Topic 2: Physical Layer

Digital Transmission in Computer Networks

- The purpose is to transfer a data sequence of 0s and 1s from a transmitter to a receiver
- It uses pulses or sinusoids to transmit binary information over a physical transmission medium
- We are particularly interested in the bit rate measured in bits/second

(bps)

0110101...

0110101...

discrete symbols : finite symbol set {0, 1}
finite # possible symbols
finite # signal formats (pulses)

$$\text{bit rate} = \frac{\#\text{ bits}}{\text{second}} = \frac{\#\text{ bits}}{\text{pulse}} * \frac{\#\text{ pulses}}{\text{second}}$$

Coding rate ($\frac{\#\text{ bits}}{\text{pulse}}$)

- pulse shape
- # diff pulses

Baud rate ($\frac{\#\text{ pulses}}{\text{second}}$)

- Channel bandwidth
- Pulse Shape

$$\left\{\begin{array}{lcl} 1 \text{ bits per pulse} & \Rightarrow & 2 \text{ diff pulses} \\ 2 & & 4 \\ \vdots & & \vdots \\ m & & 2^m \end{array}\right.$$

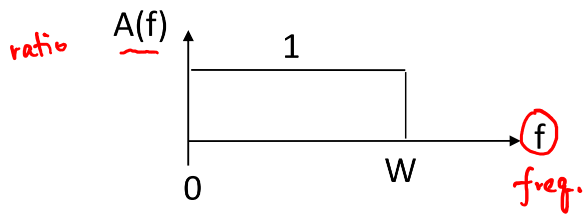
Bit Rate vs. Baud Rate

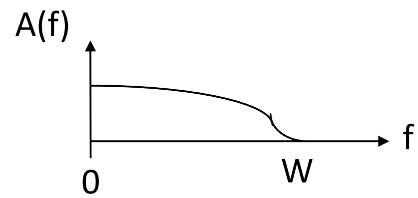
- Definitions
  - Bit Rate = # of bits transmitted per second
  - Baud Rate = # of signal transitions per second
- Baud Rate depends on the channel bandwidth
- Bit Rate = (Baud Rate) × (# bits per pulse)
  - It depends on the channel bandwidth as well as the coding scheme

Transmission Channel and Channel Bandwidth

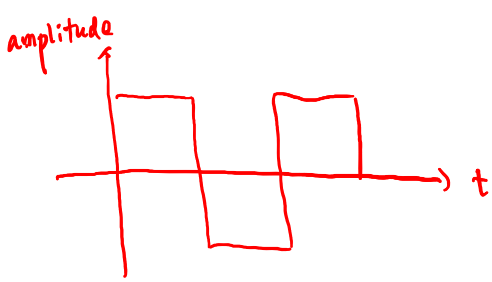
- A transmission channel can be characterized by its effect on input sinusoidal signals (tones) of various frequencies

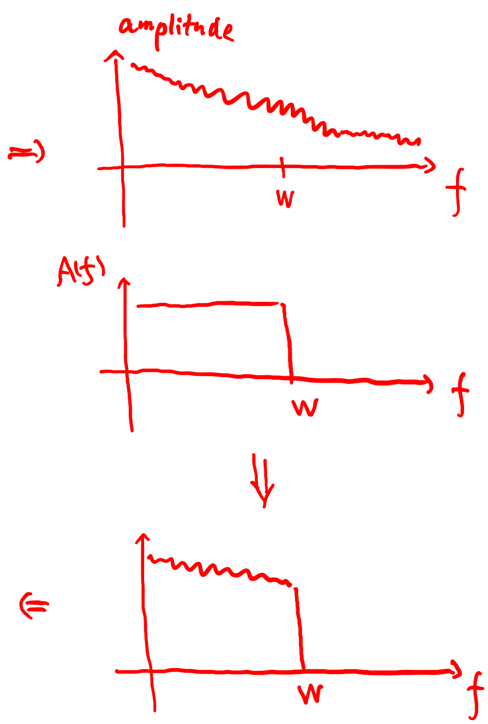
- The ability of the channel to transfer a tone of frequency f is given by the amplitude-response function (A(f)), which is defined as the ratio of the amplitude of the output tone to the amplitude of the input tone



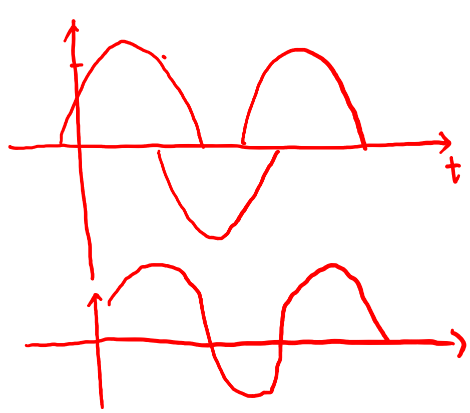


- The bandwidth of a transmission channel (W) is the range of frequencies that is passed by the channel





Inter Symbol Interference (ISI)



Nyquist Rate

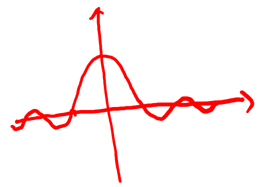
Nyquist Pulse : sinc function

$$\mathrm{sinc}(x) = \begin{cases} 1 & \text{for } x = 0 \\ \frac{\sin(x)}{x} & \text{else} \end{cases}$$

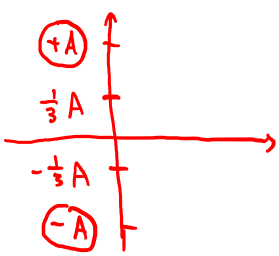
- The fastest rate at which (ideal) pulses can be transmitted over the channel (called the Nyquist Rate) is:

$$r_{max} = 2W \text{ pulses/second}$$

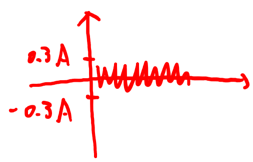
max Baud rate



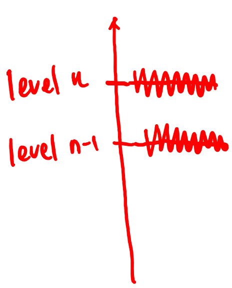
Signal



additive noise



max coding rate = ?



min separation between pulse levels

= 0.3 − (−0.3) = 0.6 A

$$\left\lfloor \frac{A-(-A)}{0.6\,A} \right\rfloor + 1 = 4 \text{ levels}$$

⇒ 2 bits / pulse

" line coding "

Multilevel Pulse Transmission

- Assume channel bandwidth of W
- If pulse amplitudes are either $-A$ or $+A$, then each pulse conveys 1 bit,
  Bit Rate = (2W pulses/sec) × (1 bit/pulse) = 2W bps
- If amplitudes are from $\{-A, -A/3, +A/3, +A\}$, then each pulse conveys 2 bits,
  Bit Rate = (2W pulses/sec) × (2 bits/pulse) = 4W bps
- By going with $M = 2^m$ amplitude levels, we achieve
  Bit Rate = (2W pulses/sec) × (m bits/pulse) = 2mW bps
- In the absence of noise, the bit rate can be increased without limit by increasing the pulse level m

Noise & Reliable Communication

- All physical systems have noise
  - Electrons always vibrate at non-zero temperature
  - Motion of electrons induces noise
- Presence of noise limits the accuracy of measurement of received signal amplitude
- Noise places a limit on how many amplitude levels can be used in multilevel pulse transmission
- Errors occur if signal separation is comparable to noise level
- Bit Error Rate (BER) increases with decreasing Signal-to-Noise Ratio (SNR)

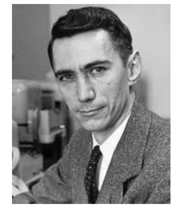
$$= \frac{\text{avg. signal power}}{\text{avg. noise power}}$$

$10 \log_{10}(SNR)$ = SNR in dB

10000 → 40 dB

10 → 10 dB

Shannon Channel Capacity



BW   absolute value ratio

$$C = \overbrace{W}^{\text{BW}} \log_2 (1 + \overbrace{SNR}^{\text{absolute value ratio}}) \text{ bps}$$

- Channel Bandwidth (W) & Signal to Noise Ratio (SNR) determine C
- If transmission rate R > C, reliable communication is not possible
- If transmission rate R ≤ C, arbitrarily reliable communication is possible
  - "Arbitrarily reliable" means the BER can be made arbitrarily small through sufficiently complex coding
- The relation between R_{max} and C is used as a measure of how well a communication system is designed

AWGN Channel
Additive White Gaussian Noise

Example

- Find the Shannon channel capacity for a telephone channel with W = 3.4 KHz and SNR (dB) = 40 dB

$$C = W \cdot \log_2 (1+ SNR)$$

$$= 3.4 \text{ KHz} \cdot \log_2 (1+ 10000)$$

$$= 45.2 \text{ k bps}$$

Example

- Consider an AWGN channel with a bandwidth of 27 KHz and SNR = 35 dB. Is it possible to transmit reliably over this channel at R = 350 Kbps?

bit rate

$$C = W \cdot \log_2(1+SNR)$$
$$= 27\text{ kHz} \cdot \log_2(1+3162)$$
$$= 313.93\text{ kbps}$$
$$< R = 350\text{ kbps}$$

So: not possible

35 dB

$$= 10 \log_{10}(SNR)$$
$$\Rightarrow SNR = 10^{3.5}$$
$$= 3162$$

Example

- Consider an AWGN channel with a bandwidth of 27 KHz. To transmit reliably over this channel at 200 Kbps, what is the minimum required SNR?

$$C = W \cdot \log_2(1+SNR) \geq 200\text{ kbps}$$
$$27\text{ kHz} \cdot \log_2(1+SNR) \geq 200\text{ kbps}$$
$$SNR \geq (2^{\frac{200}{27}}) - 1$$
$$\approx 169\ \cancel{dB}$$
$$\Rightarrow 10 \log_{10}(169) \approx 22.3\text{ dB} \ \checkmark$$