Analog Data (=voice) → Telephone → Analog Signal
  - Digital Data → Modem → Analog Signal
  - Analog Data (=voice) → Codec → Digital Signal
  - Digital Data → Digital Transmitter → Digital Signal
Data Encoding

• Data encoding describes the techniques used to map data into signals

• With digital signals:
  – Data is encoded onto a digital signal.

\[ g(t) \text{ digital or analog} \rightarrow \text{Encoder} \rightarrow x(t) \text{ digital} \rightarrow \text{Decoder} \rightarrow g(t) \]

Data Encoding

• With analog signals:
• Data is encoded onto a carrier signal with frequency \( f_c \). This process is called Modulation.

\[ m(t) \text{ digital or analog} \rightarrow \text{Modulator} \rightarrow x(t) \text{ Analog} \rightarrow \text{Demodulator} \rightarrow m(t) \]
Digital Data / Digital Signals

• Recall:
  • A digital signal is a discrete voltage pulse.
  • Each pulse represents one or several bits.

• Terminology
  – Data Rate. Rate at which data can be transmitted (measured in bps)
  – Bit Length. Time to transmit a bit.
  – Modulation Rate. Rate at which the signal is changed (measured in signal elements per second or baud)

Digital Data / Digital Signals

• A large number of digital data/digital signal encoding techniques are available. The criteria for selecting a scheme are:
  • Frequency Spectrum
  • Bit Timing (Clocking)
  • Error Detection
  • Immunity to interference.
Digital Data / Digital Signal

- Encoding Schemes

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

- NRZI (Nonreturn-to-zero-Inverted)
  0 = no transition at beginning of interval
  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
Digital Data / Digital Signal

- NRZ-L
- NRZ-I
- Bipolar-AMI
- Pseudoternary
- Manchester
- Differential Manchester

Digital Data / Analog Signal

- Familiar example:
  - Using a modem over the (analog) telephone network
- Recall:
  - Basis for analog signaling is carrier signal
  - Data are modulated onto carrier signal
- There are 3 encoding techniques for transforming digital data to analog signals:
  - Amplitude-shift keying
  - Frequency-shift keying
  - Phase-shift keying
Digital Data/Analog Signal

• Carrier Signal:

\[ s(t) = A \cdot \cos(2\pi f_c t + \theta_c) \]

• Amplitude-shift keying (ASK)

\[ s(t) = A \cdot \cos(2\pi f_c t + \theta_c) \quad \text{for binary 1} \]
\[ s(t) = 0 \quad \text{for binary 0} \]

Digital Data/Analog Signal

• Frequency-shift keying (FSK)

\[ s(t) = A \cdot \cos(2\pi f_1 t + \theta_c) \quad \text{for binary 1} \]
\[ s(t) = A \cdot \cos(2\pi f_2 t + \theta_c) \quad \text{for binary 0} \]

• Phase-shift keying (PSK)

\[ s(t) = A \cdot \cos(2\pi f_c t + \pi) \quad \text{for binary 1} \]
\[ s(t) = A \cdot \cos(2\pi f_c t) \quad \text{for binary 0} \]
Digital Data/Analog Signal

- Transmission is accomplished in two steps:
  1. Conversion of analog data into digital data (Digitization)
  2. Digital data is converted into an analog signal (Modulation)

- Codec is a device for converting analog data into digital data (and vice versa).

Analog Data/Analog Signal

- Transmission is accomplished in two steps:
  1. Conversion of analog data into digital data (Digitization)
  2. Digital data is converted into an analog signal (Modulation)

- Codec is a device for converting analog data into digital data (and vice versa).
Sampling Theorem (by Nyquist): If a signal $f(t)$ is sampled at regular intervals of time and at a rate higher than twice the highest significant signal frequency, then the samples contain all the information of the original signal. The function $f(t)$ may be reconstructed from these samples by the use of a low pass filter.

Pulse Code Modulation (PCM)

- Example: PCM encoding of voice data:
  - Voice has a bandwidth of about 4 kHz
  - Sampling rate must be 8000 samples/second
  - Typically, the sample size is 7-8 bits
  - Voice channel requires 56-64 kbps
  - PCM for voice is standardized as ITU-TS G.711
  - Note: ISDN B-channel has 64 kbps
Analog Data/Analog Signal

- There are three types of modulation:
  - Amplitude Modulation (AM)
  - Frequency Modulation (FM)
  - Phase Modulation (PM)

Multiplexing at the Physical Layer

- **Goal**: Get many information flows on a single physical channel.

- Basic techniques:
  - For circuit-switched networks:
    - Frequency Division Multiplexing (FDM)
    - Time Division Multiplexing (TDM)
  - For packet-switched networks:
    - Statistical Multiplexing
**Frequency Division Multiplexing (FDM)**

- Used in radio, TV, analog telephone transmission, satellite communication
- **Idea:** Divide the frequency spectrum into logical channels and assign each information flow one logical channel

**Example:** Voice in (analog) telephone network:
- Needed bandwidth: 3000 Hz
- Allocated bandwidth: 4000 Hz
Therefore, a channel with 64 kHz can carry 16 voice conversations
**Time Division Multiplexing (TDM)**

- Used for digital telephone transmission, satellite communication
- **Idea:** Multiple signals can be carried on a single transmission medium by interleaving portions of each signal in time

![Diagram of Time Division Multiplexing](image)

---

**Statistical Multiplexing**

- Basically: a different term for “packet switching”
- Assumes that data is organized in “packets”.
- **Idea:** Store packets from different streams in a common buffer, and transmit from the buffer in a FIFO fashion.
- Advantage over TDM: Statistical multiplexing utilizes the available bandwidth more efficiently

![Diagram of Statistical Multiplexing](image)