Wireless Communication Systems
@CS.NCTU

Lecture 1: Basics

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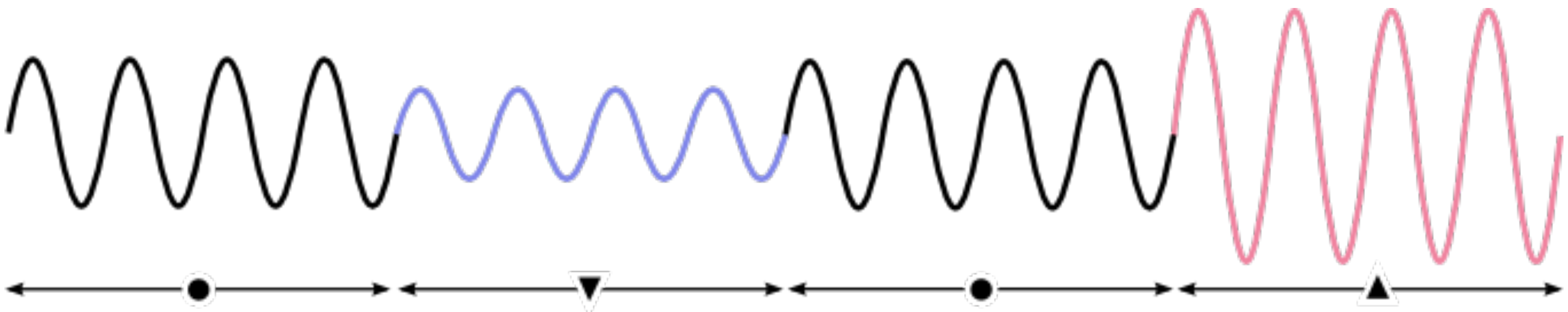
Wireless Signal

- Sine wave $e^{ix} = \cos x + j \sin x$



channel noise

$$y = hx + n$$

received signal transmitted signal

phase change due to propagation delay

$$h = \alpha e^{-2j\pi f_c (t+\theta)}$$

amplitude

What is channel? Signal variation (amplitude and phase) over the air

Constellation Diagram

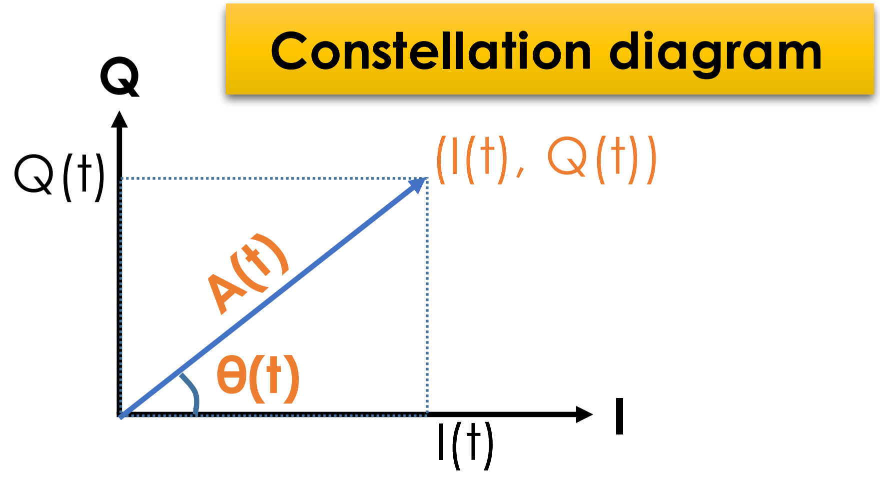
- Signal can be described as a sine wave

$$
\begin{aligned}
x(t) &= A(t)\cos(\omega t + \theta(t)) \\
&= A(t)\frac{e^{j(\omega t+\theta(t))} + e^{-j(\omega t+\theta(t))}}{2} \\
&= \text{Re}[A(t)e^{-j(\omega t+\theta(t))}] \\
&= \text{Re}[A(t)e^{-j\theta(t)}e^{-j\omega t}] \\
&= \text{Re}[\tilde{x}(t)e^{-j\omega t}] \\
&= \text{Re}[(I(t)+jQ(t))e^{-j\omega t}] \\
&= I(t)\cos(\omega t) + Q(t)\sin(\omega t)
\end{aligned}
$$

- Rearranged as **inphase** and **quadrature**

Constellation Diagram

$$
\begin{aligned}
x(t) &= A(t)\cos(\omega t + \theta(t)) \\
&= I(t)\cos(\omega t) + Q(t)\sin(\omega t) \\
&= I(t) + jQ(t)
\end{aligned}
$$



- Represent a wireless signal as a complex number
  - Sine carrier: image part
  - Cosine carrier: real part
- Why complex value?
  - Sine and Cosine are orthogonal with each other
  - Two carriers on the same frequency → rate ↑

Signal Power

- Watt vs. Decibel (**dBm**)
  - dBm is usually used in radio
  - Able to express both very large and very small values in a short form

$$P_{dBm} = 10\log_{10}(1000P_W)$$

$$P_W = \frac{10^{P_{dBm}/10}}{1000}$$

- **dB**: difference between two dBm values
  - ratio of two power = difference between two dBm

$$\text{P1toP2}_{dB} = 10\log_{10}(\frac{P_1}{P_2})$$
$$= 10\log_{10}(P_1) - 10\log_{10}(P_2)$$
$$= P_{1,dBm} - P_{2,dBm}$$

SNR

- Signal-to-Noise Ratio

$$\frac{S}{N}$$

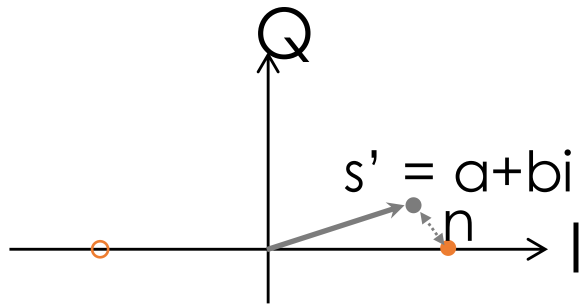
- In dB

$$10\log_{10}\frac{S}{N}$$

- From equation

$$y = hx + n$$

$$SNR = \frac{|h|^2}{\mathbb{E}[|n|^2]}$$



- Decoding SNR
  - Sent s=1+0i
    but receive s'= a+bi
  - Signal power
    = s^2 = | 1+0i | ^{2}
  - Noise power = | s-s' | ^{2}
    = | (a+bi) – (1+0i) | ^{2}
    = | (a-1)+bi | ^{2}

$$SNR = \frac{|1+0i|^2}{|(a-1)+bi|^2}$$

Power vs. dB

- Because of the log operation, double the power produces 3dB gain

$$SNR_{dB} = 10\log_{10} SNR$$

$$P_1 = 2 * P_2 \iff P_{1,dB} = P_{2,dB} + 3\text{dB}$$

Path Loss

- Attenuation reduction as the signal propagates through the air
- <u>**Friis Transmission Formula**</u>

$$\frac{P_r}{P_t} = D_t D_r \left(\frac{\lambda}{4\pi d}\right)^2$$ (in Watt)

$$P_r - P_t = D_t + D_r + 20\log_{10}\left(\frac{\lambda}{4\pi d}\right)$$ (in dB)

  - λ: signal wavelength
  - Pt/Pr: transmitting/receiving power
  - Dt/Dr: directivity of transmitting/receiving antenna
- Loss $\propto$ distance^2

Shannon Capacity

- The tight upper bound on the data rate

$$C = B\log_2\left(1+\frac{S}{N}\right) = B\log_2\left(1+SNR\right)$$

- B: bandwidth (Hz), e.g., WiFi with 20MHz
- S and N is in Watt (SNR is power ratio, not in dB)

- In low SNR regime, increasing SNR can increase the rate significantly
- In high SNR regime, the increase in rate from SNR gain is relatively small

Equalization

- Reversal of distortion incurred by a signal transmitted through a channel
- **Equalizer**: recover the transmitted signal from the received signal
  - a.k.a. decoding
- Solution: MMSE, Zero-forcing, etc.
- Example

$$y = hx + n \Rightarrow x' = \frac{y}{h} = x + \frac{n}{h}$$

Coherence Time

- The time over which a propagating wave may be considered coherent (i.e., staying constant)
- Why this is important?
  - To decode the signal, we need to estimate the channel h
  - The time interval between consecutive channel estimation should be shorter than coherence time
  - Otherwise, decoding can be erroneous due to incorrect channel h