# Wireless Communications & Networking

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# Agenda

- Lecture: Basics of Wireless Communications
- Lab 11: Wireless Measurement
- HW10 will be announced today

# Main Difference between Wired and Wireless

- Signal not “sealed” in the cable -
  **power loss** over long distance & obstructions
  - Low Signal-to-Noise Ratio (SNR)
    —> erroneous transmission
- Multi-path
  - Rapid signal fluctuation and self-interference
- Shared medium
  - Shared bandwidth & interference

# Outline

- Modulation - how to represent information with waveform
- Path loss - power loss over distance
- Multi-path fading -
  rapid power fluctuation & self-interference
- Multiplexing - how to share
- Additional MAC designs
- Rate adaption
- What can we do (for WiFi systems)

# The fundamental waveform - sinusoidal wave

$$y = \cos(\omega t) \ = \cos(2\pi f t)$$

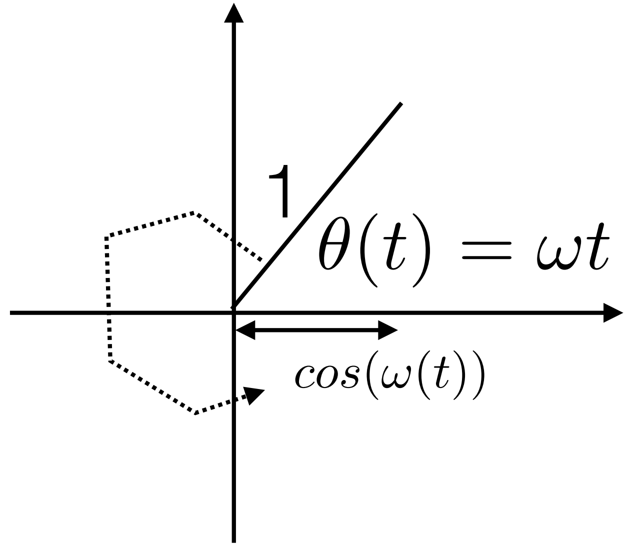
$\omega$ : angular frequency
(每單位時間轉多少弧度)

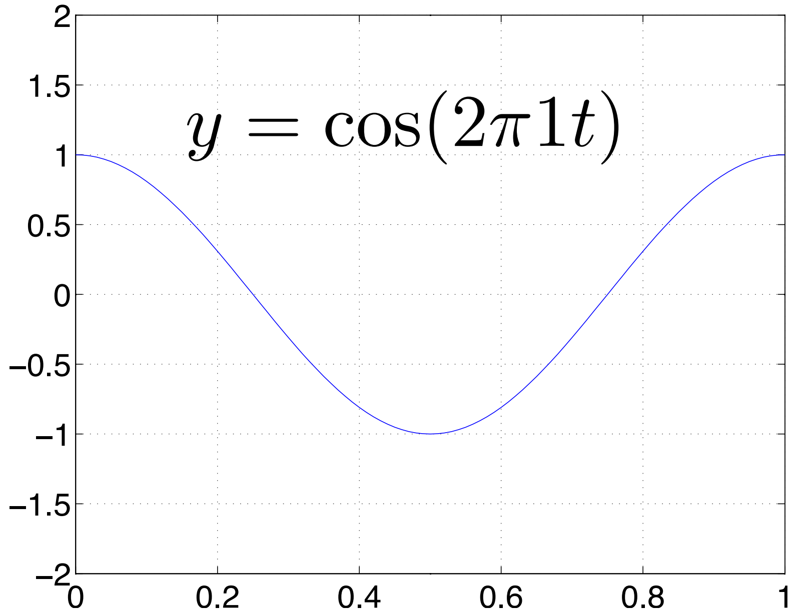
$$\omega = 2\pi f$$

$f$ : frequency (Hz)
(每單位時間轉多少2 pi, 圈)

How about

$$y = \cos(2\pi \cdot (2.4 \cdot 10^9) \cdot t)\,?$$



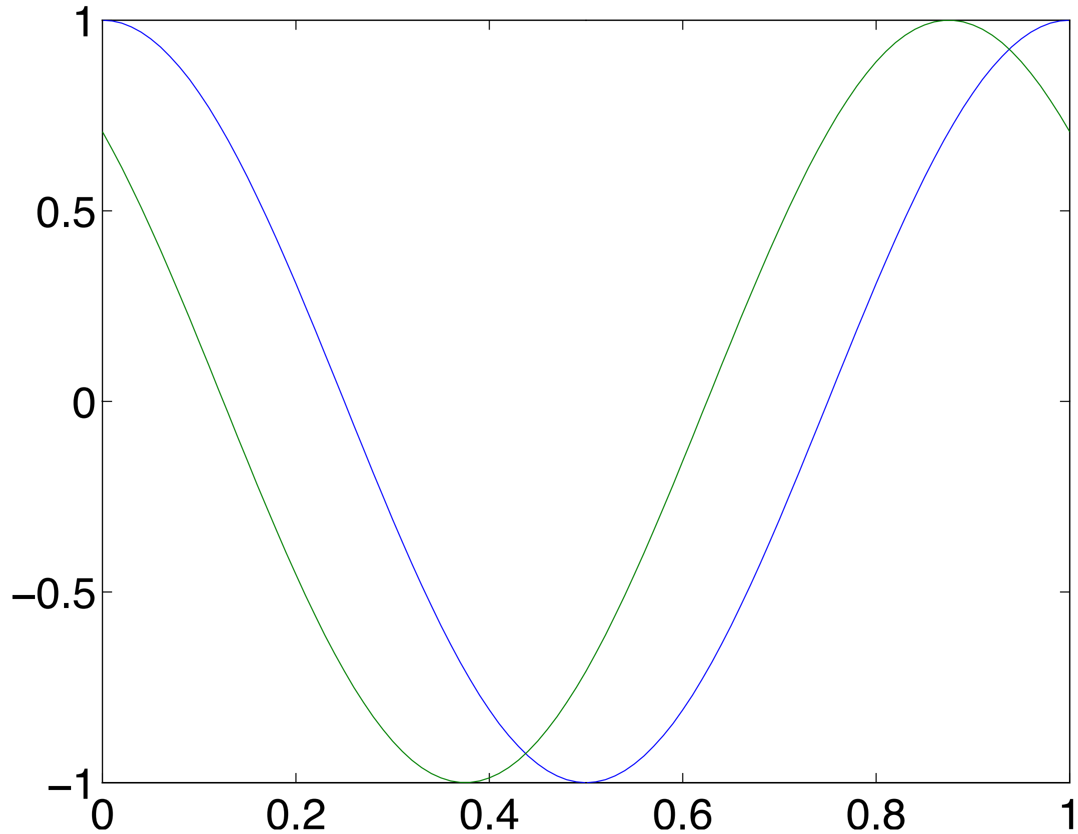



# Sinusoidal Wave - Initial Phase

Initial phase created “shifted” waveform

$$y = \cos(2\pi f t + \phi)$$

$$\phi = \frac{\pi}{4}$$



# Modulation - How to represent information?

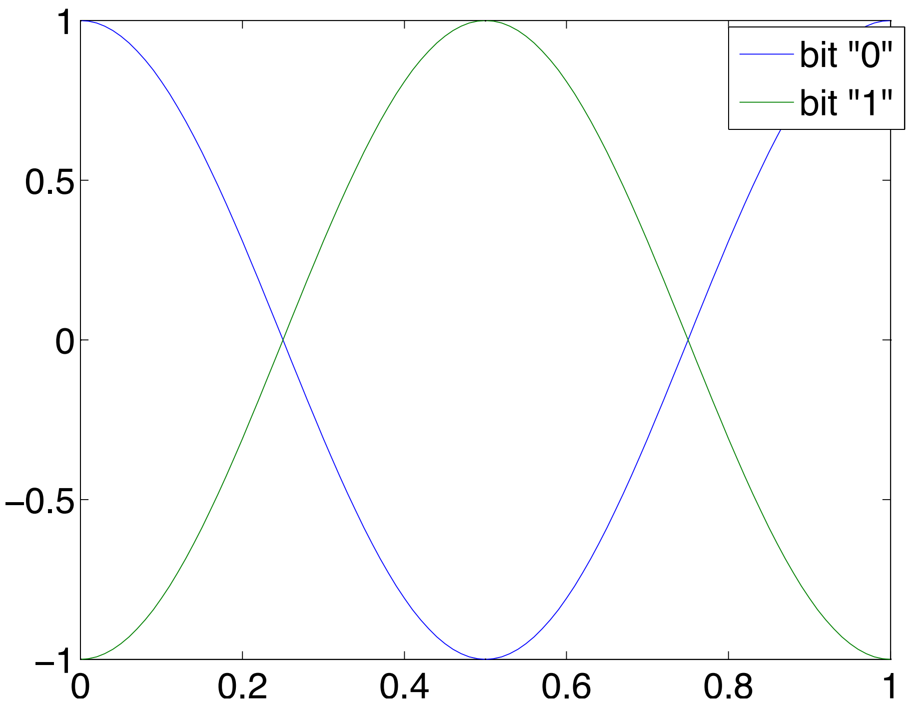
- Symbol: map to a number of bits
- Example: When one symbol map to:
  - 1 bit, then there are 2 kinds of symbol, mapping to “0” and “1”
  - 2 bits, then there are 4 kinds of symbol, mapping to “00”, “01”, “10”, and “11”
- Each symbol corresponds to a particular waveform

# Phase Shift Keying (PSK)

Binary Phase Shift Keying (BPSK, or 2-PSK)

$$s(t) = \cos(2\pi f_c t + 0) \quad \text{bit “0”}$$

$$s(t) = \cos(2\pi f_c t + \pi) = -\cos(2\pi f_c t) \quad \text{bit “1”}$$



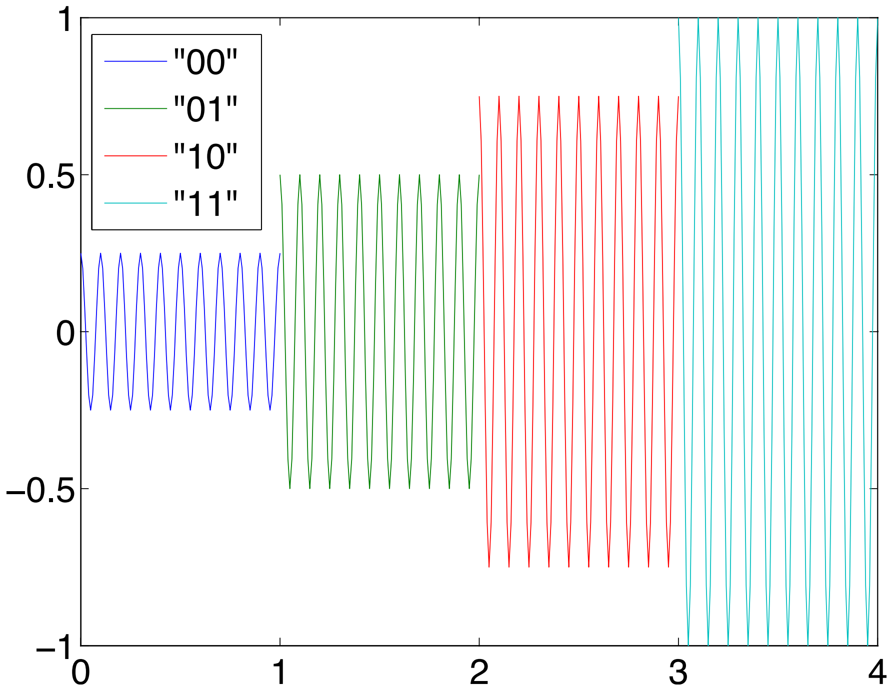

$$s(t) = \cos(2\pi f_c t + \phi_i)$$

$$\phi_i = \{0, \pi\}$$

# Amplitude Shift Keying (ASK)

## 4-Amplitude Shift Keying (4-ASK)

$$s(t) = a_i \cos(2\pi f t) \qquad a_i = \{\frac{1}{4}, \frac{2}{4}, \frac{3}{4}, 1\}$$




Q: Think about 8-ASK, what would the waveforms look like?

# Power loss and noise

$$r(t) = \frac{1}{a(t)} s(t) + n(t)$$

*n(t)*: noise

*a(t)*: path loss

$$SNR = \frac{P_r}{\sigma_n^2}$$

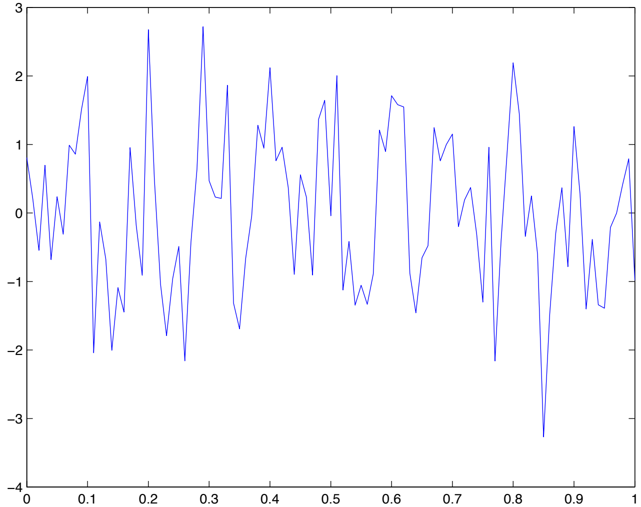
signal power

noise variance (power)

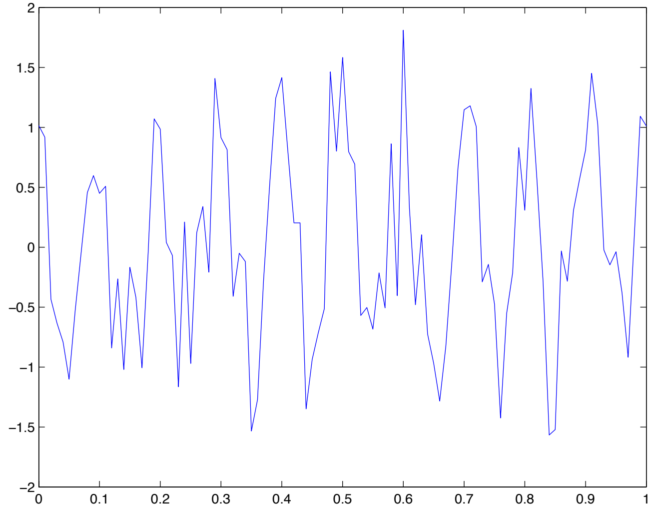
# SNR versus Error Rate

Low SNR —> hard to decode
—> higher error rate

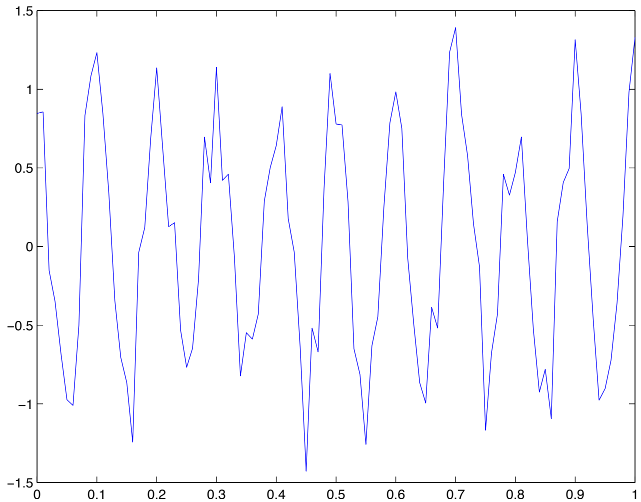
SNR=0 dB



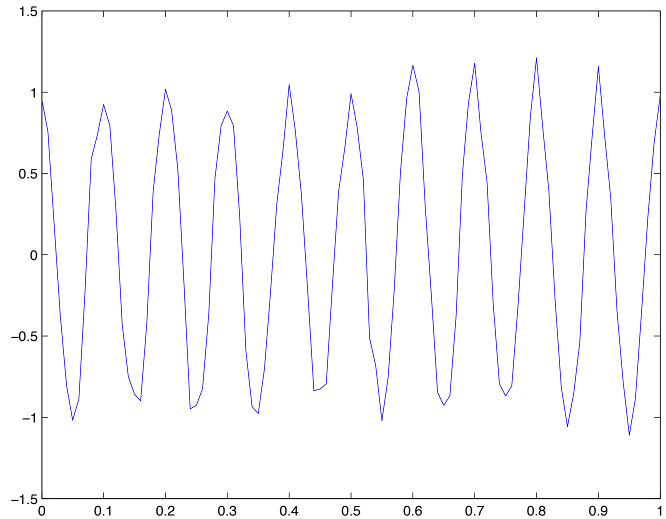

SNR=6 dB




SNR=12 dB




SNR=20 dB

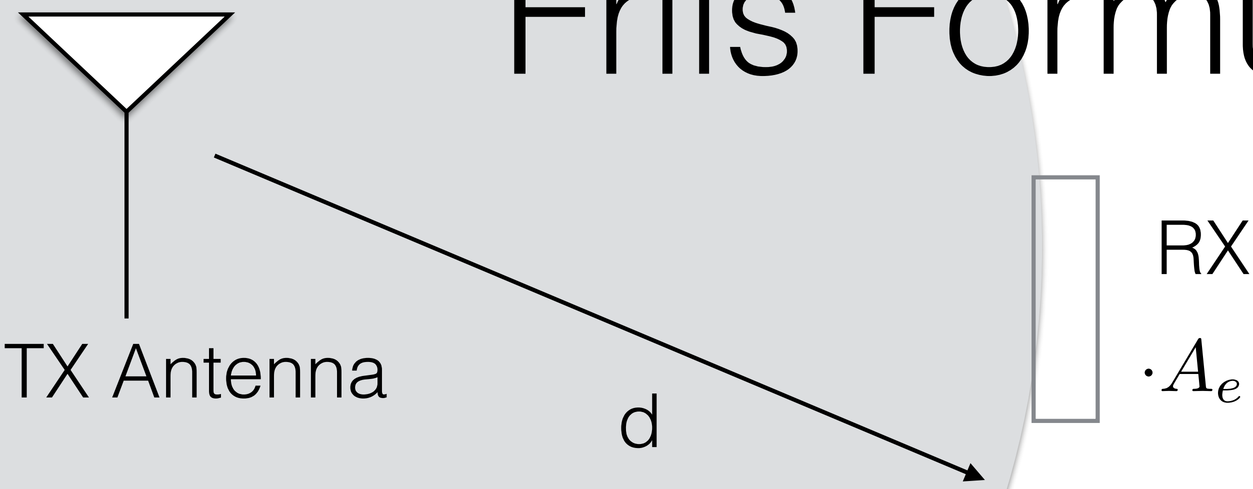


# Path Loss

$$r(t) = \frac{1}{a(t)} s(t) + n(t)$$

- Noise level is usually fixed (given a particular environment)
- Path loss determines the SNR (and error rate)
- Path loss is usually determined by **distance & obstruction**

# Friis Formula




Antenna gain *G*

$$G = \frac{4\pi}{\lambda^2} A_e$$

EIRP= $P_t G_t$

Power spatial density (W/m$^2$)

$$\cdot \frac{1}{4\pi d^2}$$

$$P_r = \frac{P_t G_t A_e}{4\pi d^2} = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2}$$

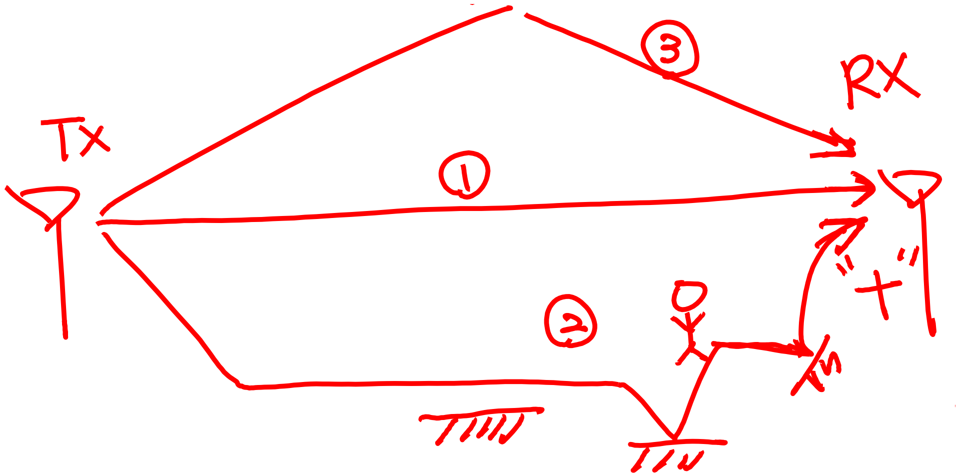
# Friis formula & path loss exponent

- Free space path loss exponent = 2 (power attenuates with a factor of $1/d^2$)
- **Higher frequency** signal experiences larger path loss (with the same antenna gain)
- In reality, $P_r \propto \frac{1}{d^\gamma}$

  $\gamma$ : path loss exponent

| Environment | Path-loss Exponent |
|---|---|
| Free-space | 2 |
| Urban area cellular radio | 2.7-3.5 |
| Shadowed urban cellular radio | 3-5 |
| In building LOS | 1.6 to 1.8 |
| Obstructed in building | 4 to 6 |
| Obstructed in factories | 2 to 3 |

# Multi-(propagation-)path



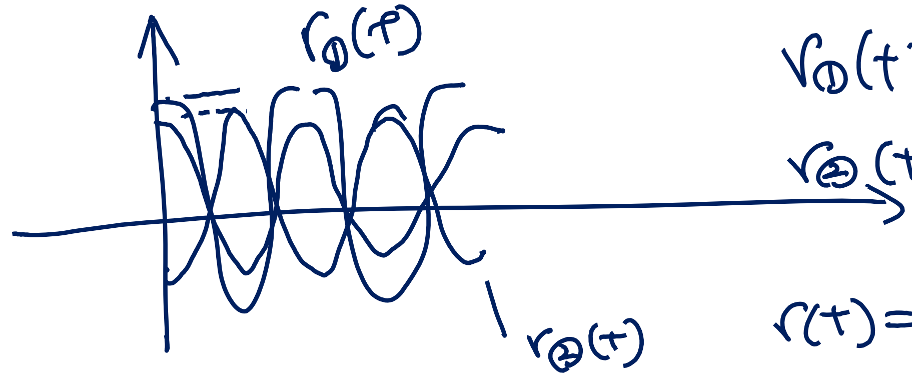

$$r_i(t) = \frac{a(t)}{\boxed{\rho}} \cos\left(\omega_c\left(t - \boxed{\Delta t}\right) + \phi\right)$$

$i =$ ①, ②, ③

$$r(t) = r_1(t) + r_2(t) + r_3(t) + \cdots$$

$$= \frac{a(t)}{\rho_1}\cos(\omega_c t + \phi_1) + \frac{a(t)}{\rho_2}\cos(\omega_c t + \phi_2) + \cdots$$

# Multi-path —> power fluctuation (fading)

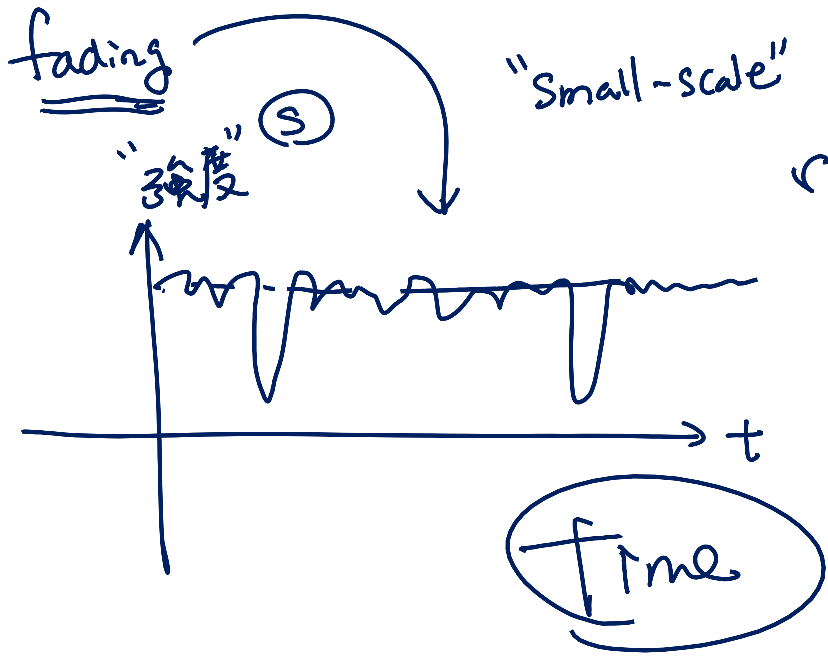



$$r_1(t) = \cos(\omega_c t)$$

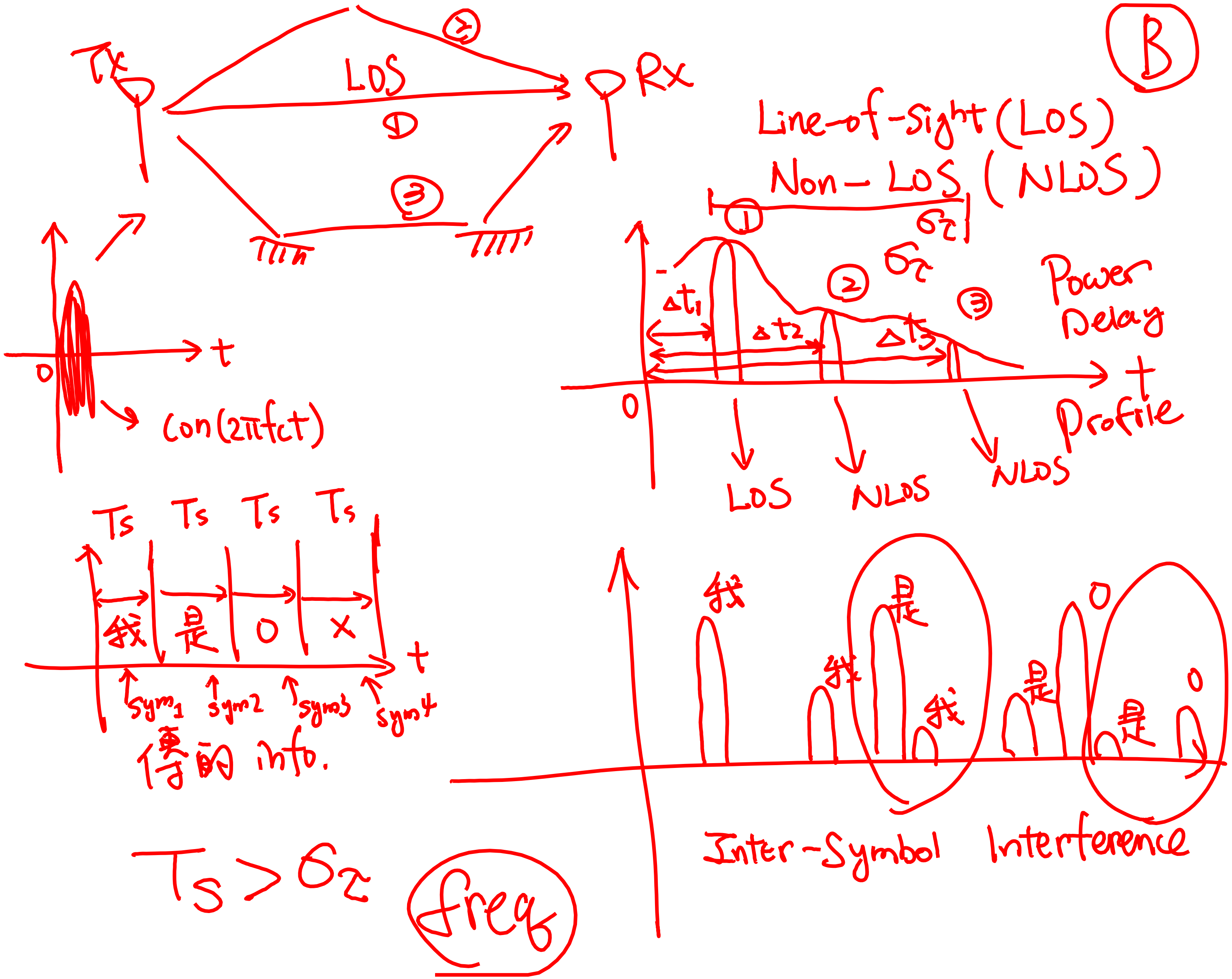
$$r_2(t) = 0.8\cos(\omega_c t + \pi)$$

$$\begin{aligned} r(t) &= r_1(t) + r_2(t) \\ &= \cos(\omega_c t)(1 - 0.8) \\ &= 0.2\cos(\omega_c t) \end{aligned}$$

$$\begin{aligned} r(t) &= r_1(t) + r_3(t) \\ &= \cos(\omega_c t)(1 + 0.6) \\ &= 1.6\cos(\omega_c t) \end{aligned}$$



# Multi-path —> inter symbol interference



# Multiplexing - how to share the medium

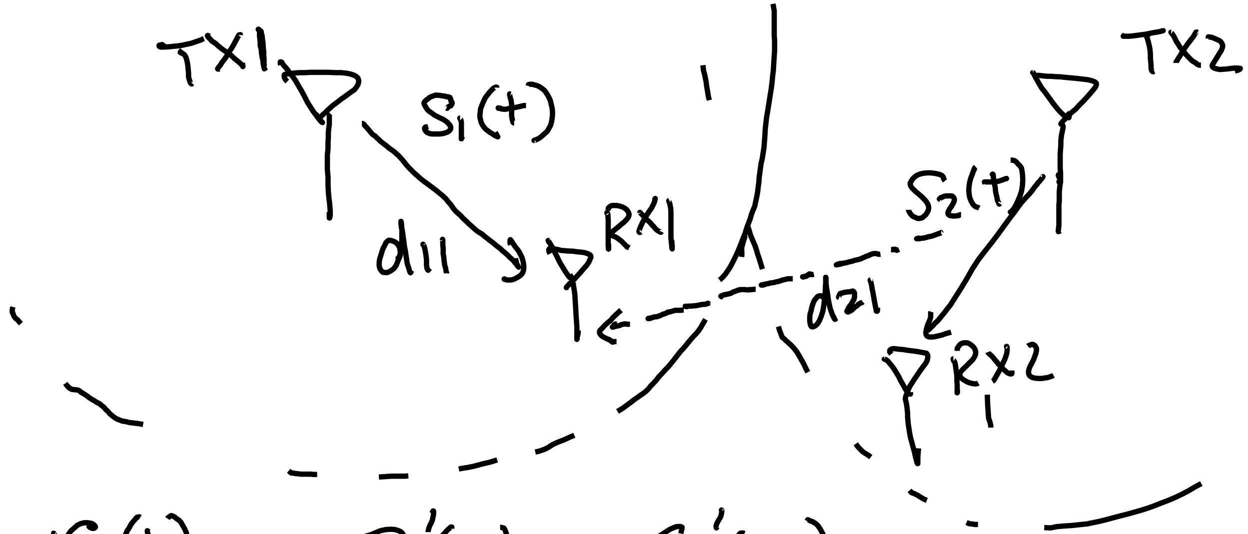
- Wireless channel is a broadcast channel
  —> when you transmits, “everyone can hear”

- Duplexing: allows TX & RX to both happen
  Multiplexing:
  allows multiple sets of TX and RX to both happen

- Examples of multiplexing methods:
  Spatial, frequency, and time multiplexing

# Spatial Multiplexing

① Spatial Multiplexing (Spatial Reuse)




$d_{11} \ll d_{21}$

$L_{21} \propto d_{21}^{\gamma}$

$L_{11} \propto d_{11}^{\gamma}$

$$r_1(t) = s_1'(t) + s_2'(t)$$

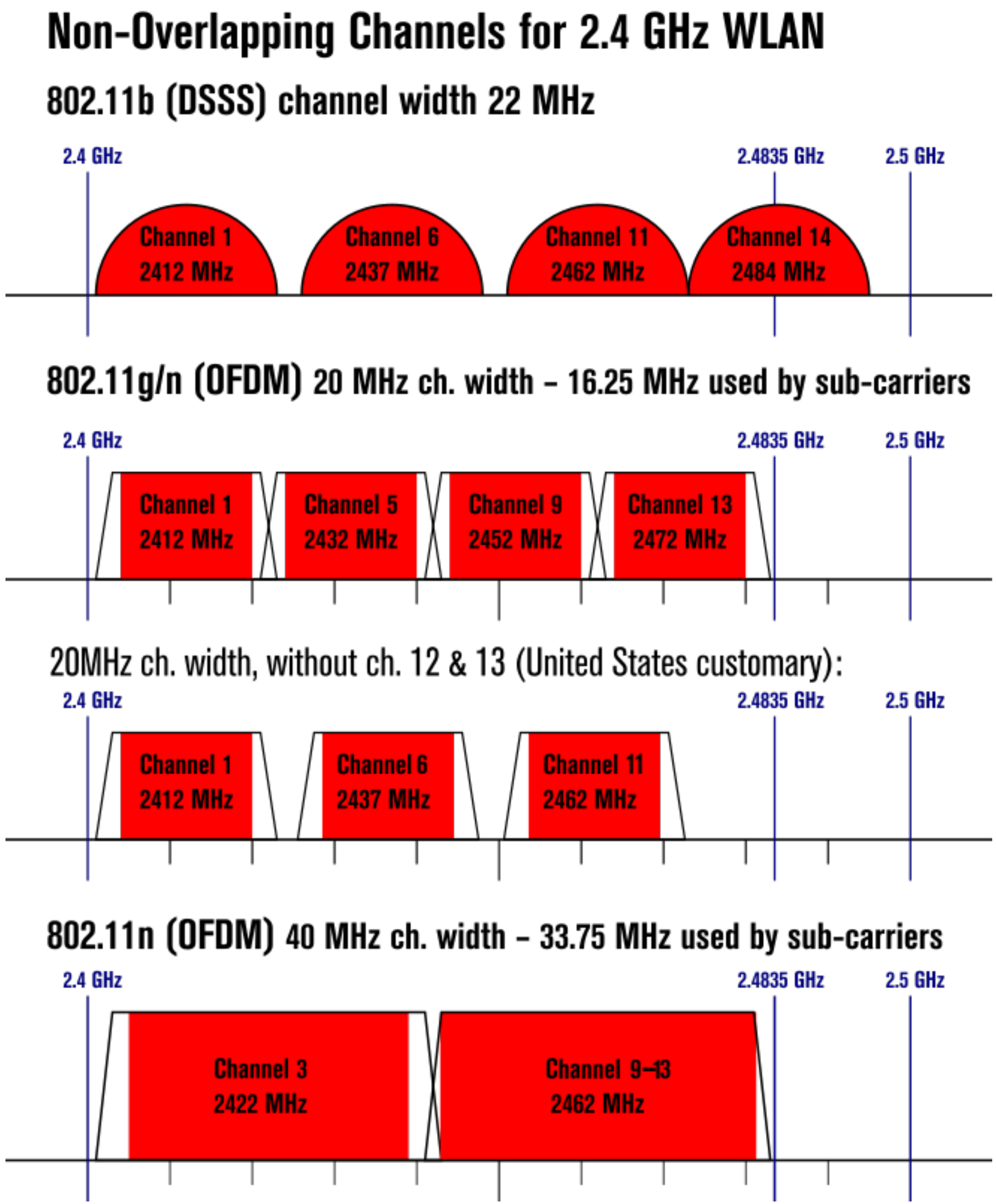
$$= \boxed{\frac{a_1}{L_{11}} s_1(t+\phi_1)} + \boxed{\cancel{\frac{a_2}{L_{21}} s_2(t+\phi_2)}} \rightarrow 0$$

intended received signal

interference

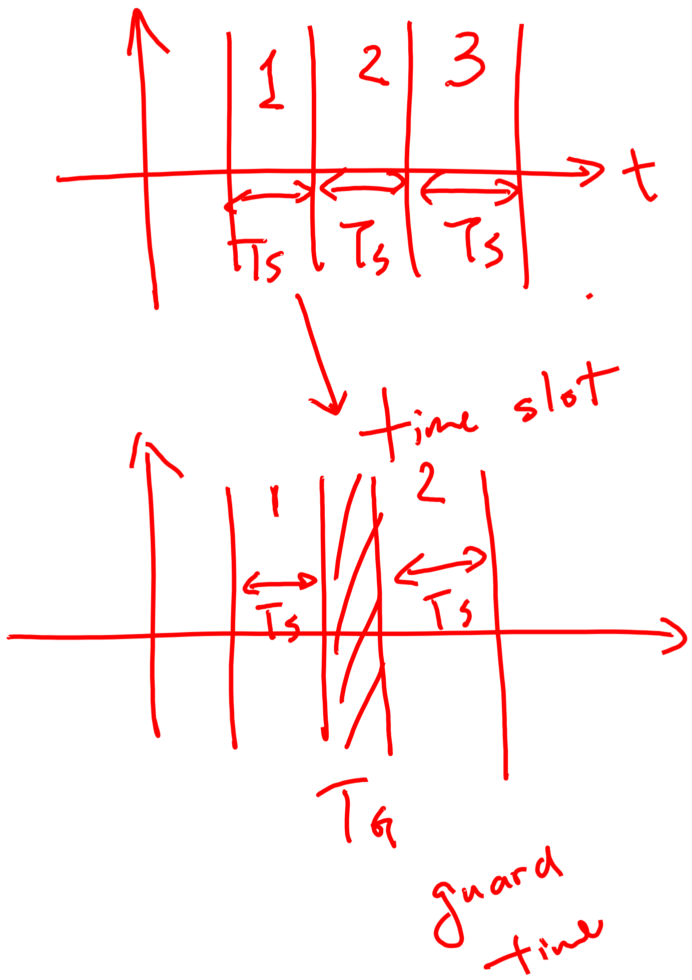
干擾

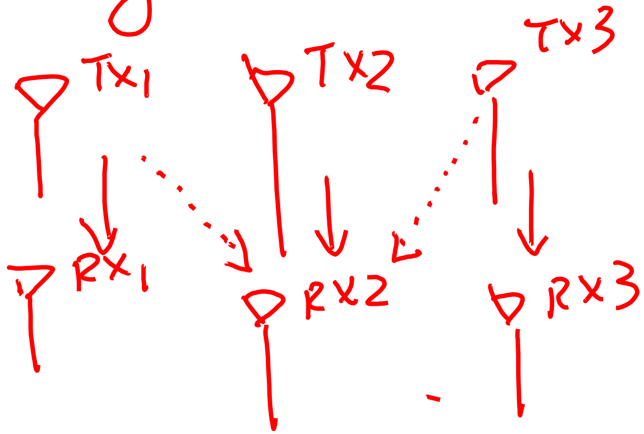
# Frequency-Division Multiplexing



# Time-Division Multiplexing

② Time-Division Multiplexing



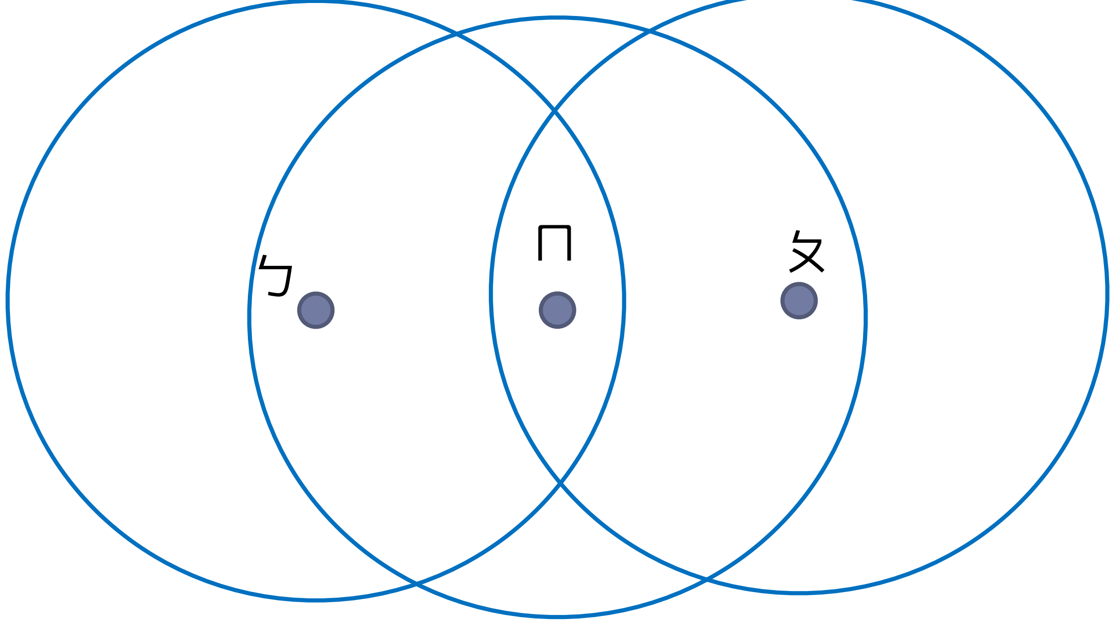




① time synchronization

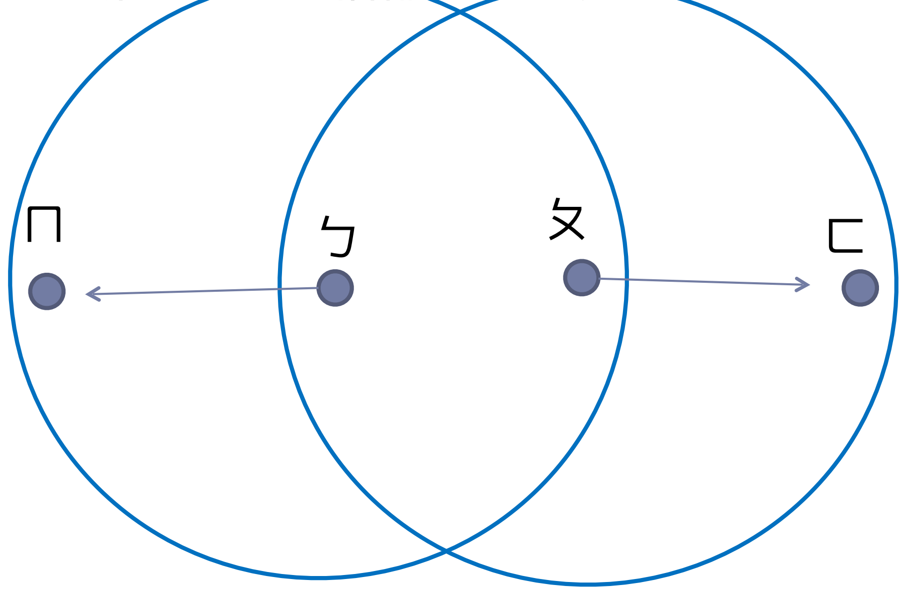
② guard time → overhead

# Additional MAC Design for Collision Avoidance

- IEEE 802.11 (WiFi)
- Handshake四部曲
  - RTS (Request to send)
  - CTS (Clear to send)
  - Data
  - ACK (Acknowledgement)
- 使用 NAV (Network Allocation Vector)
  - 在CTS中標示需要保留通道的時間(虛擬CSMA)

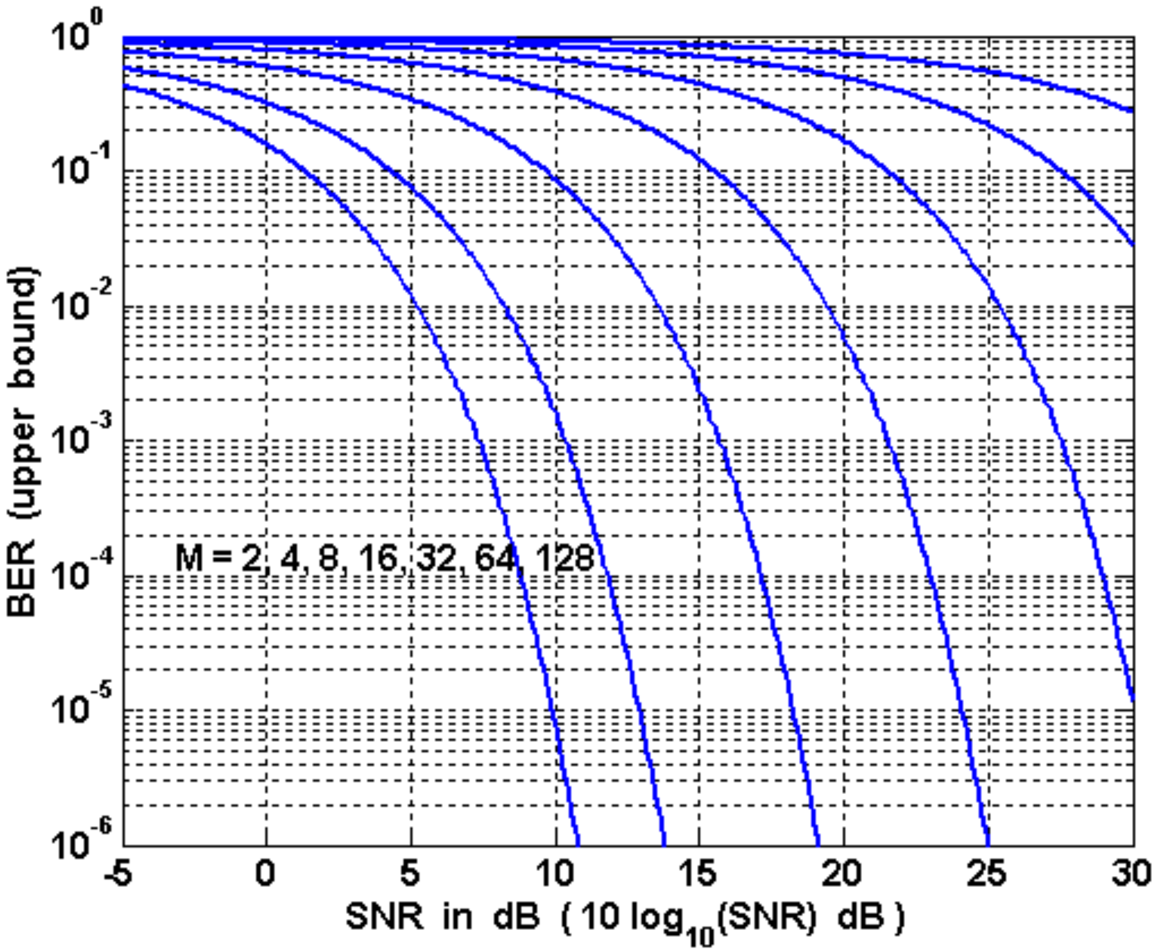


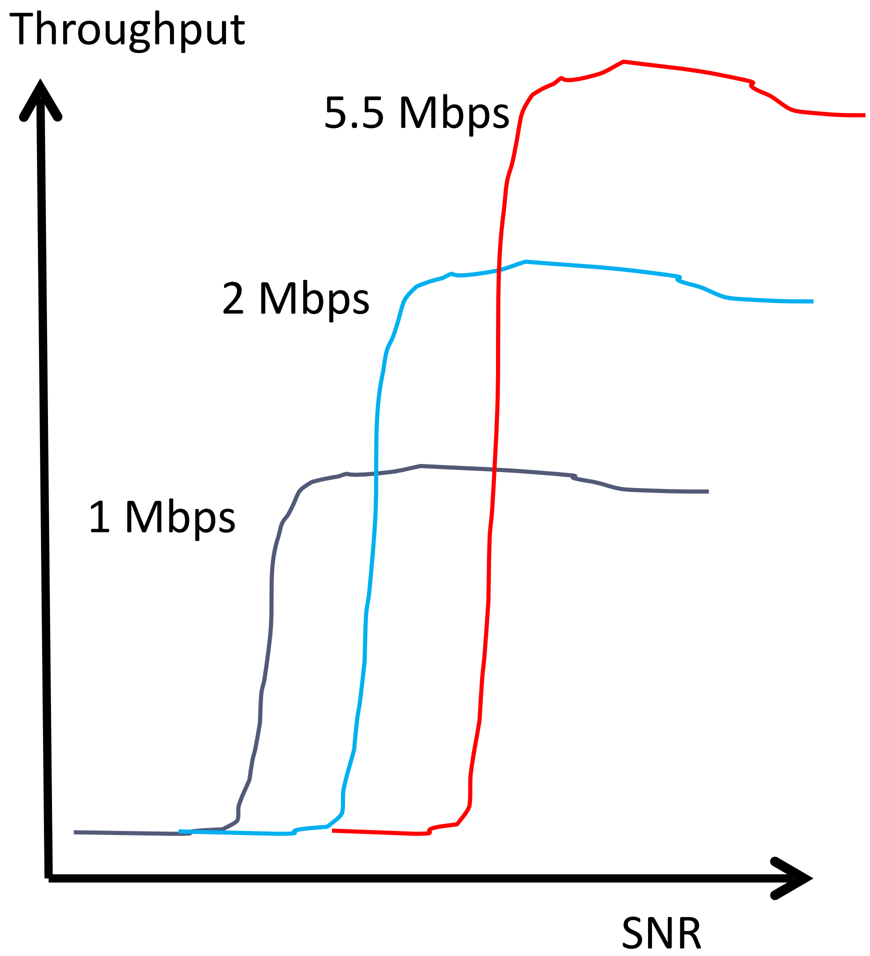

CTS 會被ㄅ和ㄆ接收到，
所以它們互相都知道對方




CTS of ㄇ→ㄅ 不會被 ㄆ接收到
CTS of ㄈ→ㄆ 不會被 ㄅ接收到
因此它們可以同時傳輸

# Rate Adaptation




- 當SNR不足，但是傳輸速率(data rate)太高時會使一大部分的封包都錯誤
- 一般作法:
  - 當出現連續封包錯誤時，降低傳輸速率一級。
  - 當出現連續封包正確時，提升傳輸速率一級。
- 問題: 當封包出現連續錯誤時，並無法確定是因為SNR太低! (可能是碰撞!)
- 降速→相同大小封包傳更久→更容易碰撞!

# What can / can't we do (to improve WiFi systems)?

- Can't:
  - Wireless channel (time variation, ISI)
  - Type of modulation (standard)
- Can:
  - Bandwidth (20/40/80/160 MHz)
  - Frequency (2.4 GHz, 5 GHz, channel assignment)
  - Data rate (e.g., 1 Mbps, 2 Mbps, 5.5 Mbps, etc.)
- Planning:
  - Transmission power
  - Location of the AP (distance, obstruction)
  - Traffic throttling

# How do we add more system capacity?

- We can add more APs!
- But TX power (AP/client) needs to be scaled down.
- Otherwise:
  - Collision
  - Back-off (MAC)
  - Rate adaption algorithm selects a lower rate